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Occurrence of the Nine-banded Armadillo,  
*Dasypus novemcinctus* (Mammalia: Edentata),  
in South Carolina

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*ABSTRACT.*— The occurrence of the nine-banded armadillo, *Dasypus novemcinctus*, in South Carolina has been poorly documented. The recent discovery of a road-killed individual in Aiken County, capture of a live individual in Barnwell County, and results of a questionnaire sent statewide to wildlife personnel in South Carolina indicate an increased frequency and concentration of records of the species in the southern portion of the state. Results of the survey also revealed that human importation of this mammal is still occurring in South Carolina. Based on climatic limiting factors, the nine-banded armadillo should be capable of expanding its range throughout most of South Carolina. The presence of an established viable population of this species in South Carolina remains uncertain.

Since the introduction of the nine-banded armadillo, *Dasypus novemcinctus* Linnaeus, into Florida between 1915 and 1922 (Bailey 1924, Fitch et al. 1952), this mammal has expanded its range through or into four states in the Southeast (Fitch et al. 1952, Humphrey 1974, Hall 1981). However, the significance of its occurrence in South Carolina is uncertain. Although sight records have been reported for this state (three individuals by Golley 1966; one individual by Humphrey 1974; ten individuals by Sanders 1978), these animals were assumed to be escapees either from tourists' automobiles traveling north from Florida and Georgia or from circuses (Golley 1966; Sanders 1978; R. E. Mancke, pers. comm.). No museum voucher specimens of this species from South Carolina have been reported. In addition, undocumented occurrences of the nine-banded armadillo in South Carolina have been either stated or illustrated with maps by Hamilton and Whitaker (1979) and Wetzel (1982).

On 2 August 1985, an adult male nine-banded armadillo roadkill was found in Aiken County in the central portion of the Savannah River Plant (SRP), a 77,000-ha federal nuclear facility that is closed to public access. Therefore, it is unlikely that this animal was released by a tourist traveling north. This specimen (ChM CM1143) has been

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deposited in the Charleston Museum. A subsequent check with other biologists at this site resulted in six additional reports of roadkilled armadillos in Aiken, Allendale, and Beaufort counties in South Carolina during the spring and summer of 1985. The frequency of these sightings suggests that this species is present in higher numbers in South Carolina than had been suspected previously.

A second adult male nine-banded armadillo was discovered alive at an elementary school in Williston, Barnwell County, on 26 June 1986 after becoming trapped in a drainage well. The animal was captured by state wildlife personnel and later sent to the South Carolina State Museum Commission.

A survey of the mammal collections in South Carolina resulted in the location of another specimen and one additional sight record (Charleston Museum files) from the state. The specimen (ChM CM1142) was taken alive in a barn in Bonneau, Berkeley County, in the mid-1970s; it was later sent to the Charleston Museum where it was prepared as a study skin. The additional sight record was from Piedmont, Greenville County, in 1941.

In an effort to assess the recent population status and distribution of this species in South Carolina, a questionnaire was sent to state wildlife biologists, state wildlife law enforcement officers, superintendents of the national forests in the state, and managers of the national wildlife refuges in the state. The questionnaire requested details concerning any recent sightings of this species in the respondent's area of South Carolina or any other sightings in the state known to the respondent. It also asked whether or not the respondent believed that the nine-banded armadillo was established in South Carolina. The response to the 246 questionnaires was 57%.

Eleven respondents (8%) reported a total of 15 recent sightings of the nine-banded armadillo in South Carolina, most of which were from the southern portion of the state (Fig. 1). Most reports (73%) were of roadkills along interstate highways and primary and secondary state roads. Of the live sightings, two were seen along roadsides, one was captured near a motel in Florence, Florence County, and one was killed in a chicken coop by a farmer in Brunson, Hampton County. Ninety-nine percent of the respondents did not believe that the nine-banded armadillo was established in South Carolina at this time. Of the two respondents who did believe this species to be established in the state, only one reported any sightings. Two respondents stated that they had encountered persons who either had been found in South Carolina with armadillos that had been captured in Florida for release in South Carolina or were in the process of capturing armadillos in southern Georgia for transport to and release in South Carolina.

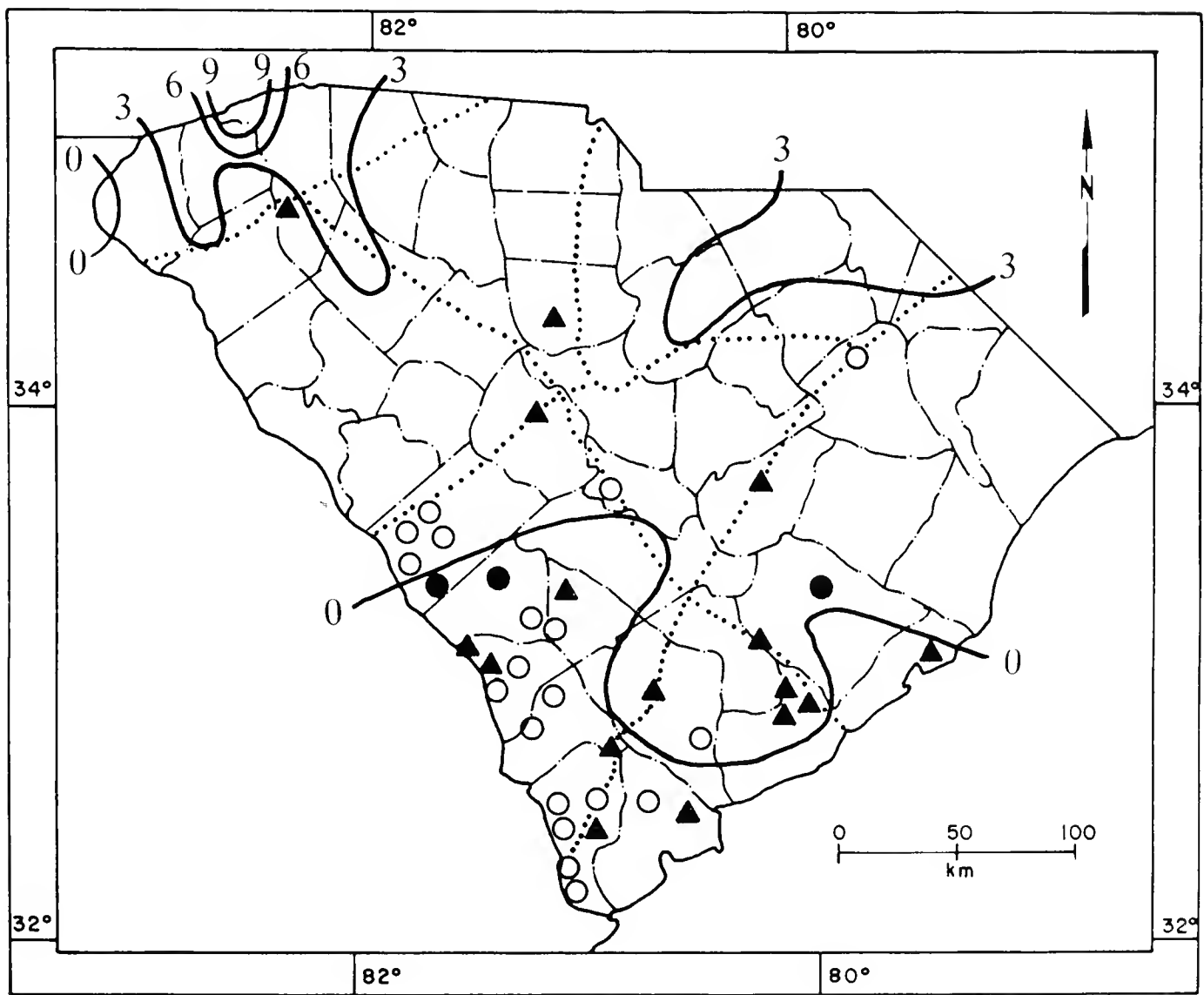


Fig. 1. Past and recent occurrence of the nine-banded armadillo, *Dasypus novemcinctus*, in South Carolina. Solid dots indicate the localities of museum specimens. Open circles indicate the 1980-to-present localities resulting from this report. Solid triangles indicate the localities of the early (pre-1980) sightings in the state resulting from this report, records at the Charleston Museum, and records from Golley (1966), Humphrey (1974), and Sanders (1978). Limits of the mean annual number of freeze-days are indicated by the numbered solid lines. Routes of the Interstate Highway System in South Carolina are indicated by the dotted lines.

Early records of the nine-banded armadillo in South Carolina were most likely the result of escaped or released individuals that had been imported into the state (Humphrey 1974, Sanders 1978). Most of these records came from localities close to major highways (Fig. 1) that carry tourist traffic north from Florida (Sanders 1978). Other records from farther north along the Atlantic seaboard of the United States have occurred in North Carolina, Washington, D.C., Delaware (Humphrey 1974, Lee et al. 1982), and Connecticut (UCONN 11249). The results of the survey determined that introductions by humans are still occurring in South Carolina. However, because of the recent increased frequency and concentration of records of this species in the southern portion of

South Carolina adjacent to the Savannah River, it is possible that some of these occurrences in the state represent natural range extensions. Humphrey (1974) noted that the nine-banded armadillo has a strong pioneering capability as indicated by the large number of extralimital records in its distribution. The results of Humphrey's (1974) study also indicated that the distribution of the nine-banded armadillo had a lower limit of about 380 mm annual precipitation and an approximate upper limit of nine freeze-days per year (total number of days in a year during which the maximum daily temperature does not exceed 0 degrees Centigrade). Based on these data, Humphrey (1974) stated that the range extension of the nine-banded armadillo could be expected to reach at least the edge of the southern Appalachian piedmont in the southeastern United States. Records of climatic data for South Carolina from 1980 to 1985 (Anon. 1980-1985) indicate that the total annual precipitation ranges from 733 to 1,517 mm and the average annual number of freeze-days varies from 0 in southern South Carolina to 11 at Caesar's Head in the mountains (Fig. 1). Using Humphrey's climatic limiting factors, then, the nine-banded armadillo should be capable of expanding its range throughout most of South Carolina. The only areas that might be excluded would include the mountainous portions of the extreme northwestern edge of the state.

In conclusion, reports of the nine-banded armadillo in South Carolina are increasing at present, but because direct evidence for the existence of an established viable population in South Carolina is lacking, its status in the state remains uncertain.

ACKNOWLEDGMENTS.— I thank the many respondents to my survey; Albert E. Sanders of the Charleston Museum (ChM) and Robert E. Dubos of the University of Connecticut Museum of Natural History (UCONN) for their helpful input; and I. Lehr Brisbin, Jr., Michael H. Smith, W. David Webster, Michael C. Kennedy, and James M. Novak for critically reading earlier drafts of this manuscript. This work was supported by Contract DE-AC09-76SROO819 between the Institute of Ecology at the University of Georgia and the United States Department of Energy.

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# Distribution and Seasonality of Branchiopod and Malacostracan Crustaceans of the Santee National Wildlife Refuge, South Carolina<sup>1</sup>

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*ABSTRACT.*— Distribution and seasonal changes in abundance of branchiopod and malacostracan crustaceans were studied at the approximately 6100-ha Santee National Wildlife Refuge, on the edge of Lake Marion in the mid-coastal plain of South Carolina. A total of 42 species were collected, of which 19 are new records for the state. Winter crustacean fauna is dominated by the cladocerans *Simocephalus serrulatus* and *Eurycercus (Bulatifrons) vernalis*, the isopods *Caecidotea forbesi* and *Lirceus lineatus*, the amphipods *Hyaella azteca* and *Crangonyx richmondensis*, mature individuals of the shrimp *Palaeomonetes paludosus*, and the crayfish *Procambarus (Ortmannicus) blandingii*. Spring is characterized by high water levels, population pulses in several cladoceran species, occasional occurrences of the anostracan *Streptocephalus seali* and conchostracan *Eulimnadia ventricosa*, and more habitats for *C. forbesi* and *P. (O.) blandingii*. Summer crustacean fauna is dominated by *H. azteca*, *Caecidotea laticaudata*, reduced numbers of *C. forbesi*, and immature specimens of *P. paludosus*. Variations exist among species with respect to the types of habitats inhabited (ditches, pools, impoundments, lake) and seasons of abundance and reproductive activity. Most species have been previously documented as being closely associated with aquatic macrophytes, which reach high densities in several habitats.

Crustaceans are important components of practically all freshwater ecosystems and many terrestrial ecosystems. Unfortunately, however, little documented research has been done in South Carolina on the distribution and ecology of nonmarine species, with the possible exception of crayfish. Information about species occurrences, seasonal changes in abundance, and seasonal reproductive characteristics is especially valuable in areas that are managed for wildlife that may use these crustaceans directly or indirectly as food. The Santee National Wildlife Refuge, like many refuges, is very important as a winter sanctuary for waterfowl, having more than 120,000 overwintering birds annually (D. J. Voros, Santee National Wildlife Refuge, pers. comm.).

<sup>1</sup>Contribution Number 69 of the Grice Marine Biological Laboratory, College of Charleston.

Waterfowl, though reduced in numbers, are abundant during other times of the year as well. In addition to their trophic importance to these birds, aquatic crustaceans are also important in food chains leading to other animals, including the American alligator (*Alligator mississippiensis*), an endangered species that is abundant within the refuge boundaries.

Previous studies on freshwater and terrestrial crustaceans of South Carolina are meager. There are many references to crayfish occurrences in the state, one dating back more than 200 years (e.g., Bartram 1771; Hobbs 1940, 1947, 1956a,b,c, 1958a,b, 1983; Hobbs and Carlson 1983; Prins and Hobbs 1972; Hobbs III et al. 1976). Other taxa, however, have not been as readily seen or surveyed. Important studies include a survey of the Savannah River fauna (Patrick et al. 1966); several reports of research involving a few crustacean species at the Savannah River Plant, an approximately 80,000-ha federal production reactor and field laboratory complex on the southwestern border of the state (e.g., Vigerstad and Tilly 1977; Thorp and Ammerman 1978; Cherry et al. 1979a,b; Giesy et al. 1980; Brown 1981; Dickson and Giesy 1981; Thorp and Bergey 1981); some records of ostracod and copepod occurrences (Hoff 1944; Ferguson 1952, 1954; Crawford 1957; Roache 1959); a recent survey of zooplankton of an acidic (pH 4.3-4.5) cooling pond (Mallin 1984); and documentation of the occurrence of two exotic terrestrial amphipod species in the state (Biernbaum 1980). Except for some early studies by a few biologists, some of which resulted in the description of new species (Say 1818; Ellis 1940, 1941), very little work has been done on nonmarine amphipods or isopods in the state. Fox (1978) and Kelley (1978) summarized distributional information that is known for these two groups in the coastal zone of South Carolina. No information about the fauna or flora of the Santee National Wildlife Refuge appears in the scientific literature. However, the United States Department of the Interior has prepared pamphlets (1983:RF-42570-2, 42570-5, 42570-7; 1985:RF-42570-3) listing the species of fishes (based on studies by P. Coleman), amphibians and reptiles (based on studies by J. R. Harrison, III), and birds and mammals (based on many surveys) occurring on refuge property.

## STUDY AREA

Established in 1941, the Santee National Wildlife Refuge comprises about 6100 ha in the mid-coastal plain of South Carolina (Fig. 1). The four noncontiguous units of the refuge (Bluff, Dingle Pond, Pine Island, and Cuddo) border Lake Marion, a reservoir created by the construction of a hydroelectric dam on the Santee River. These units consist of mixed pine-hardwood forests, croplands, marshes, ponds, and impoundments.

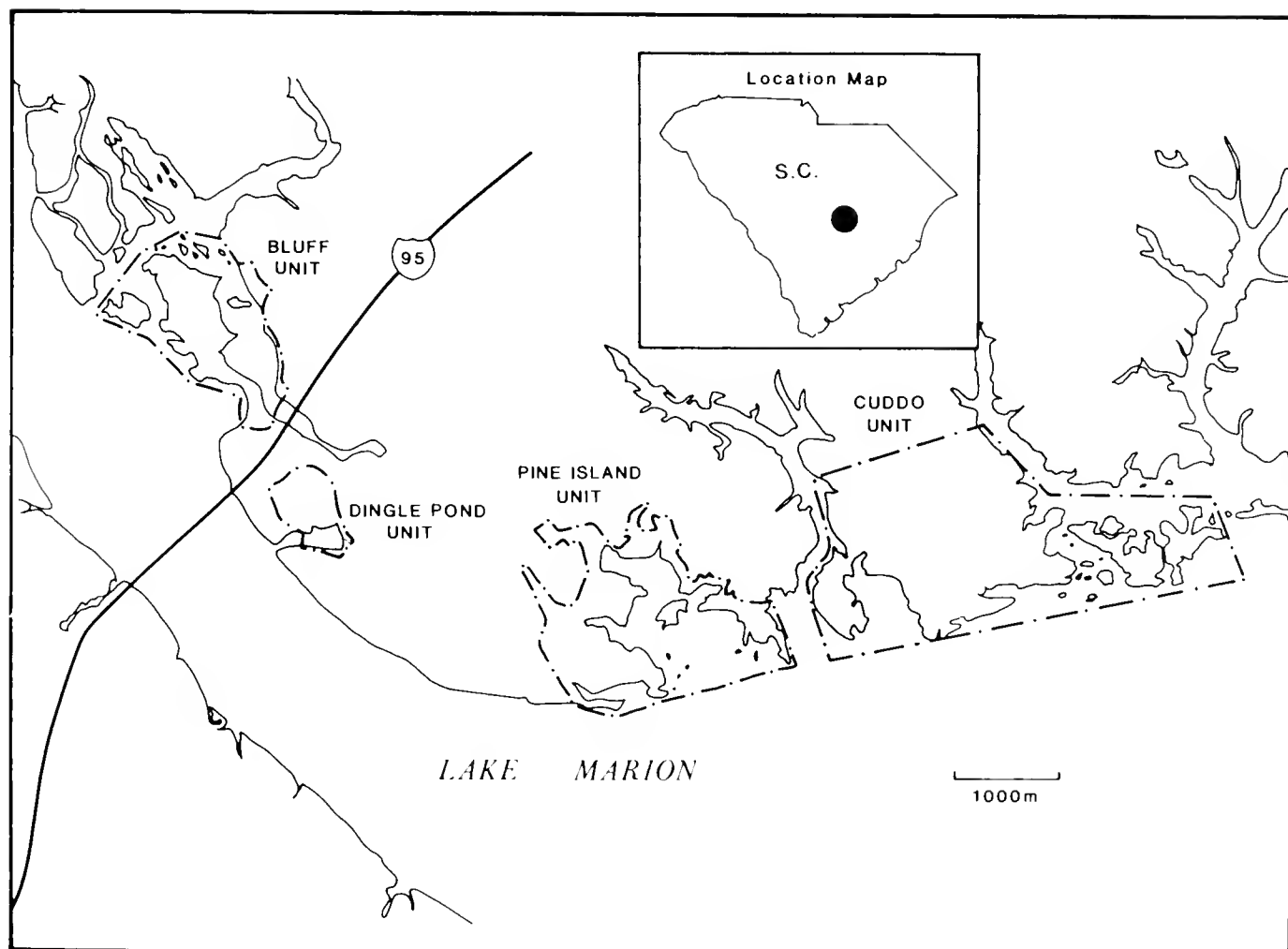


Fig. 1. Map showing sampling areas, Santee National Wildlife Refuge, S.C.

The four units of the refuge are managed primarily for waterfowl. Consequently, extensive complexes of water impoundments with connecting ditches have been constructed on these sites. These impoundments vary in size, but a majority are 1 to 2 ha in size and quite shallow, with most being virtually covered in summer with such rooted vegetation as lilies or lotus. Other aquatic habitats occurring in the refuge are small borrow pits and shallow swamps, some bordering the lake and others found as isolated forest depressions.

There are significant seasonal variations in the amount of water present in these aquatic habitats. The water level in Lake Marion is reduced prior to spring in anticipation of increased runoff farther up the Santee basin. As a result of such runoff, coupled with increased local rainfall, water levels in the refuge are high in the spring, except for some isolated habitats when spring rainfall is minimal. Usually, spring water levels become so high that substantial areas of forest are also flooded, at times up to 0.5 m in depth. Water levels then drop during summer and fall, frequently resulting in the total drying-out of some impoundments, ditches, and swamps.

At any one time, temperatures of aquatic habitats at the refuge are highly variable because of differences in water depth and degree of shading. The highest water temperature recorded during the study was

34 °C, but it is certain that temperatures occasionally exceed this in small exposed pools or ditches on hot days. During the winter some locations may rarely have a thin sheet of ice on the surface. Mid-June pH measurements along the margin of Lake Marion ranged from 6.9 to 7.3, depending on location. Other aquatic habitats had pH values from 5.4 to 6.3.

Most aquatic habitats of the refuge, with the exception of swamps, are characterized by having dense growths of a variety of aquatic plants. Most such locations have large populations of floating plants, including water lilies (*Nymphaea odorata*), American lotus (*Nelumbo lutea*), and frequently water shield (*Brasenia schreberi*) and duck weed (*Lemna* spp.). Submergent plants that are very abundant include bladderwort (*Utricularia* sp.), hornwort (*Ceratophyllum demersum*), Brazilian waterweed (*Elodea densa*), water milfoil (*Myriophyllum* sp.), *Chara* sp., and a variety of filamentous green algae. Along the bordering shallows such emergent plants as arrowhead (*Sagittaria latifolia*), water pennywort (*Hydrocotyle* sp.), alligator weed (*Alternanthera philoxeroides*), smartweed (*Polygonum* spp.), pickerel weed (*Pontederia cordata*), and an introduced false loosestrife (*Ludwigia uruguayensis*) are usually abundant. At the water's edge a variety of sedges (*Cyperus* spp.), rushes (*Juncus effusus*, *Scirpus* spp.), and cattails (*Typha* sp.) are frequently found in dense stands. Many impoundments additionally have buttonbushes (*Cephalanthus occidentalis*) scattered throughout. Bald cypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), willows (*Salix* spp.), and redbay (*Persea borbonia*) are commonly found. Trees usually dominating swamps include those listed above plus sweet gum (*Liquidambar styraciflua*), oaks (*Quercus* spp.), and, in those swamps and flooded woods not bordering the lake, some pines (*Pinus* spp.).

## METHODS

Sampling was done approximately every 4 to 8 weeks from January 1982 to November 1983. Occasional samples were taken during 1984. Aquatic sampling was done primarily by use of a dipnet (0.9-mm mesh), although some supplemental collections were made by plankton net (100- $\mu$ m mesh) at selected locations. Sampling was reduced in certain areas during the cooler months to avoid disturbing overwintering waterfowl. Specimens were collected at 105 refuge locations, over 75% of which were sampled during at least two different months. Sixty-three stations were sampled during at least two different seasons, 34 stations during at least three seasons, and 16 for all four seasons.

Specimens were preserved in the field and returned to the laboratory for identification and enumeration. Owing to the difficulty in identifying females of *Caecidotea* to the species level, occurrences of species of this

isopod genus are based solely on the collection of males, plus those females found at sites where males of only one species of *Caecidotea* were collected. Individuals of the two dominant amphipod species, *Hyalella azteca* and *Crangonyx richmondensis richmondensis*, were identified as male, female, or juvenile. Because immature members of these species resemble females, juveniles were defined as all individuals shorter than the smallest recognizable male collected for each species. All individuals of *H. azteca* were able to be sexed; however, many unsexed *C. r. richmondensis* juveniles were collected. Voucher specimens of all species have been deposited in the collections in the Division of Crustacea of the United States National Museum of Natural History, Washington, D.C.

## RESULTS AND DISCUSSION

### BRANCHIOPODS

Results of the crustacean survey are shown in Table 1. Two species of non-cladoceran branchiopods were collected, the anostracan *Streptocephalus seali* and the conchostracan *Eulimnadia ventricosa*. Both species were found in one location only, two shallow pools adjoining a shaded borrow pit (depression formed by soil excavation) in a forest. They were absent in these pools in May 1982, present the following July and September, and absent in December 1982. In July and September *S. seali* was very abundant, with *E. ventricosa* less so. Also present were large numbers of the cladoceran *Simocephalus exspinosus* and the isopod *Caecidotea forbesi*. The pools, which contained water throughout 1982, were approximately 3 x 4 m and 4 x 4.5 m and were separated by about 1 m; in July and September they were separated from the borrow pit by a ridge approximately 0.5 m wide and 15 cm in elevation above the water level. In July and September all four crustacean species were abundant in the two pools, but absent from the borrow pit. There were large numbers of small fish in the borrow pit, but none in the two pools. By December 1982, water levels had risen as a result of rainfall so that the pools and borrow pit were confluent. No anostracans or conchostracans could be found at that time. Spring and summer were drier in 1983 than in 1982, and the pools were totally dry in May and August. They contained water in the early summer of 1983, but no branchiopods were found in this habitat during that year. Such sporadic occurrences of non-cladoceran branchiopods is not uncommon (Pennak 1978).

*Streptocephalus seali* is the most widely distributed anostracan species in North America, being found in pools and ponds from the Canadian prairies south to Mexico and east to the Atlantic States (Moore 1966, Fitzpatrick 1983). There is only one previous record of its occurrence in South Carolina, and that is based on a single specimen

Table 1. Summary of the branchiopod and malacostracan crustaceans collected in the Santee National Wildlife Refuge, S.C.

	Habitat <sup>1</sup>	Occurrence <sup>2</sup>	Unit <sup>3</sup>
Class Branchiopoda			
Order Anostraca			
Family Streptocephalidae			
<i>Streptocephalus seali</i> Ryder	I	4	C
Order Conchostraca			
Family Limnadiidae			
* <i>Eulimnadia ventricosa</i> Mattox	I	4	C
Order Cladocera			
Family Sididae			
<i>Diaphanosoma brachyurum</i> (Liéven)	D,I,L	3	B,C,PI
* <i>Latona setifera</i> (O.F. Müller)	D,L	5	C,PI
* <i>Pseudosida bidentata</i> Herrick	D,I,L,S	5	B,C,DP
<i>Sida crystallina</i> (O.F. Müller)	I,L	4	B,C
Family Holopedidae			
<i>Holopedium amazonicum</i> Stingelin	D,I	5	PI
Family Daphnidae			
<i>Ceriodaphnia reticulata</i> (Jurine)	D,I,L,S	2	B,C,PI
* <i>Daphnia laevis</i> Birge	S	4	DP
* <i>Daphnia pulex</i> Leydig	S	5	PI
<i>Scapholeberis kingi</i> Sars	D,I,L,S	2	B,C
* <i>Simocephalus exspinosus</i> (Koch)	I,S	2	B,C,DP
* <i>Simocephalus serrulatus</i> (Koch)	D,I,L,S	1	B,C,DP,PI
Family Bosminidae			
<i>Bosmina</i> cf. <i>B. longirostris</i> (O.F. Müller)	D	5	PI
Family Macrothricidae			
<i>Ilyocryptus spinifer</i> Herrick	D,I,L	1	C,DP,PI
* <i>Macrothrix rosea</i> (Jurine)	D,I,L	2	B,C,DP,PI
Family Chydoridae			
* <i>Alona costata</i> Sars	L	5	C
* <i>Alona</i> cf. <i>A. guttata</i> Sars	L	5	DP
* <i>Alona intermedia</i> Sars	D,L	5	C,PI
<i>Alonella dadayi</i> Birge	I	5	PI
<i>Alonella hamulata</i> (Birge)	I,L	5	C,PI
* <i>Camptocercus</i> cf. <i>C. rectirostris</i> Schodler	D	5	PI
<i>Chydorus</i> cf. <i>C. sphaericus</i> (O.F. Müller)	D,I,L	3	C,DP,PI
* <i>Eurycercus (Bulatifrons) vernalis</i> Hann	D,I,L	1	B,C,DP,PI
* <i>Monospilus</i> sp.	L	4	C
<i>Oxyurella brevicaudis</i> Michael and Frey	I	5	DP
* <i>Pseudochydorus globosus</i> (Baird)	S	5	B
Class Malacostraca			
Order Isopoda			
Family Asellidae			
<i>Caecidotea forbesi</i> (Williams)	D,I,L,S	1	B,C,DP,PI

Table 1. Continued.

	Habitat <sup>1</sup>	Occurrence <sup>2</sup>	Unit <sup>3</sup>
†* <i>Caecidotea laticaudata</i> (Williams)	D,I,L,S	1	B,C,DP
†* <i>Caecidotea obtusa</i> (Williams)	I	5	DP
<i>Lirceus lineatus</i> (Say)	I,L	1	C,DP,PI
Family Armadillididae			
<i>Armadillidium vulgare</i> (Latreille)	T	4	B
Family Oniscidae			
†* <i>Porcellionides floria</i> Garthwaite and Sassaman	T	4	B
Family Trichoniscidae			
* <i>Miktoniscus halophilus</i> Blake	T	4	B
Order Amphipoda (See also Addendum.)			
Family Crangonyctidae			
<i>Crangonyx r. richmondensis</i> Ellis	D,I,L,S	1	B,C,DP,PI
<i>Crangonyx serratus</i> (Embry)	I,L	4	DP
Family Hyalellidae			
<i>Hyalella azteca</i> (Saussure)	D,I,L,S	1	B,C,DP,PI
Order Decapoda			
Family Cambaridae			
<i>Fallicambarus (Creaserinus)</i> <i>uhleri</i> (Faxon)	I	5	C
<i>Procambarus (Ortmannicus)</i> <i>blandingii</i> (Harlan)	D,I,L,S	1	B,C,PI
<i>Procambarus (Ortmannicus)</i> <i>hirsutus</i> Hobbs	L	5	B
<i>Procambarus (Scapulicambarus)</i> <i>troglydites</i> (LeConte)	I	4	PI
Family Palaemonidae			
<i>Palaemonetes paludosus</i> (Gibbes)	D,I,L	1	B,C,DP,PI

\*First record for South Carolina.  
†Range extension.

<sup>1</sup>Habitat Codes:      D:Ditch  
                          I: Impoundment, borrow pit  
                          L: Lake Marion  
                          S: Swamp; tree-shaded, shallow  
                          T: Terrestrial

<sup>3</sup>Unit Codes:        B: Bluff  
                          C: Cuddo  
                          DP: Dingle Pond  
                          PI: Pine Island

<sup>2</sup>Occurrence Codes: 1: Commonly encountered and usually abundant when present.  
                          2: Commonly encountered and usually not abundant, but  
                              with incidences of large numbers.  
                          3: Commonly encountered, but usually not abundant.  
                          4: Not commonly encountered, but usually abundant when present.  
                          5: Not commonly encountered and usually not abundant  
                              when present.

(Dexter 1953). *Eulimnadia ventricosa* occurs in the Atlantic drainage from Maryland to Georgia (Fitzpatrick 1983), but has not been previously reported from South Carolina.

Of the 25 cladoceran species collected, only three were widely distributed and, when present, usually abundant: *Simocephalus serrulatus*, *Eurycercus (Bullatifrons) vernalis*, and *Ilyocryptus spinifer*. Of these, *S. serrulatus* was the most commonly encountered species. *Simocephalus serrulatus* had two pulses of increased numbers: May through June and December, with June's population increase being especially pronounced. Population fluctuations of *E. vernalis* were similar, with pulses occurring in June and from December through January.

Four cladoceran species (*Simocephalus exspinosus*, *Ceriodaphnia reticulata*, *Scapholeberis kingi*, *Macrothrix rosea*) were widely distributed in the refuge, but usually present in small numbers. There were occasions, however, when each of these species was abundant. *Simocephalus exspinosus*, for example, reached very high densities in the borrow pit and adjacent pools referred to above from July through January and in a swamp and flooded forest floor in January. It was widely distributed at other locations and at other times, but in low numbers. *Ceriodaphnia reticulata*, otherwise found in low numbers, became very abundant in a ditch and impoundment in June 1983. *Scapholeberis kingi* reached enormous numbers in a borrow pit in June 1983. There were fairly high numbers of *Macrothrix rosea* in a few samples. Like the species mentioned above, *Chydorus* cf. *C. sphaericus* and *Diaphanosoma brachyurum* were widely distributed, but never collected in abundance. This is in contrast to the findings of Mallin (1984), who found *D. brachyurum* to be one of only two major cladoceran species (the other being *Bosmina longirostris*) in an acidic South Carolina impoundment.

Three cladoceran species were very restricted in their distribution, but usually abundant when present. In August 1982 *Daphnia laevis* reached enormous numbers in a swamp adjoining Dingle Pond, a habitat that was dry in August 1983. That species was found nowhere else in the refuge. Elsewhere, *Daphnia laevis* has often been found in temporary ponds (Brooks 1959). *Sida crystallina* was restricted to Lake Marion and a few impoundments, being very abundant in the lake during June 1983. *Monospilus* sp., although restricted to the lake, was found there in large numbers.

Frey (1982a,b,c) urged caution when identifying cladoceran species because several species, previously believed to be cosmopolitan, have been found to be species complexes, e.g. Black's (1980) report on *Bosmina longirostris* and that by Frey (1980) on *Chydorus sphaericus*.



Also, there are several undescribed species of *Camptocercus* in the United States (Fitzpatrick 1983). As pointed out by Hann (1982), to distinguish *Eurycercus vernalis* from the closely related sibling species *E. longirostris*, one must examine the anatomy of individuals of various ages within a population; I did not do this. Nevertheless, the refuge is within the presently recognized range of *E. vernalis* (North Carolina to Louisiana) and a considerable distance from that of the sibling *E. longirostris* (Indiana). Frey (1982a) has recently mentioned species in the southern United States in particular when commenting on the present systematic confusion within several cladoceran groups. He states that the cladoceran fauna of the southern United States consists of several undescribed species, many possibly constituting species pairs with non-conspecific populations having the same name in the northern part of the country.

With the above caveats in mind, I have determined that the 25 cladoceran species collected in the study include 14 not previously reported from South Carolina (Table 1). All 14 species are found virtually throughout North America except for *E. vernalis* (as described above), *Pseudosida bidentata* (largely restricted to the southern states; Fitzpatrick 1983), and *Monospilus* sp. The only species of *Monospilus* previously reported from North America is *M. dispar*, which is known only from the northern United States and Canada (Fitzpatrick 1983). The species from the refuge differs from *M. dispar* primarily in the shape of the labrum. Another possibly undescribed refuge species is *Alona* cf. *A. guttata*, specimens of which differ slightly, but probably in a taxonomically significant manner, from those of *A. guttata* Sars in having a distal expansion of the postabdomen.

#### ISOPODS

There are three common aquatic isopod species (*Caecidotea forbesi*, *C. laticaudata*, *Lirceus lineatus*) at the refuge and one very rare species (*C. obtusa*); the rare species was found during both winters, but only in Dingle Pond. Of these species, *C. forbesi* was the one most commonly encountered throughout the refuge and throughout the year. *Caecidotea forbesi* was most widely distributed from winter into early summer, with occurrences decreasing during late summer and fall (Table 2). This species was most abundant when the water was cool, either during the winter at many sites or throughout the year at some shaded locations, such as shallow forest swamps and shaded ditches. Although *C. forbesi* was found in a wide variety of habitats, it was largely restricted to shallow, shaded areas and was rarely found in impoundments. At locations where the only species of *Caecidotea* collected was *C. forbesi* (based on identification of males), brooding females were found in all

seasons. However, because females were not identified (taxonomically important morphological characters were variable and overlapping in these species), caution is urged when interpreting such reproductive data.

*Caecidotea laticaudata* was most extensively distributed in the summer (Table 2), when it was numerically most abundant. Although found in various habitats, frequently co-occurring with *C. forbesi*, *C. laticaudata* was largely restricted to the lake margin of the refuge units, plus some immediately adjacent aquatic habitats such as impoundments or swamps. Like *C. forbesi*, it was common in swamps; however, it did not occur in such habitats in the interior of the units, as did *C. forbesi*. Unlike *C. forbesi*, *C. laticaudata* was at times abundant in certain impoundments next to Lake Marion. During the winter this species occurred only in a few sunlit impoundments. *Caecidotea laticaudata* occurred in shaded areas only in summer. At refuge sites where only *C. laticaudata* was collected (based on identification of males), brooding females were found in January and June. As mentioned above, one must be cautious when using data based on unidentified females, particularly because reproduction in January of a species like *C. laticaudata*, which is rare in winter and abundant in summer, would be unexpected.

Differences exist between refuge units with respect to occurrences of *Caecidotea* species. These differences most likely result from inter-unit variations in lake proximity and types of aquatic habitats present. Prime examples are comparisons of the Bluff and Cuddo units. Bluff unit is very narrow, with most of its area close to the lake; considerably less than half of Cuddo unit is as close to the lake as is all of Bluff unit (see Fig. 1). Bluff unit also has much more of its aquatic habitats consisting of impoundments, rather than swamps or ditches, than does Cuddo unit. Most likely due to these differences, *C. laticaudata* is the dominant isopod in the Bluff unit and *C. forbesi* in the Cuddo unit.

As mentioned above, there is considerable seasonal variation in the degree of flooding of aquatic habitats. In the dry summer and fall most of the shallow habitats for *C. forbesi* dry out, greatly reducing the space available for it and, as a result, its abundance. Parsons and Wharton (1978) have reported a similar reduction in numbers of an unidentified species of *Asellus* (= *Caecidotea*) when water levels dropped in summer on a Georgia flood plain. However, because *C. laticaudata* is more common in impoundments, seasonal dryness has far less effect on it.

*Lirceus lineatus* is widespread in the refuge from fall to early spring (Table 2). During the winter it reaches its greatest abundance, making up a substantial portion of the aquatic isopod fauna (Table 3), but it virtually disappears in the summer. It was found in a wide variety

Table 2. Percentages by months of isopod taxa collected at Santee National Wildlife Refuge, S.C. Stations included are only those where isopods were found at least once. Data on species of *Caecidotea* are based solely on the occurrence of males, unless only one species of *Caecidotea* was collected at a particular locality. Data from 1982 and 1983 have been combined.

	<i>Caecidotea forbesi</i>	<i>Caecidotea laticaudata</i>	<i>Caecidotea obtusa</i>	<i>Caecidotea</i> spp.	<i>Lirceus lineatus</i>	Stations Sampled
Dec-Jan	30.8	11.5	3.8	46.2	30.8	26
Mar-May	36.4	0.0	0.0	54.5	27.3	11
Jun-Jul	31.0	28.6	0.0	64.3	2.4	42
Aug-Sep	10.0	22.5	0.0	50.0	0.0	40
Nov	9.5	0.0	0.0	14.3	14.3	21

Table 3. Percentages by months of all aquatic isopod specimens from Santee National Wildlife Refuge, S.C., represented by *Caecidotea* spp. and *Lirceus lineatus*. Data from 1982 and 1983 have been combined.

	<i>Caecidotea</i> spp.	<i>L. lineatus</i>	Total
Dec-Jan	57.6	42.4	295
Mar-May	79.8	20.2	89
Jun-Jul	99.5	0.5	384
Aug-Sep	100.0	0.0	74
Nov	45.4	54.5	33

of habitats, but impoundments were more commonly occupied than were shallow forest swamps or ditches. Brooding females were collected only from December through March.

Oniscoid isopods were found only on and near the Indian Mound Historic Site at Fort Watson on the edge of Bluff unit. This site is outside the protected refuge area and is subject to significant human disturbance. Repeated searches for terrestrial isopods elsewhere in the refuge met with no success.

Collection of *C. laticaudata*, *C. obtusa*, *Porcellionides floria*, and *Miktoniscus halophilus* at the refuge constitutes their first documented occurrences in South Carolina. *Caecidotea laticaudata* has been reported previously from Louisiana, Alabama, Mississippi, Kentucky, and Illinois (Williams 1970, 1972; Fleming 1972). *Caecidotea obtusa* is also primarily

a southern species, having been reported from Georgia and Florida west to Louisiana and southern Arkansas (Williams 1970, 1972; Fleming 1972). *Caecidotea forbesi* is widespread east of the Mississippi River, with the exception of the Gulf coastal region (Williams 1970, 1972; Fleming 1972). Williams (1970) has previously reported the occurrence of *C. forbesi* in Anderson County, S.C. It is interesting that there appear to be correlations between the geographical distribution of *C. laticaudata* and *A. forbesi* and their respective seasonal occurrences at the refuge (Table 2). The northerly occurring *C. forbesi* is most common during cool seasons (March-May), whereas the southern species, *C. laticaudata*, is most common in summer. *Lirceus lineatus* was originally described by Say (1818) from Berkeley County, S.C. It is widespread east of the Mississippi River from the Great Lakes through the Gulf coastal region (Hubricht and Mackin 1949, Williams 1972). The oniscoid *Armadillidium vulgare* is cosmopolitan. Kelley (1978) reported *A. vulgare* from Aiken and Charleston counties, S.C. *Porcellionides floria* has been recently described by Garthwaite and Sassaman (1985) from the southern and western United States, Mexico, and the Bahamas. Its presence at the refuge constitutes its northernmost documented occurrence in the eastern part of the country. *Miktoniscus halophilus* ranges from Massachusetts to Georgia (Schultz 1975, 1976), but it has not been previously reported from South Carolina.

#### AMPHIPODS

Three amphipod species were collected in the refuge. Two species (*Hyaella azteca* and *Crangonyx richmondensis richmondensis*) were common, whereas one species (*C. serratus*) was rare. *Crangonyx serratus* was collected only in winter in one unit, Dingle Pond (Table 4). No brooding females of this species were encountered. Fox (1978) reported all three species from the state.

The most widespread and abundant amphipod was *H. azteca*, which reached high densities in practically all types of aquatic habitats. Although common throughout the year, examination of its degree of dispersion throughout the refuge (Table 5) and its abundance where it was found (Table 6) indicates that populations in many habitats were reduced during two periods. The first was a notable reduction in winter. The second was in mid-to-late summer, when two important environmental changes were evident. One was progressive drying out of many habitats that were flooded during the spring peak in abundance of the species. Another change in some locations having very dense growths of aquatic vegetation was apparent deterioration in water quality, as evidenced by abundant flocculent material in the water, the formation of an organic film on the surface, and occasionally the odor of hydrogen

Table 4. Percentages by months of all amphipod specimens from Santee National Wildlife Refuge, S.C., represented by each of the three species collected: *Hyaella azteca*, *Crangonyx r. richmondensis*, and *Crangonyx serratus*.

	<i>Hyaella azteca</i>	<i>Crangonyx r. richmondensis</i>	<i>Crangonyx serratus</i>	Total
Jan 82	23.9	67.6	8.4	71
Mar 82	95.3	4.7	0.0	277
May 82	94.3	5.7	0.0	263
Jun 82	99.0	1.0	0.0	102
Jul 82	100.0	0.0	0.0	359
Aug 82	98.1	1.9	0.0	106
Sep 82	99.2	0.8	0.0	130
Dec 82	74.5	23.5	2.0	349
Jan 83	52.8	46.5	0.6	159
Jun 83	94.7	5.2	0.0	1635
Aug 83	98.0	2.0	0.0	540
Nov 83	87.4	12.6	0.0	546

Table 5. Percentages by months of stations at Santee National Wildlife Refuge, S.C., where amphipod species were collected. Stations included are all those at which amphipods were found at least once during the study. Data from 1982 and 1983 have been combined.

	<i>Hyaella azteca</i>	<i>Crangonyx r. richmondensis</i>	<i>Crangonyx serratus</i>	Stations Sampled
Jan	57.9	63.2	5.3	19
Mar	83.3	16.7	0.0	6
May	80.0	30.0	0.0	10
Jun	87.3	35.2	0.0	71
Jul	77.8	0.0	0.0	36
Aug	69.7	9.1	0.0	66
Sep	62.5	12.5	0.0	8
Nov	73.3	35.6	0.0	45
Dec	71.4	66.7	9.5	21

sulfide. Most such areas showed a dramatic reduction in numbers of crustaceans, *H. azteca* included, while in nearby habitats that lacked such apparently detrimental characteristics *H. azteca* was frequently abundant. Brooding females of *H. azteca* were collected throughout the year; however, reproduction was greatly reduced in fall and winter (Table 7). Bousfield (1958, 1973) has previously reported that ovigerous females of *H. azteca* occur from April to October, as reflected by studies done in such northern locations as Ontario (Lindeman and Momot 1983), British Columbia (Hargrave 1970, Mathias 1971); Oregon (Strong 1972), Michigan (Cooper 1965), and New York (Embrey 1912). However, Strong (1972) reported that *H. azteca* reproduces all year in a hot spring (12-40 °C) in Oregon.

*Crangonyx r. richmondensis*, equally varied as *H. azteca* in the aquatic habitats occupied, was collected all year, but, in contrast to *H. azteca*, was common only during winter (Tables 4 and 5); it was very rare in summer. Mathias (1971) reported that *Crangonyx* is much more tolerant of cold than is *Hyaella*, and that species of *Crangonyx* frequently breed in winter and spring. No relationship was found between the few summer occurrences of *C. r. richmondensis* and specific habitats; it seems to become rare at all of its locations as winter passes into summer. Reproduction in this species occurred at the refuge from late fall through spring (Table 7), which is similar to Bousfield's (1958) report that ovigerous females of this subspecies occurred from December to June in southern portions of its range.

*Hyaella azteca* occurs throughout North and Central America and the Caribbean islands north to the tree line in Canada and Alaska in all permanent fresh water that reaches a monthly mean summer temperature of over 10 °C (Bousfield 1958). Cooper (1965) reported several sources referring to the high degree of association between large populations of this species and such aquatic plants as *Chara*, *Elodea*, and *Myriophyllum*. Such an association probably accounts in large part for the very high numbers of *H. azteca* frequently seen at the refuge, where dense growths of aquatic plants are extremely common. The presence of large numbers of waterfowl at the refuge provides a means of widespread dissemination, as reported by Daborn (1976) and Swanson (1984) for this species. Over Lake Marion in December 1982, J. Pinckney shot a female wood duck (*Aix sponsa*) that had 10 amphipods in the breast feathers. Three were retained and identified as *H. azteca*.

*Crangonyx richmondensis* was originally described from a site in Berkeley County, S.C. (Ellis 1940). The subspecies *C. r. richmondensis* occurs east of the Appalachians from Georgia north to Nova Scotia and Newfoundland (Bousfield 1958, 1973). However, the distribution is disjunct, with no records of occurrence between Massachusetts and

Table 6. Seasonal abundance of *Hyalella azteca* at sites where collected. Data are expressed as percentage of such stations at which its occurrence was common or uncommon. Data from 1982 and 1983 have been combined.

	Common	Uncommon	Number of Stations
Dec-Jan	45.6	54.3	23
Mar-May	83.3	16.7	12
June	88.7	11.3	62
July	67.8	32.1	28
Aug	41.3	58.7	46
Nov	60.6	39.4	33

Table 7. Sex ratios and percentages of females of *Hyalella azteca* and *Crangonyx r. richmondensis* that were ovigerous, by month. Data from 1982 and 1983 have been combined. N = number of sexed individuals; Total N = total number of sexed individuals plus unsexed juveniles.

	Male: Female	% Ovig.	N	Total N
<i>H. azteca</i>				
Jan	0.71	5.1	101	101
Mar	0.49	69.8	264	264
May	0.50	72.9	248	248
Jun	0.46	52.7	1650	1650
Jul	0.57	52.6	359	359
Aug	0.67	52.0	633	633
Sep	0.92	68.6	129	129
Nov	0.61	18.0	477	477
Dec	0.82	3.5	260	260
<i>C. r. richmondensis</i>				
Jan	0.97	16.9	116	122
Mar	12.00	0.0	13	13
May	1.14	28.6	15	15
Jun	0.67	0.0	5	87
Jul	—	—	0	0
Aug	0.00	0.0	2	13
Sep	—	0.0	0	1
Nov	0.79	5.3	68	69
Dec	0.86	4.5	80	82

Virginia. Holsinger (1972) has reported that the northern and southern forms of this subspecies differ morphologically. In fact, the systematics of the entire *C. obliquis-richmondensis* group is presently unclear (Holsinger 1972).

*Crangonyx serratus* occurs in the coastal plain and piedmont areas from Florida to Maryland (Holsinger 1972). Bousfield (1958) pointed out that the first record of this species in the literature was Say's (1818) report of specimens from South Carolina, which Say identified as "*Ampithoe dentata*." Holsinger (1972) mentioned that *C. serratus* commonly co-occurs with *C. r. richmondensis*.

#### DECAPODS

*Palaemonetes paludosus* was found in large numbers in all types of aquatic habitats, with the exception of those that are isolated and occasionally dry out. It was most abundant from fall to early winter. From midwinter through late spring there was a reduction in abundance, with an increase from summer through late fall (Table 8). However, some locations had abundant numbers at all seasons. Brooding females of *P. paludosus* occurred from May through July. Postlarvae were abundant by June, and immature individuals were dominant from then through August. Average individual size increased notably through fall and winter.

The type locality for *P. paludosus* is Charleston County, S.C. (Gibbes 1850). It has been subsequently reported from the state by other authors, including Hobbs et al. (1976). This species is common in fresh waters of the coastal plain and lower piedmont east of the Appalachians from New Jersey to Florida and thence west to Texas (Fitzpatrick 1983). It has also been introduced to several areas outside of its natural range (Hobbs et al. 1976). Hobbs et al. (1976) report that the species is most abundant where vegetation is dense, as is usually the condition in Santee Refuge impoundments and ditches. The life history of the species at the refuge agrees with reported studies: Ovigerous females occur in spring; young appear in midsummer; young increase in size until they reproduce the following spring, soon after which death occurs. Fleming (1969) and Strenth (1976) have emphasized the importance of setal characteristics of the appendix masculina when distinguishing among different species of *Palaemonetes*. Both of these authors report that *P. paludosus* has four apical setae on this structure. However, I found this characteristic to be variable, with specimens collected having from four to six apical setae. Significant variations in spine position on the telson were also observed.

Of the four species of crayfish found, only one (*Procambarus blandingii*) was common. The other three species (*P. hirsutus*, *P.*



Table 8. Seasonal abundance of *Palaemonetes paludosus* at stations where the species was collected at least once during the study. Data are expressed as percentage of stations at which the species was abundant or absent. Data from 1982 and 1983 have been combined.

	Abundant	Absent	Number of Stations
Jan	27.3	36.4	11
Mar-May	16.7	41.7	12
Jun	14.6	51.2	41
Jul	25.9	48.1	27
Aug	20.0	62.5	40
Nov	40.6	31.2	32
Dec	37.5	31.2	16

*troglydites*, *Fallicambarus uhleri*) were each found in only one location. No brooding females of any species were collected.

*Procambarus blandingii* was commonly encountered throughout the refuge in habitats ranging from vegetated margins of Lake Marion to ditches, impoundments, and shaded swamps. Juveniles were found in all seasons, but were particularly abundant in June. This species has been reported from lentic and lotic sites in southern North Carolina and from the Santee River to the Pee Dee River in South Carolina. Its type locality is in Kershaw County, S.C. (Hobbs 1974).

*Procambarus hirsutus* was found only in one sample taken in emergent vegetation along the edge of Lake Marion. Because immature specimens are easily confused with those of *P. blandingii*, this species may be more widespread in the refuge than this one sample indicates. *Procambarus hirsutus* has been previously reported from streams in the Edisto, Salkehatchie, and Savannah drainage systems in South Carolina. Its type locality is Barnwell County, S.C. (Hobbs 1958a).

*Procambarus troglodytes* was found in one location that consisted of a series of small unshaded puddles resulting from excavation work less than 100 m from Lake Marion. Individuals were abundant in June in these puddles, where they constructed large chimneys. *Procambarus blandingii* occurred in some puddles and an impoundment within 30 m of the puddles used by *P. troglodytes*; however, neither species was collected from a puddle inhabited by the other. *Procambarus troglodytes* occurs in lentic and lotic habitats between the Altamaha River in Georgia and the Pee Dee River in South Carolina (Hobbs 1974).

*Fallicambarus uhleri* was found in only one locality, a borrow pit, and in small numbers. *Procambarus blandingii* occurred in much greater

numbers in this same borrow pit. Juveniles of *F. uhleri* were collected in September and November. *Fallicambarus uhleri* occurs in lentic and lotic habitats along the coastal plain from Maryland to South Carolina (Hobbs 1974).

Horton H. Hobbs, Jr., stated (pers. comm.) that other crayfishes are found near the refuge and may occur, perhaps rarely, in the refuge. These include *Cambarus (Depressicambarus) latimanus* (Le Conte), *Cambarus (Depressicambarus) reflexus* Hobbs, *Cambarus (Puncticambarus) acuminatus* Faxon, and *Procambarus (Ortmannicus) enploternum* Hobbs. It is also possible that *Procambarus (Ortmannicus) ancylus* Hobbs and *Cambarus (Lacunicambarus) diogenes diogenes* Girard may be encountered.

### SUMMARY

Diversity of crustaceans within the Santee National Wildlife Refuge is quite high, especially for the cladocerans. The high diversity of cladocerans is due in part to the variety of aquatic habitats available, from open lake to ditches and swamps, but probably is chiefly due to the great amount of vegetation occurring in most of the impoundments, in ditches, and along the margin of the lake. As suggested by Lemly and Dimmick (1982) in a study of zooplankton in the littoral zone of some North Carolina lakes, a large quantity of aquatic macrophytes provides great habitat heterogeneity, resulting in increased species diversity in vegetated areas (Brooks 1959). Of the 25 cladoceran species collected at the refuge, at least 17 are known to be directly associated with vegetation (Brooks 1959).

Crustaceans of the refuge go through significant seasonal fluctuations in abundance and dominance. Such seasonal changes are correlated with temperature changes as well as with such seasonal variations as the amount of water in shallow aquatic habitats and the late-summer deterioration of certain habitats owing to prolific growth of vegetation and subsequent decomposition.

In winter the crustacean fauna of the refuge is dominated by the cladocerans *Simocephalus serrulatus*, *Eurycercus vernalis*, and, to a lesser extent, *Ilyocryptus spinifer*; the isopods *Caecidotea forbesi* and *Lirceus lineatus*; the amphipods *Hyaella azteca* and *Crangonyx r. richmondensis*; mature *Palaemonetes paludosus*; and the crayfish *Procambarus blandingii*. Early spring is characterized by reductions in numbers of cladocerans, *Lirceus lineatus*, and *Crangonyx r. richmondensis*, with an increase in numbers of *Hyaella azteca*. In late spring the refuge has very high water levels, resulting in expanded habitats for swamp- and ditch-dwelling *Caecidotea forbesi* and *Procambarus blandingii*. By June there are large numbers of juvenile

crayfish present. In addition, in June there are population pulses of several cladoceran species, including *Simocephalus serrulatus*, *Eurycerus vernalis*, *Ceriodaphnia reticulata*, *Scapholeberis kingi*, and *Sida crystallina*. The occurrence of one or two population pulses during a year is characteristic of many cladoceran species (Pennak 1978).

In summer, the cladoceran fauna, with the exception of a few species, is again generally reduced in numbers. Peracarids that are commonly encountered include *Hyaella azteca*, *Caecidotea laticaudata*, and reduced numbers of *Caecidotea forbesi*. Dryness eliminates many shallow-water habitats for *Caecidotea forbesi* and, in late summer, this aridity, as well as the growth and decomposition of large quantities of vegetation in certain locations, leads to reductions in numbers of *Hyaella azteca* and other crustaceans at several sites. Populations of *Palaemonetes paludosus* consist of large numbers of postlarvae and juveniles in summer.

Late autumn is characterized by increasing numbers of *Caecidotea forbesi*, *Lirceus lineatus*, and *Crangonyx r. richmondensis*, and decreasing numbers of *Caecidotea laticaudata* and, to a moderate extent, *Hyaella azteca*. Large numbers of *Palaemonetes paludosus* mature during this period.

Two habitats on the refuge are quite distinctive and warrant further investigation. Dingle Pond is unique in the refuge in that all seven peracarid species occur there. The pond itself is in the latter stages of hydrarch succession, characterized by a mixture of connected open pools and swamps, with scattered tree- and bush-covered hummocks. The second habitat is in Cuddo unit; it consists of a small, forest-surrounded borrow pit encircled by a series of small, swampy pools. In it I found *Procambarus blandingii*, *Fallicambarus uhleri*, *Caecidotea forbesi*, *Crangonyx r. richmondensis*, *Simocephalus exspinosus*, and, occasionally in summer, *Streptocephalus seali* and *Eulimnadia ventricosa*. *Streptocephalus seali* and *Eulimnadia ventricosa* were restricted to shallow pools bordering the borrow pit during low water when fishes were abundant but limited to the borrow pit. That these two crustacean species disappeared when the water rose, making the pools and borrow pit confluent, suggests that predation by fishes may eliminate them. The usual absence of non-cladoceran branchiopods from bodies of water containing fishes is well known and has been thought to be the result of predation on these large, easily seen, and almost totally defenseless species (Pennak 1978).

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#### ADDENDUM

In June 1986, two specimens belonging to an undescribed amphipod species in the genus *Gammarus* were collected from the sandy bottom of Lake Marion adjoining Cuddo unit. This species belongs in the *G. fasciatus-tigrinus* complex that, according to Fox (1978), includes two or three undescribed species from South Carolina to Louisiana.



# Taxonomic Analysis of the Coastal Marsh Raccoon (*Procyon lotor maritimus*) in Maryland

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**ABSTRACT.**— Skulls of raccoons were collected from three physiographic regions in Maryland. Based on multivariate analyses of skull measurements, it is suggested that the coastal marsh raccoon, *Procyon lotor maritimus*, be considered a synonym of *P. l. lotor*.

Most taxonomic studies describing subspecies of raccoons (*Procyon lotor*) were based on qualitative cranial characteristics and pelage (see Goldman 1950). Pelage is highly variable within geographic regions and is a poor diagnostic character. The coastal marsh raccoon (*P. l. maritimus*) was described by Dozier (1948) on the basis of 34 specimens (skins, skulls, or both) from marsh habitats on the Delmarva Peninsula. According to Dozier (1948), skulls of *P. l. maritimus* were smaller and narrower than those of *P. l. lotor* and had shorter postorbital processes. He also stated that the two subspecies occupied different habitats on the Delmarva Peninsula, with *P. l. maritimus* in marshes and *P. l. lotor* in upland wooded areas. Neither the cranial nor the habitat differences were quantified, however, and not all researchers accepted the coastal marsh raccoon as a new subspecies. Paradiso (1969:145) felt that the differences in *P. l. maritimus* were “slightly marked” and within the limits of individual variation of *P. l. lotor*. Without commenting on the validity of current taxonomy, Hall and Kelson (1959) and Hall (1982) treated *P. l. maritimus* as a valid subspecies. Our objective was to determine if *P. l. maritimus* was a valid taxon based on statistical analyses of cranial characteristics.

## MATERIALS AND METHODS

Skulls of male raccoons (n = 63) from the museum collections of the Appalachian Environmental Laboratory and the National Museum

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of Natural History were used in the analysis. Females were excluded because of small, unequal sample sizes among groups. Adults only were examined and distinguished from juveniles according to tooth wear (Grau et al. 1970), closure of parietal sutures, and month of capture.

Raccoon skulls were grouped according to capture location in Maryland into one of three physiographic regions (see Paradiso 1969): (1) western, which included the Appalachian Plateau and Ridge and Valley regions ( $n = 21$ ); (2) central, which included the Piedmont region ( $n = 23$ ); and (3) eastern, which included the Coastal Plain region ( $n = 19$ ). Skulls from the two initial groups represented *P. l. lotor*. The third group represented *P. l. maritimus*, based on all captures being from the type locality, Blackwater National Wildlife Refuge, Dorchester County, adjacent Fishing Bay, or similar marsh habitats in five other counties on Maryland's eastern shore. Comparisons also were made with skulls of *P. l. fuscipes* ( $n = 16$ ) from Texas and Mexico.

Differences among groups were determined by analysis of variance of 12 skull measurements (see Table 2), with Duncan's Multiple Range test, and by stepwise discriminant function analysis, after elimination of correlated variables ( $r \geq 0.70$ ). The selection criterion was the maximum Mahalanobis distance. Analyses were conducted using programs of SPSS (Nie et al. 1975).

Table 1. Actual and predicted group membership for male raccoon skulls from western and central Maryland (*P. l. lotor*), eastern shore of Maryland (*P. l. maritimus*), and Texas (*P. l. fuscipes*).

Actual group	(N)	Predicted group			
		W. Md.	C. Md.	E. Md.	Texas
W. Md.	(21)	13	6	2	0
C. Md.	(23)	5	15	3	0
E. Md.	(19)	1	5	12	1
Texas	(16)	2	0	4	10

## RESULTS AND DISCUSSION

In the discriminant function analysis of the three Maryland groups and *P. l. fuscipes* (Fig. 1), width of braincase had the highest standardized coefficient (-0.849) in the first function, followed by basilar length (0.830). The first function explained 69.0% of the variation among groups. In the second function, width of rostrum (0.505) and width of

Table 2. Means  $\pm$  one standard deviation, ranges (mm), and F values for 12 cranial characteristics from adult male raccoon (*Procyon lotor*) skulls from three regions of Maryland. \* =  $P < 0.01$ .

Measurement <sup>1</sup>	Group			F
	Western (n = 21)	Central (n = 23)	Eastern (n = 19)	
LEN	98.9 $\pm$ 3.5 (93.4 - 104.8)	99.3 $\pm$ 2.6 (95.2 - 105.8)	100.1 $\pm$ 2.8 (95.4 - 105.7)	0.866
ZG	73.1 $\pm$ 3.7 (62.7 - 78.2)	72.0 $\pm$ 3.9 (64.1 - 77.9)	70.5 $\pm$ 4.9 (62.5 - 81.9)	1.955
POSTC	23.1 $\pm$ 2.1 (18.8 - 26.9)	23.0 $\pm$ 1.0 (21.2 - 24.7)	22.3 $\pm$ 1.4 (20.9 - 25.2)	1.728
MAXL	42.6 $\pm$ 1.4 (39.4 - 45.8)	42.7 $\pm$ 1.6 (40.4 - 46.5)	42.4 $\pm$ 1.2 (39.5 - 45.0)	0.313
BR	49.7 $\pm$ 1.3 (46.9 - 52.2)	49.4 $\pm$ 1.8 (43.4 - 51.9)	47.6 $\pm$ 1.4 (45.8 - 50.4)	10.925*
PAL	66.2 $\pm$ 2.3 (62.9 - 71.0)	66.9 $\pm$ 2.1 (63.4 - 72.5)	67.0 $\pm$ 2.1 (63.6 - 70.9)	0.807
INC	5.8 $\pm$ 0.5 (4.8 - 6.6)	6.4 $\pm$ 0.7 (5.0 - 7.5)	6.5 $\pm$ 0.9 (5.0 - 7.8)	5.799*
BUL	17.4 $\pm$ 1.0 (15.1 - 18.7)	18.1 $\pm$ 0.9 (16.7 - 19.2)	17.7 $\pm$ 0.9 (16.2 - 19.7)	2.937
ROS	26.6 $\pm$ 1.0 (25.0 - 29.1)	26.4 $\pm$ 1.3 (24.4 - 29.0)	25.5 $\pm$ 1.0 (23.1 - 27.3)	6.146*
MAXW	40.6 $\pm$ 1.2 (38.1 - 43.9)	41.0 $\pm$ 1.7 (37.5 - 44.7)	40.0 $\pm$ 1.2 (38.1 - 41.9)	1.601
PORB	26.7 $\pm$ 2.7 (22.1 - 31.8)	26.8 $\pm$ 2.1 (23.2 - 31.9)	24.8 $\pm$ 1.9 (22.0 - 28.1)	5.059*
LORB	23.6 $\pm$ 1.9 (19.3 - 27.1)	23.4 $\pm$ 1.1 (21.2 - 25.8)	22.8 $\pm$ 1.4 (20.8 - 27.0)	2.347

<sup>1</sup> Measurements: The following cranial measurements were taken to the nearest 0.1 mm with vernier calipers: basilar length (LEN), zygomatic breadth (ZG), width of postorbital constriction (POSTC), length of maxillary tooth row (MAXL), width of braincase (BR), length of palatal bridge (PAL), length of incisive foramina (INC), length of bullae (BUL), width of rostrum between alveoli of upper canines (ROS), maxillary width between alveoli of upper first molar (MAXW), width of postorbital process (PORB), and least orbital width (LORB).

postorbital process (0.385) were the most important discriminating variables and accounted for an additional 22.9% of among-group variation. The overall percentage of individuals correctly classified was only 63.3% (Table 1). Because all cases were used to derive the functions, this percentage actually overestimated the accuracy of the functions (Williams 1983). That the correct-classification rate was inflated is further suggested by the calculation of Cohen's kappa = 0.447 ( $Z = 4.96$ ,  $P < 0.0001$ ), the chance-corrected percentage of agreement between actual and predicted group memberships (Titus et al. 1984). Specimens from central Maryland overlapped considerably with the western and eastern groups. There also was considerable overlap among Maryland raccoons and *P. l. fuscipes*, possibly because subadults may have been included in the latter sample.

Significant differences (ANOVA F-test,  $P < 0.05$ ) among the three Maryland groups occurred in four skull variables. Duncan's Multiple Range test indicated the width of rostrum, width of braincase, and width of postorbital processes were significantly smaller in the eastern group; western and central groups were not different. The western group had significantly shorter incisive foramina (Table 2). This supports Dozier's statement (1948) that the skull of *P. l. maritimus* is narrower than in raccoons from western or central Maryland.

There is no ecological or geographic evidence (Vokes 1957) that raccoons in Maryland were ever isolated. Dozier's (1948) statements that *P. l. maritimus* is restricted to marshland are not necessarily supported by recent telemetry studies. Sherfy and Chapman (1983) found that radiocollared raccoons at Blackwater National Wildlife Refuge alternately used marsh and woodland as activity areas, although sample size ( $n = 2$ ) was very small. Thus, there probably is no ecological barrier to isolate what Dozier termed *maritimus* from *lotor*. Raccoons are highly mobile with observed morphological variation among populations often explained by elevation, temperature, and habitat factors (Kennedy and Lindsay 1984) as well as genetic considerations. Although there is no clear consensus on subspecific criteria, we concur with Paradiso's (1969) opinion that the morphological differences among Maryland raccoons do not justify designating those on the eastern shore as a subspecies, and *P. l. maritimus* Dozier should be considered a synonym of *P. l. lotor* (Linnaeus).

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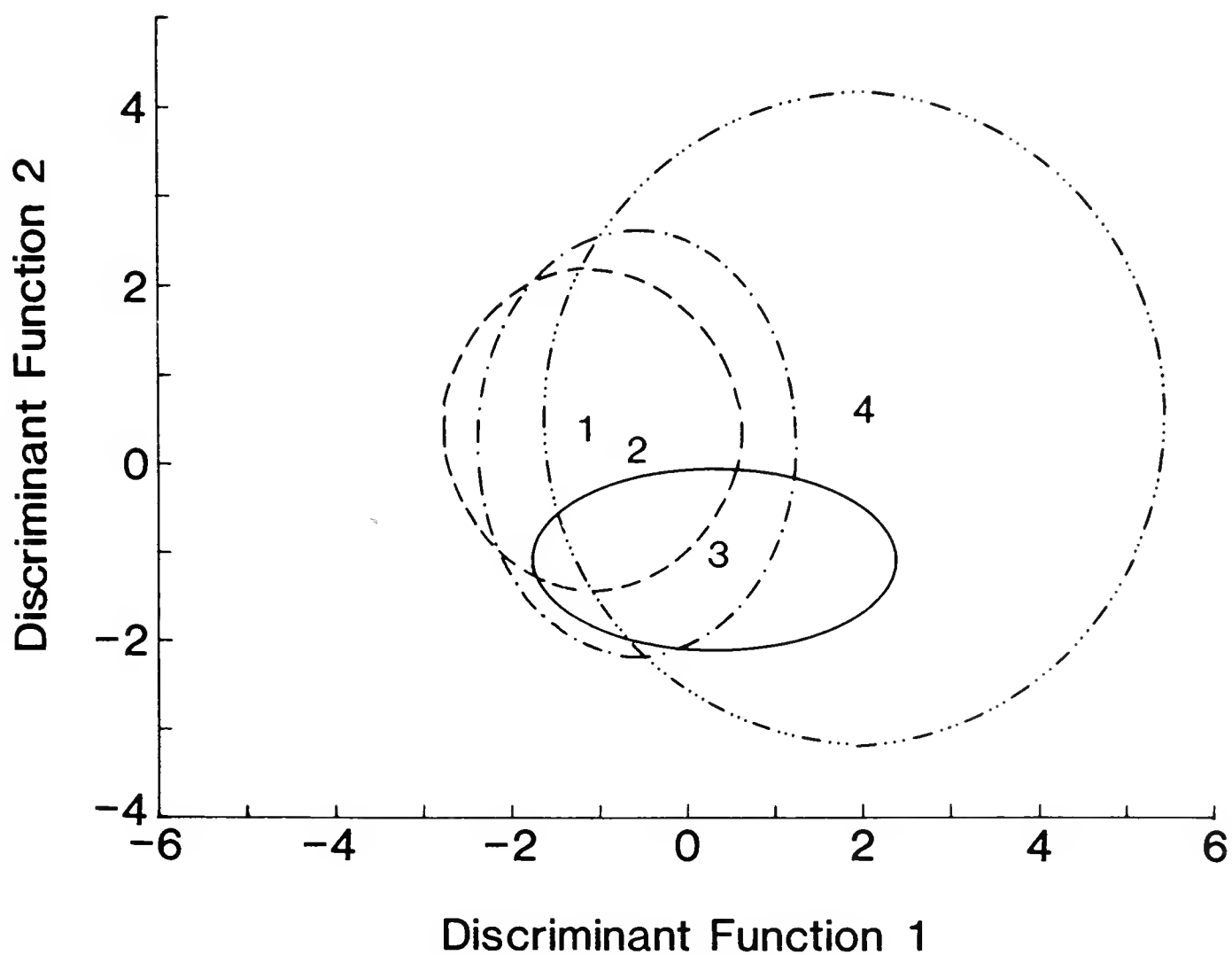


Fig. 1. Ninety-five percent confidence ellipses around the group centroids for raccoon skulls from (1) western and (2) central Maryland (*P. L. lotor*); (3) marsh areas of Maryland's eastern shore (*P. l. maritimus*); and (4) *P. l. fuscipes* from Texas and Mexico. Function 1, from left to right, represents a gradient of increasing skull length and decreasing width. Function 2, from bottom to top, represents a gradient of increasing skull width.

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# Tolerance of Acidity in a Virginia Population of the Spotted Salamander, *Ambystoma maculatum* (Amphibia: Ambystomatidae)

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**ABSTRACT.**— We investigated apparent acid tolerance of egg masses of the spotted salamander, *Ambystoma maculatum*, in the lower piedmont and coastal plain of Virginia. All temporary ponds that we tested in east-central Virginia were acidic (i.e., pH < 6.0), and the majority (about 93%) had no ambystomatid egg masses in them during the spring breeding season. However, a few ponds continued to support successful spotted salamander populations, even though their pH levels were below those that caused extensive mortality of eggs and larvae in the laboratory. In laboratory tests, more than 50% of the eggs removed from these ponds survived pH levels of 4.3 to 4.7, but no eggs or larvae tolerated experimental exposure to a pH less than 4.0. Local tolerance of low pH may result from natural selection of resistant individuals through long exposure to the acidic, boggish waters of the coastal plain and lower piedmont. However, we hypothesize that aluminum may be involved in apparent resistance to low pH. Some coastal plain and piedmont soils are low in aluminum, and large amounts of organic materials may bind and inactivate the aluminum that is present. Lowered levels of dissolved aluminum may permit survival of salamander embryos/larvae at a low pH. This hypothesis is supported by increased mortality of embryos in test containers to which small (< 0.3 ppm) amounts of aluminum were added. Soils and temporary ponds of the lower piedmont and coastal plain of Virginia are naturally acidic and have little buffering capacity. Future acidification of the environment as a result of acid precipitation is likely in this region. Our tests indicate that slight decreases in pH of temporary ponds may result in eradication of the spotted salamander from this part of Virginia.

Tolerance of low pH by amphibians recently has received much attention (for a review, see Pierce 1985). In general, most adult amphibians are relatively tolerant of acidity or conditions associated with low pH, but eggs and larvae may suffer extreme mortality under mildly acidic conditions (Saber and Dunson 1978, Dunson and Connell 1982). Eggs and larvae of the spotted salamander, *Ambystoma maculatum*, seem to be especially sensitive to low pH, and the species may be decreasing in number at some locations because of acidification of breeding ponds resulting from deposition of atmospheric acid (i.e., acid rain; see Pough 1976, Pough and Wilson 1977).

Pough (1976) and Pough and Wilson (1977) found that New York populations of the spotted salamander suffered high mortality of larvae at a pH lower than 6.0, and the species has declined or disappeared from parts of the northeastern United States. However, Cook (1983), working with spotted salamanders at sites within the Connecticut Valley of Massachusetts, found that the percent of mortality of embryos/larvae was small (i.e., usually less than 20%) in ponds of pH 4.2 to 6.0. He concluded that survival of embryos/larvae in some populations of the spotted salamander indicated embryonic acid tolerance, an idea echoed by others (see Pierce 1985). The present study examines a similar apparent tolerance of acidity in coastal plain and piedmont populations of the spotted salamander in Virginia.

### MATERIALS AND METHODS

Studies were conducted in the spring (February - April) of 1983 through 1986. Initially we surveyed temporary ponds in six counties (Charles City, Chesterfield, Goochland, Hanover, Henrico, and Powhatan) of the coastal plain and piedmont of east-central Virginia. We specifically looked for egg masses, larvae, and spermatophores in all 168 temporary ponds we encountered.

In 64 of the ponds, we measured pH by means of an electronic, portable meter (Digital Mini-pH meter) and confirmed these determinations with two laboratory meters (Corning and Orion), Merck colorpHast pH paper, or both. The pH of the remaining 104 ponds was not measured, in the interest of time, because the ponds were near others whose pH was known, or for both reasons. Although the point is seldom mentioned in the literature, pH is difficult to measure in low conductivity waters such as those encountered in temporary ponds. We therefore were careful to duplicate most determinations with at least two different meters, or with a meter and pH paper. Different techniques never produced pH's that differed by more than 0.2; duplicate measurements were averaged in those instances where two methods were used. Additionally, we confirmed most determinations by adding small amounts of KCl to aliquots of the solution to be tested before using a pH meter. This increases the conductivity of the solution and increases the accuracy and speed of measuring pH (F. Hawkrige, pers. comm.).

Tests of pH-related mortality were performed on *A. maculatum* egg masses that were removed from a temporary pond in Chesterfield County, Virginia. This site is within the coastal plain and is acidic (mean pH =  $4.35 \pm 0.30$ ; calculated from 22 determinations made on different days over a span of 4 years). One-liter aquaria filled with water from the temporary pond were used for all tolerance tests as well as



controls. All water was filtered through cheesecloth before eggs were added. All tests were carried out in a controlled temperature (15°C) cabinet at a photoperiod of 12L:12D. Oxygen levels in the aquaria remained high (i.e., near saturation) through the tests and were monitored periodically with an electronic oxygen meter.

Two egg masses were placed in each aquarium. Although we measured masses having a volume greater than 200 cm<sup>3</sup> and containing more than 200 eggs, the volume of masses in our tests was  $65.2 \pm 10.2$  cm<sup>3</sup> (mean  $\pm$  one standard error). These contained  $57.9 \pm 0.8$  eggs/mass.

Experimental groups included tests of survival of eggs in pond water with acid added (either H<sub>2</sub>SO<sub>4</sub> or HNO<sub>3</sub>), or with aluminum added. Aluminum used in all tests was in the form of Al (SO<sub>4</sub>)<sub>2</sub>. Acid from a concentrated stock solution was added in tiny amounts until a pH of 3.0 to 4.0 was obtained. The buffering capacity of individual egg masses then caused acidity to change. This resulted in pH values of 3.1 to 4.0 (see Table 2). Aluminum sulfate was added in amounts sufficient to produce 0.05, 0.10, or 0.23 ppm aluminum in the solution. Controls were performed in exactly the same manner as experimental groups. In addition, we tested survival of eggs in local spring water having a slightly higher pH and little or no dissolved organic materials (pH =  $4.65 \pm 0.30$ ; N = 5).

Egg masses were inspected daily, and embryos were classified according to Harrison stage (Pough 1976; modification of Rugh 1962). Mortality of salamander eggs may be a function of shrinkage of the gelatinous matrix surrounding the eggs. Accordingly, the length and width of each egg mass was measured with a plastic ruler at the beginning of each test, and at 3, 6, 14, and 25 days. Volume of individual masses was then computed from the prolate spheroid formula:  $V = 0.523 AB^2$ , where A is the length of the mass (cm), B is the width, and V is the volume in cm<sup>3</sup>. All free-swimming larvae were removed within 48 hours of hatching, examined for morphological defects, and released into a central holding tank. No long-term tests of mortality of larvae were performed; references to larval survival in the present paper are valid only for the 24 hours after hatching. Most surviving larvae were returned to the breeding pond.

## RESULTS

All temporary ponds (64) whose pH was known were acidic, and the majority (63/64 = 98.4%) had pH values during the spring *Ambystoma* breeding season that were below levels known to cause mortality (i.e., pH < 6.0; see Pough 1976, Pough and Wilson 1977, Cook 1983). A small percentage (5/64 = 7.8%) had pH's of less than 4.0 (Table 1). Of the total of 168 ponds that were surveyed, only a few (12/168 = 7.1%)

had egg masses or larvae in them during the breeding season. However, two ponds with pH's less than 4.5 produced larvae, and one of these, a large temporary pond in Chesterfield County, had more than 300 egg masses in it during each of the five breeding seasons from 1982 through 1986.

Mortality of controls was highly variable among egg masses in the laboratory, but in general was relatively low for water with such low pH values (Table 2; see Pough 1976, Pough and Wilson 1977). Control results for 1984 did not differ significantly ( $t = 1.6$ ;  $p < 0.05$ ) from those of 1985, and neither of these groups was different from spring-water tests ( $t = 1.3$  and  $0.4$ , respectively;  $p < 0.05$ ). Mortality in control groups occurred during early embryonic stages, that is, stages 1 through 9 (Rugh 1962). The only abnormalities noted were deformities of the posterior trunk of hatched larvae and there were relatively few of these (see Pough 1976).

Very small amounts of sulfuric or nitric acid decreased the pH of test waters severely, indicating that water from these temporary ponds is poorly buffered. Furthermore, even small decreases in pH resulted in nearly total mortality of eggs/larvae (Table 2). Mortality appeared to be caused mainly by severe shrinkage of the total egg mass, as described by Pough (1976). Shrinkage did not occur at pH levels of the natural ponds (Fig. 1). In fact, egg masses increased in size as expected in newly deposited eggs (Pough 1976). Acidity of pH less than 4.0 resulted in shrinkage of egg masses, in some cases to less than one-third of the original size (see Fig. 1). Shrinkage was roughly a function of pH, that is, the lower the pH, the greater the amount of shrinkage. The most severe cases resulted in egg masses less than one-fourth the expected size.

Addition of aluminum sulfate to test aquaria resulted in higher mortality, and the mortality rate increased rapidly with very small increases in aluminum sulfate (Table 3). Slight increases of aluminum (0.05 ppm) did not significantly increase mortality as compared with pooled controls ( $t = 0.8$ ), but 0.10 and 0.23 ppm caused significant ( $p < 0.05$ ) increases in mortality ( $t = 2.1$  and  $3.8$ , respectively).

## DISCUSSION

The observation that one low-pH pond apparently has supported a very large, successful population of spotted salamanders while few others have done so, suggests that this population is acid-tolerant or that the pond has one or more characteristics that reduce the deleterious effect of low pH. Our control tests indicate that tolerance of acidity was greater than that reported by Pough (1976) and was similar to that of an acid-tolerant population investigated by Cook (1983). Field observations,

Table 1. Acidity of 64 temporary ponds in the lower piedmont and coastal plain of east-central Virginia. Sample size (N) represents individual ponds having given pH values during early spring.

pH	N	Ponds with egg masses
Less than 4.0	5	1
4.0 - 4.5	11	1
4.5 - 5.0	20	3
5.0 - 5.5	24	5
5.5 - 6.0	3	2
6.0 - 6.5	1	0

Table 2. Percent mortality of spotted salamander eggs exposed to different aquatic media. Mortality rates are means  $\pm$  one standard error; ranges of mortality are in parentheses. N is the number of tests, two egg masses per test. All egg masses were taken from a temporary pond in Chesterfield County, Virginia.

Test	N	pH	Mortality (%)
Control (1984)	9	4.3 - 4.7	26.1 $\pm$ 13.5 (12.9 - 50.9)
Control (1985)	3	4.4 - 4.5	57.3 $\pm$ 14.6 (45.5 - 69.0)
Spring water	4	4.6 - 4.7	32.7 $\pm$ 9.7 (17.3 - 43.3)
H <sub>2</sub> SO <sub>4</sub> added	8	3.1 - 4.0	100
HNO <sub>3</sub> added	6	3.7 - 4.0	99.8*

\*One larva survived at pH = 4.0.

Table 3. Mortality of spotted salamander eggs in media to which aluminum sulfate was added. Percent mortality is given as in Table 2.

Aluminum supplement (ppm)	N	pH	Mortality (%)
0.05	3	4.3	45.5 $\pm$ 7.3
0.10	3	4.3	57.0 $\pm$ 21.3
0.23	3	4.2	88.5 $\pm$ 7.9

as well as the great number of egg masses found in the Chesterfield County pond, indicate that natural reproduction was successful there. One hypothesis is that such success may represent evolution of acid tolerance as a result of long exposure to low pH in this pond (e.g., Tome and Pough 1982, Cook 1983). However, there is another plausible explanation. While low pH can have direct effects upon amphibian larvae (Pough 1981, Freda and Dunson 1984), external cation concentration may be the source of the damage (Hall and Likens 1981, Freda and Dunson 1985; but see Dale et al. 1985). In most natural waters, decreases in pH would increase the amount of free aluminum (and other cations) available to aquatic organisms (see Hall and Likens 1981, Clark and Hall 1985). Decreasing pH may then cause mortality by the increase in toxic aluminum, rather than by direct pH effects. Aluminum has long been known to be detrimental to fish, particularly their eggs and larvae (Freeman and Everhart 1981, Schofield 1980), and it appears to have a similar effect on amphibian larvae (Clark and Hall 1985).

Our tests of aluminum toxicity (Table 3) support the hypothesis that aluminum is harmful to spotted salamander eggs. It should be noted that addition of  $\text{Al}(\text{SO}_4)_2$  decreased the pH of the aquaria media slightly as a result of the addition of  $\text{SO}_4$  ions (Table 3). The extent of the extra acidity was only slight; this was not expected to affect egg mortality because we found no significant correlation between mortality and pH in the pH range of 4.2 to 4.8 (Table 2). Very small amounts of aluminum increased mortality of larvae to the point that we estimate (by extrapolation) that total mortality should occur at increases of 0.28 ppm aluminum. This is similar to levels of toxicity for brook trout (*Salvelinus fontinalis*) eggs at similar pH's (Hall and Likens 1981). This by no means proves a causal relationship between aluminum concentration and egg mortality, but does suggest that the hypothesis deserves further testing.

Acidity of many temporary ponds in the coastal plain and eastern piedmont of east-central Virginia is near the minimum tolerance levels for spotted salamander embryos/larvae (see Pough 1976). Only one larva survived any of our tests in which the pH was 4.0 or less, and mortality in excess of 50% was observed in aquaria at pH's of 4.3 to 4.4 or less. This indicates that only a slight further acidification of local temporary ponds in east-central Virginia may result in total extirpation of the species from the area.

Hatching success of spotted salamanders in acidic pools depends on at least two factors. The first is the volume of the egg mass. However, in the present study, there was no obvious relationship between mortality rate and size of the egg mass. We excluded both very small and large,

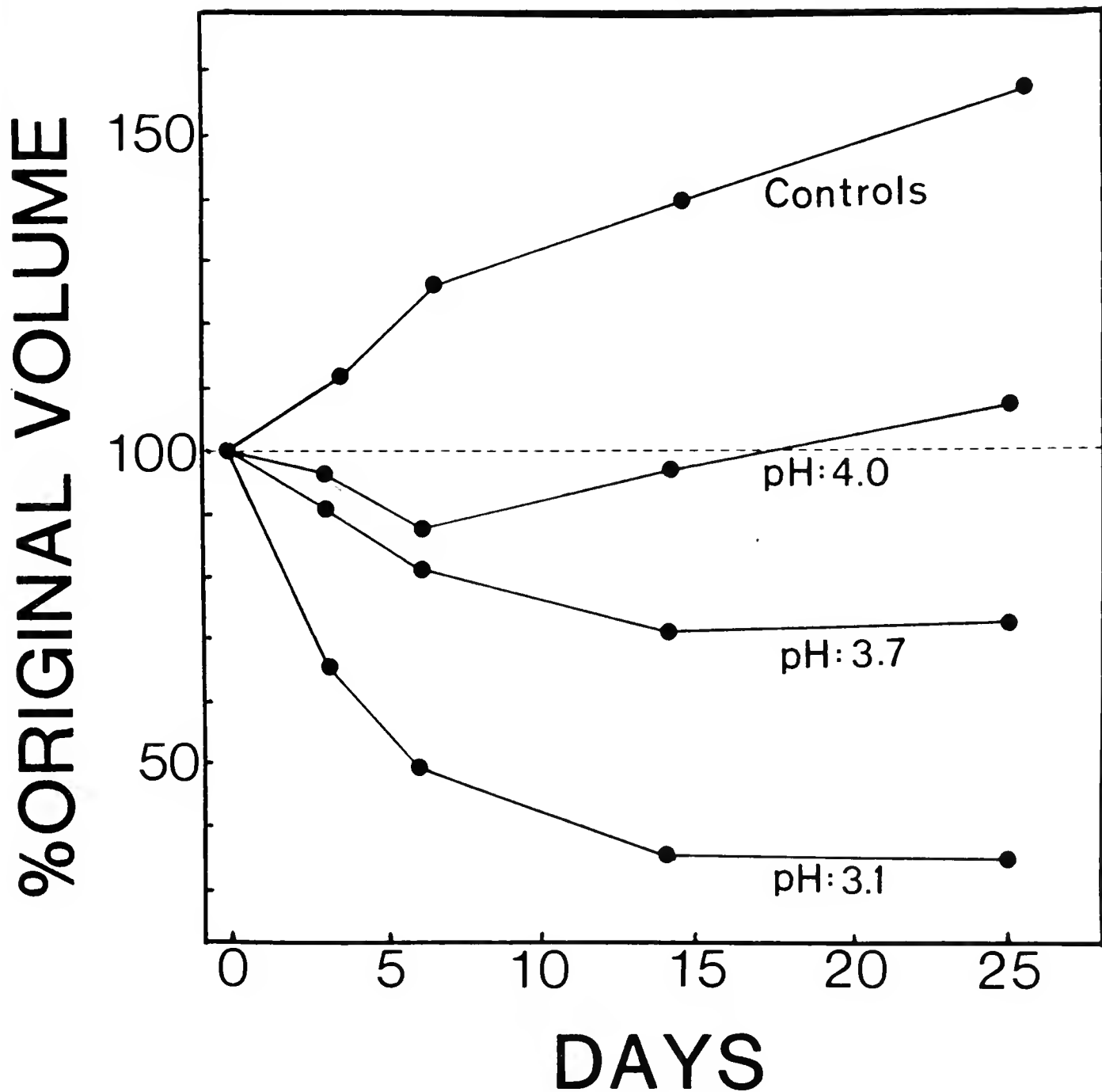


Fig. 1. Volume of spotted salamander egg masses as a percentage of the original volume. The dotted line indicates no change.

irregular egg masses from the study because these may not be representative of normal, single reproductive attempts. As a result, our experiments were performed using egg masses that were rather uniform. Although large egg masses may have a beneficial effect on larvae deep within the mass by providing local buffering, we observed that mortality was largely a matter of death of most eggs within single masses. Pough (1976) noted that the buffering capacity of the gelatinous matrix of ambystomatid egg masses was slight, but found that the few surviving embryos in acid waters tended to be in the centers of masses. Evolution of acid tolerance may take the form of natural selection of larger egg masses, and this hypothesis deserves consideration. Second, hatching success varies because temporary pools differ greatly in chemical

composition, depending upon the local soil composition and the nature of the decomposing organic material in the water. For example, in our study area, soil maps indicate a mosaic of soils that vary in acidity and aluminum content (Hodges 1978). The local vegetation around breeding ponds may be pines, hardwood forest, or old field. The acidity of breeding pools may be increased by pine needles and/or oak leaves through humic acids produced because of poor rates of decomposition, but the products of other plants may not be so acidic (Smith 1986). The interactions between pH, organic matter, and aluminum may be complex, but in general it appears that high concentrations of organic compounds may decrease available aluminum ions by binding with them (Pott et al. 1985).

In summary, the results of the present study indicate that we should be cautious in attributing tolerance of acidity to populations of spotted salamanders breeding in ponds of low pH. Even so, it appears that *A. maculatum* in parts of Virginia has a dismal future because the slightest increases in acidity may cause its extirpation.

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Population Structure and Biomass  
of *Sternotherus odoratus* (Testudines: Kinosternidae)  
in a Northern Alabama Lake

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*ABSTRACT.*— A population of the stinkpot, *Sternotherus odoratus*, was sampled periodically during the summer of 1985 in a small lake in northern Alabama. The population structure was similar to that reported in other studies, although the sizes of turtles were intermediate between populations located farther to the north and to the south. The sex ratio was skewed toward females, but a relatively small sample size hinders interpretation of the significance of this result. A population density estimate of 148.5 turtles per hectare indicated a biomass of 10.6 kg/ha. Mortality from drowning in traps was not influenced by the sex, body mass, or size of the affected adult.

The stinkpot or common musk turtle, *Sternotherus odoratus*, is a geographically widespread inhabitant of the eastern United States. This omnivorous species frequents sluggish and still waters, particularly lakes and ponds (Carr 1952, Ernst and Barbour 1972, Mount 1975). In Alabama, stinkpots occur statewide (Mount 1975), and they inhabit slow-moving or lentic waters, including large rivers such as the Tennessee River.

In spite of the species' ubiquitous nature, there have been relatively few field studies of stinkpot ecology, and these for the most part have concentrated on reproductive ecology (Tinkle 1961; Gibbons 1970a; Iverson 1977; McPherson and Marion 1981, 1983; Gross 1982; Mitchell 1985a, 1985b). Aspects of its life history and abundance have been reported for pond populations in the north (Risley 1933, Cagle 1942, Wade and Gifford 1965, Ernst 1986), a large lake population in central Florida (Bancroft et al. 1983), and a stream population in Oklahoma (Mahmoud 1969). Although reproductive and intrapopulational morphological variation is substantial, there is relatively little interpopulational morphological variation (Reynolds and Seidel 1983). Little is known about geographic variation in population density, or about population densities in different habitat types within close proximity to one another.

During the course of a study of the ecology of the flattened musk turtle, *Sternotherus depressus*, in the Warrior Basin of north-central Alabama (Dodd et al. 1988). I had the opportunity to sample

periodically a lake population of *S. odoratus* near one of the *S. depressus* study sites. This paper provides data on the population structure and biomass of stinkpots at that site, near the northwestern boundary of the Warrior Basin.

### STUDY AREA AND METHODS

The study was conducted on Brushy Creek Lake in the Bankhead National Forest, Winston County, Alabama (T9S R7W S4N, Grayson Quadrangle). Brushy Creek Lake was created when Brushy Creek was impounded to serve recreational purposes. It has a surface area of 13.76 ha with a maximum depth of 3.7 m, although 9.36 ha (67.3%) is less than 2.4 m. The study area (Fig. 1) comprised 0.9 ha on the north shore of the lake, including 6.4% of the total lake surface area and approximately 9.7% of the vegetated shallow-water habitat.

The primary submergent plants in Brushy Creek Lake were pondweeds (*Potamogeton* sp.) and bladderworts (*Utricularia* sp.). Major fish species included largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), redear sunfish (*L. microlophus*), warmouth (*L. gulosus*), crappie (*Pomoxis* sp.), grass pickerel (*Esox americanus*), and carp (*Cyprinus carpio*). Other species of turtles seen or trapped were the snapping turtle (*Chelydra serpentina*), eastern mud turtle (*Kinosternon subrubrum*), yellow-bellied slider (*Trachemys scripta*), and river cooter (*Pseudemys concinna*). The major benthic components of the lake have not been identified (G. Gaines, pers. comm.).

Trapping was conducted six times between 5 May and 5 September 1985, at approximately equal time intervals, using 2.54-cm mesh wire funnel traps (Iverson 1979); sardines were used as bait. Cans were partially opened or punctured and placed in the bottom of the trap. Ten traps were set on each sampling date between 1700 and 2000 hours and retrieved between 0800 and 1000 hours the next morning. The amount of time traps were in the water was recorded to the nearest 0.5 hour. Traps were set in shallow water with a heavy fringe of emergent and submerged aquatic vegetation that provided abundant cover for stinkpots and their prey.

The carapace length (CL) and plastron length (PL) were recorded for each turtle to the nearest 0.1 mm using a dial caliper and standard turtle measuring techniques. Mass was recorded to the nearest 0.5 g. Turtles were considered adults if they measured greater than 65 mm CL (McPherson and Marion 1981). Each turtle was assigned an identification number (ID) by notching marginal scutes (Cagle 1939).

Pearson correlation coefficients were generated for CL versus PL, and a linear regression line ( $y = a + bx$ ) was fitted to the plotted points. For body mass, the data were fitted to the general allometric equation  $y$

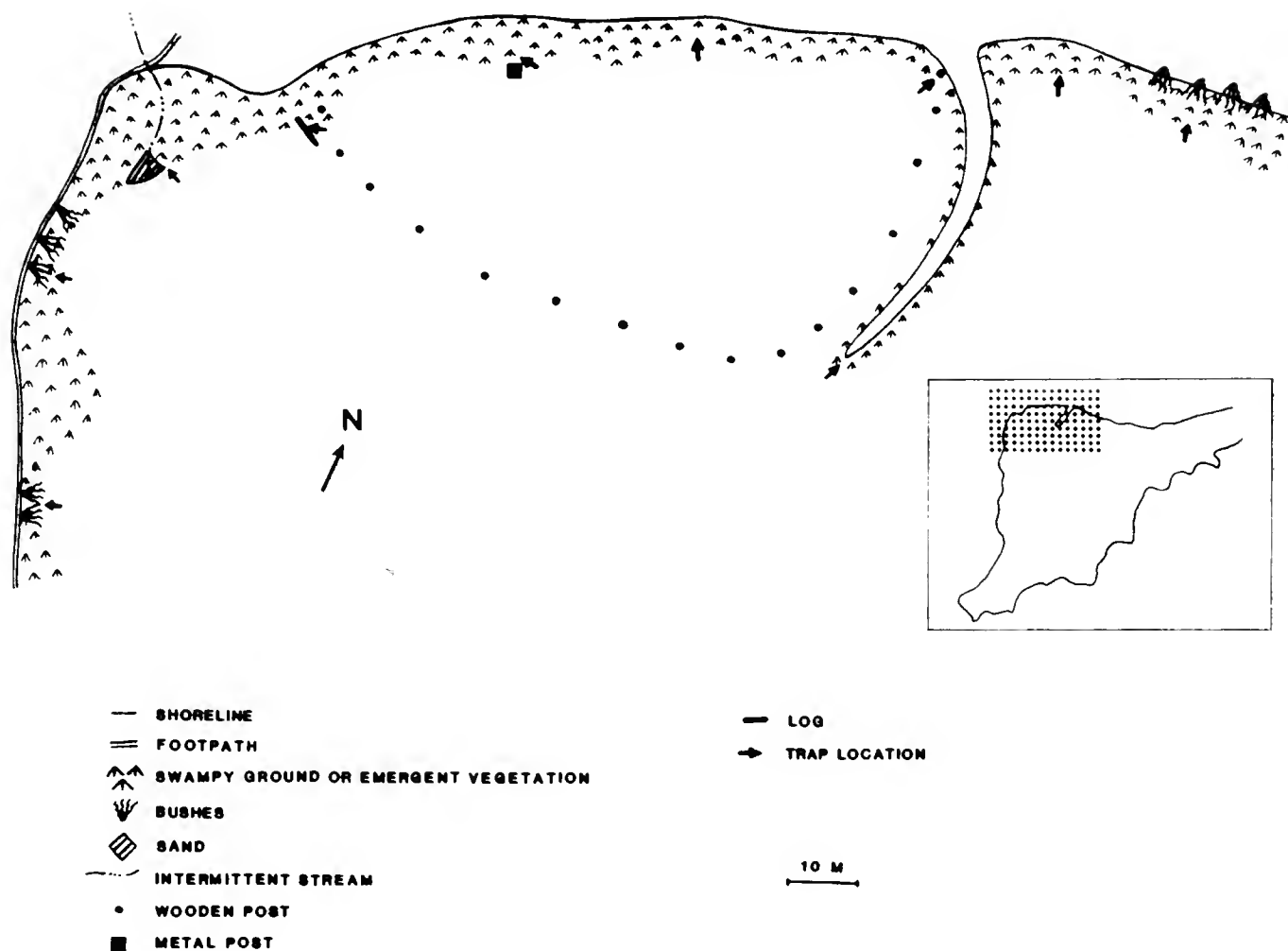


Fig. 1. Map of the study site, Brushy Creek Lake, Winston County, Alabama.

$= ax^b$ , in the form  $\log y = \log a + b(\log x)$ , by the method of least squares regression analysis. Other analyses used the  $t$ -test,  $X^2$  test of independence, and 2-way analysis of variance (ANOVA) with adjustments for unequal sample size. Statistical analyses were carried out using the SAS program for microcomputers (SAS Institute Inc. 1985). For all analyses,  $P < 0.05$  was considered indicative of statistical significance.

## RESULTS AND DISCUSSION

*Population Density.* A total of 135 individual *S. odoratus* were captured during 813 trap-hours. There were 26 recaptures for a total of 161 captures, or one turtle per 5.05 trap-hours. Unfortunately, 41 turtles, including five previously marked animals, drowned on 3 June when water temperatures reached  $32^\circ\text{C}$  in the shallows. Such mortality precluded a statistically rigorous estimate of the population size.

It is possible, however, to derive an estimate of the population density of *S. odoratus* in Brushy Creek Lake if one assumes the minimum number of turtles caught represents a minimum population size within the study area and that immigration balances emigration. As such, 135 stinkpots were caught in the study area, yielding an estimate

of 148.5 turtles per hectare. Since Brushy Creek Lake has an area of 13.76 ha, there could be as many as 2,043 *S. odoratus* in the lake, assuming an equal population density among areas. If adjustments are made to confine the estimate to optimal habitat (67.3% of the lake surface area based on depth profiles), a minimum population of 1,375 stinkpots in the lake would be indicated.

Published values of stinkpot density range from 8 to 700/ha (Mahmoud 1969, Iverson 1982, Congdon et al. 1986, Ernst 1986), and Mitchell (pers. comm.) has found densities in two Virginia populations at 188 and 194/ha. Given these figures, a density of 148 stinkpots per hectare in Brushy Creek Lake seems reasonable.

*Population Structure.* Of the 135 stinkpots, 22 (16.3%) were juveniles (< 65 mm CL); the smallest measured 39.3 mm CL. There was no significant difference in CL between males and females ( $F = 1.30$ ,  $P = 0.26$ ), although males averaged slightly larger (M:  $\bar{x} = 76.8$  mm, range 66.6-90.5 mm, SD = 7.6; F:  $\bar{x} = 75.0$  mm, range 65.0-95.1 mm, SD = 5.5). The lack of differences in the CL of adult males and females was not surprising since size dimorphism has not been reported for *S. odoratus* except in the extreme southern portions of its range (Tinkle 1961, Bancroft et al. 1983).

Most turtles were in the 65- to 79.9-mm size classes, and none were in the 50- to 54.9-mm size class (Fig. 2). Females outnumbered males in all but the 85- to 89.9-mm size class. The relationship of carapace length to plastron length was highly significant (Fig. 3) regardless of sex (Table 1).

The population structure of *S. odoratus* in Brushy Creek Lake was nearly identical with populations in Pennsylvania (Ernst 1986) and Florida (Bancroft et al. 1983). All three studies showed increasing numbers of individuals in age classes up to intermediate CLs, followed by a rapid decrease in the numbers of larger individuals. The main differences are not in the structure of the populations *per se*, but in the sizes of the animals. Pennsylvania stinkpots attain much larger CLs than Florida turtles, and northern Alabama turtles are nearly intermediate in this respect.

In some other studies (e.g., Wade and Gifford 1965), the population structure is slightly different, showing what appears to be a more gradual decline in numbers of larger turtles. The reasons for such variation are unknown, although differences may be an artifact of sampling technique. Unless data are available using comparable sampling procedures, it may be premature to speculate on the underlying causes of differences in population structure reported for distant populations.

*Sex Ratio.* Of the turtles larger than 65 mm CL, there were 30 males and 83 females, or one male per 2.8 females. This ratio is significantly different from 1:1 ( $X^2 = 12.68$ ,  $P < 0.01$ ). Proportionally more females were caught in the May (6.25 females/male) and August

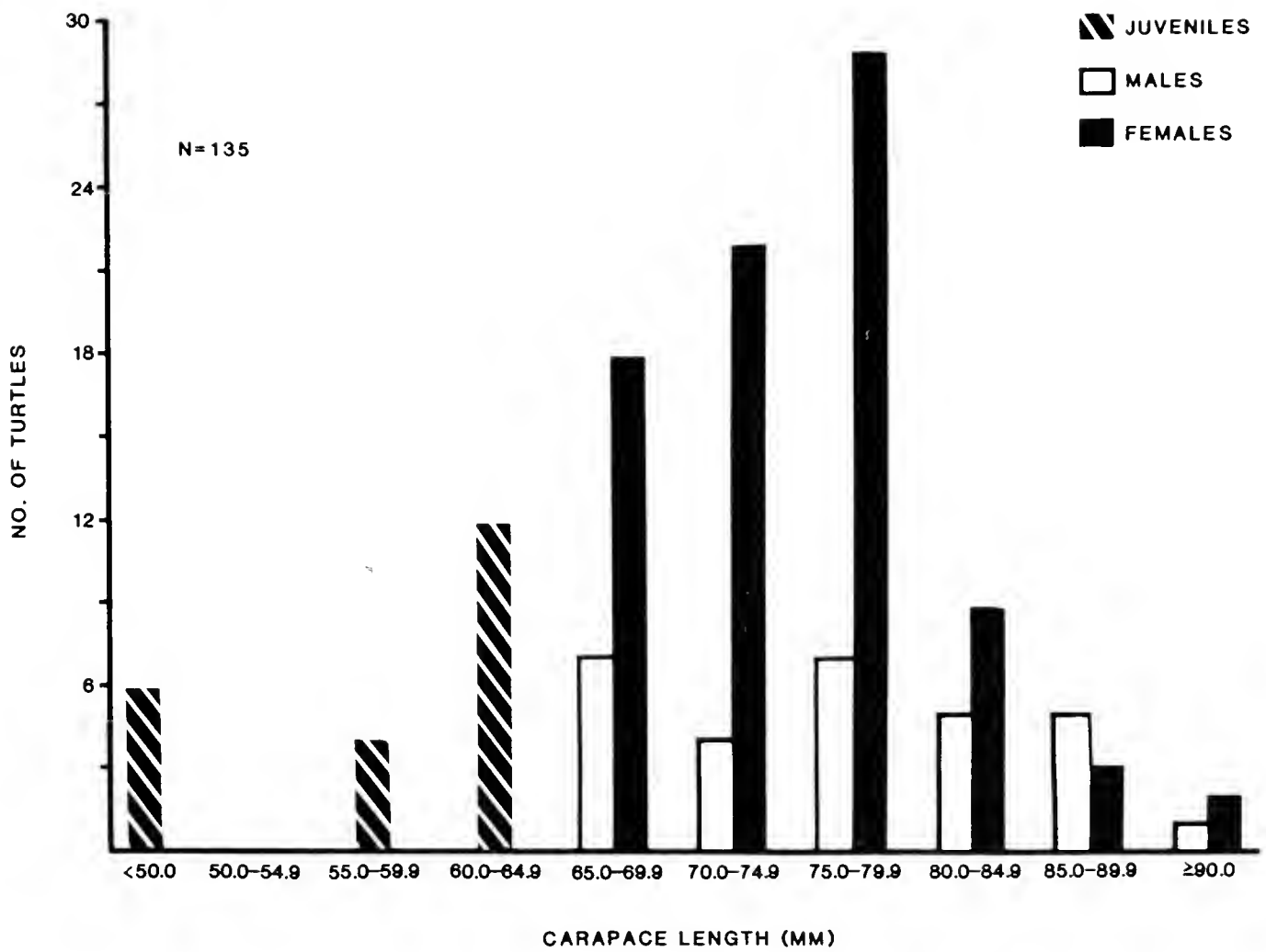


Fig. 2. Population size structure of *Sternotherus odoratus* in Brushy Creek Lake, Winston County, Alabama.

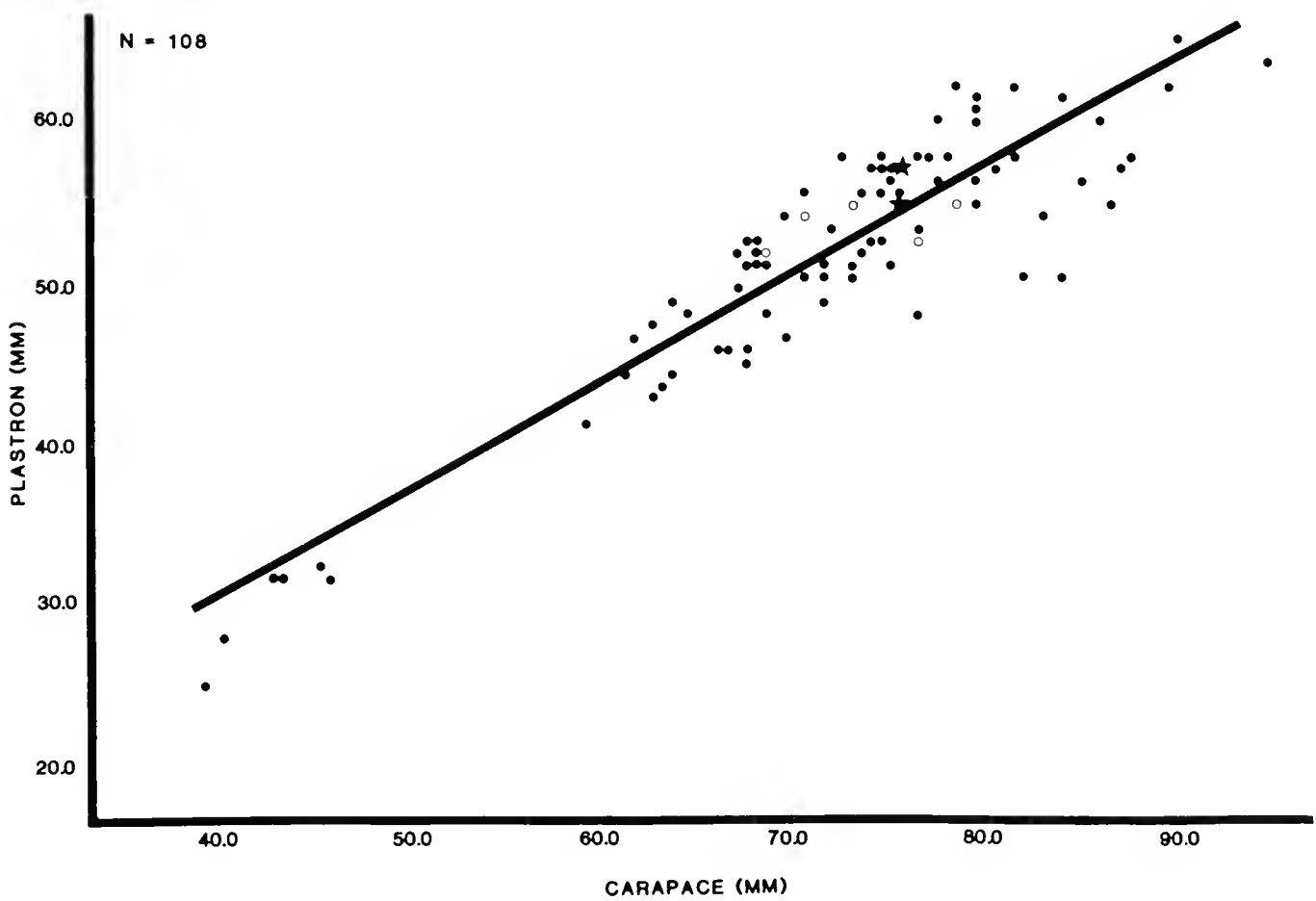


Fig. 3. Regression of carapace length versus plastron length for Brushy Creek Lake *Sternotherus odoratus*. See Table 1 for values of  $r$ ,  $a$ , and  $b$ . ● = 1 observation; ○ = 2 observations; ★ = 3 observations.

samples (4.3 females/male) as opposed to the other months (range 1.4 to 2.4 females/male). Males were never caught in greater numbers than females.

Several studies have reported sex ratios of 1:1 (Tinkle 1961, Mahmoud 1969, Mitchell 1982, Ernst 1986) or favoring females (Risley 1933, Cagle 1942). Bancroft et al. (1983), with the largest sample size of all studies to date, found that males outnumbered females (1.16:1) in a Florida lake population. They attributed the skewed ratio to the tendency of males to move greater distances than females, an explanation also used by Dodd et al. (1988) to explain a similarly skewed ratio for *S. depressus* in Sipsey Fork, Alabama. The tendency of males to move more often and over greater distances than females may not explain sex ratios in favor of females in Brushy Creek Lake, however.

It is possible that different sex ratios would result from more extensive collections made at different times of the reproductive season or from a sampling regime that placed traps over a larger portion of the lake. In Alabama, K. R. Marion (pers. comm.) found that males were caught more often in early spring and fall samples and that females tended to be more common in late spring and early summer samples. His overall results, however, still indicated a female-biased sex ratio. In Virginia, J. C. Mitchell (pers. comm.) also found sex ratios in a stinkpot population in an urban area that varied depending on season, although in his study the overall sex ratio remained at 1:1.

Moreover, if there are differences in habitat selection between the sexes, and if a sampling effort does not equally sample all potential habitat, the resulting sex ratio may be biased and not indicative of the overall sex ratio within the population. This may explain the female-biased sex ratio of stinkpots in the present study. In any case, the interpretation of studies reporting female-biased sex ratios in *S. odoratus* is often difficult because of small sample sizes and differences in trapping techniques between studies. Sex ratios based on relatively small sample sizes should be interpreted with caution (Gibbons 1970b, Bury 1979).

*Mass.* The average body mass for all stinkpots was 71.3 g (N = 108). Males averaged 78.9 g (range 46.0-130.0 g, SD = 22.6) and females averaged 76.8 g (range 47.0-132.0 g, SD = 14.4). There was no significant difference in body mass between adult males and females ( $t = -0.4819$ ,  $P = 0.63$ ). Log(body mass) was significantly correlated with both log(carapace length) and log(plastron length) (Fig. 4) regardless of sex. Power function exponents ranged from 2.5 to approximately 2.9 (Table 1).

Only four studies have reported biomass data for *S. odoratus* in lentic habitats. The estimates ranged from 1.2 to 41.7 kg/ha, but mean body mass varied considerably between studies (Wade and Gifford 1965; Iverson 1982; Congdon et al. 1986; J. C. Mitchell, pers. comm.).

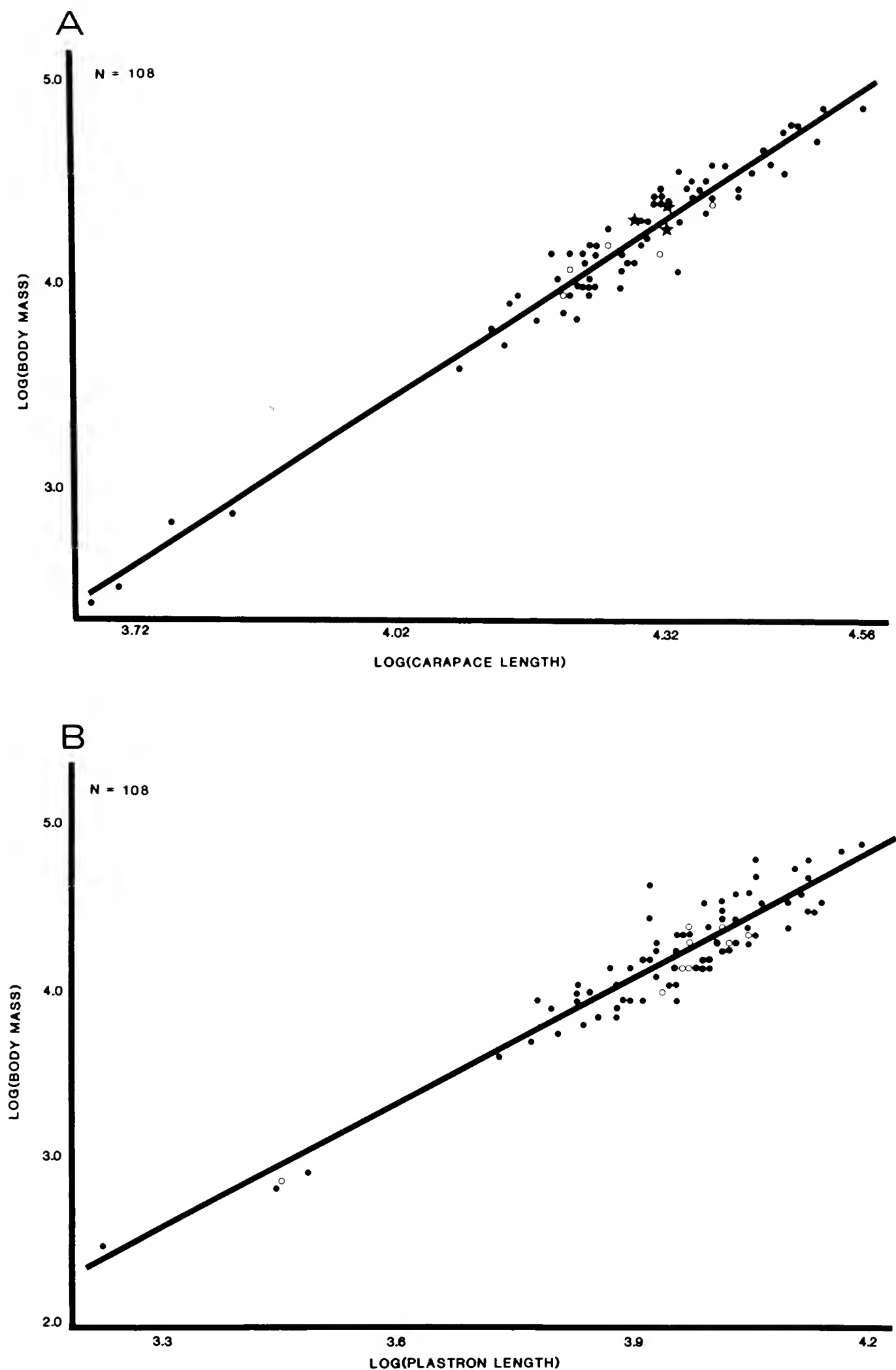


Fig. 4. A. Regression of log-log transformed data of carapace length versus body mass for Brushy Creek Lake *Stenothorus odoratus*. B. Regression of log-log transformed data of plastron length versus body mass. See Table 1 for values of  $r$ ,  $a$ , and  $b$ . ● = 1 observation; ○ = 2 observations; ★ = 3 observations.

Table 1. Relationship between the dependent variables (Y) of plastron length (PL) and body mass (W) and the independent variables (X) of carapace length (CL) and plastron length for Brushy Lake *Sternotherus odoratus*. For correlations involving body mass, the data were log-log transformed. Units in g and mm. The statistical significance of correlation coefficients is indicated (\*\*,  $P < 0.01$ ).

Sex	Y	X	N	b	a	r
F	PL	CL	70	0.6186	8.6734	0.8839**
J	PL	CL	10	0.7389	-1.8576	0.9873**
M	PL	CL	28	0.5392	10.1843	0.8876**
Total	PL	CL	108	0.6638	3.7944	0.9147**
F	W	CL	70	2.7797	-7.6707	0.9313**
J	W	CL	10	2.8811	-8.0973	0.9943**
M	W	CL	28	2.7154	-7.4658	0.9616**
F	W	PL	70	2.8170	-6.9657	0.9033**
J	W	PL	10	2.6267	-6.1680	0.9872**
M	W	PL	28	2.8640	-6.9762	0.9143**
M+F	W	CL	98	2.7066	-7.3767	0.9346**
M+F	W	PL	98	2.5299	-5.7731	0.8592**
Total	W	CL	108	2.7853	-7.7164	0.9799**
Total	W	PL	108	2.6152	-6.1140	0.9581**

Assuming a density of 148.5 *S. odoratus*/ha in Brushy Creek Lake, there was a minimum biomass of 10.6 kg/ha.

Body mass may vary seasonally, especially among females (e.g., Branch 1984), and it may be among the most important variables in life history studies (see Hedges 1985 and references therein). As such, variation in body mass between populations of turtles may be of greater importance than recognized to date. As Congdon et al. (1986) suggested, factors such as habitat suitability, body size, and population age structure may be more important in determining species-specific densities than trophic position.

*Mortality.* On 3 June, 41 of 56 *S. odoratus* drowned in traps, presumably because of high water temperature and low oxygen concentration in the unshaded study site. These included 28 females, 4 males, and 9 juveniles. There was no significant difference in the sex ratio of drowned animals and the overall sex ratio of turtles that did not drown ( $X^2 = 3.35$ ,  $P = 0.067$ ) or between the carapace lengths of drowned ( $\bar{x} = 75.2$  mm,  $SD = 6.6$ ) and non-drowned ( $\bar{x} = 75.5$  mm,  $SD = 5.9$ ) adults ( $F = 0.03$ ;  $P = 0.87$ ). Also, there was no relationship between the sex of the turtles and their CL on their tendency to drown ( $F = 0.03$ ;  $P = 0.85$ ).

Although Ultsch et al. (1984) reported that *S. odoratus* could survive submergence 5.2 days under anoxic conditions at 10°C, my trap results suggest that stinkpots have considerably less tolerance to



low oxygen or anoxic conditions at high temperatures in the field. Caution should be exercised in the placement of traps to prevent drowning.

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# Distribution, Biology, and Conservation Status of the Carolina Madtom, *Noturus furiosus*, an Endemic North Carolina Catfish

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**ABSTRACT.**— *Noturus furiosus* is endemic to the Tar and Neuse river drainages, North Carolina, where it occurs in medium- to large-size streams over sand, gravel, and detritus substrates. Because of its endemicity and relatively limited distribution, *N. furiosus* became a candidate for pre-listing studies by the Office of Endangered Species, U.S. Fish and Wildlife Service. Recent survey work throughout the Tar and Neuse rivers indicates that *N. furiosus* is reproducing and undergoing recruitment at several localities. However, numerous proposed projects and several recently constructed reservoirs pose threats to the continued successful existence of this madtom.

Aspects of the general biology of *N. furiosus* were analyzed from 326 preserved specimens from both the Tar and Neuse river drainages. Individuals live at least 4 years. The largest specimens seen were 101 mm SL (male) and 98 mm SL (female). Females mature at 2 to 3 years and a mean SL of 75 mm. Mature oocytes, produced seasonally, ranged from 79 to 298 ( $\bar{x} = 126.3$ ;  $N = 17$ ) per female. Five nests, each containing a clutch of embryos or larvae and guarded by a male, were found in cans and bottles in pools or runs. All males guarding broods were 3 to 4 years old and ranged in SL from 63 to 101 mm ( $\bar{x} = 89.8$ ). Nests were observed in May at water temperatures of 20-25°C. Clutch sizes ranged from 139 to 171+; embryos were spherical and light yellow with yolk diameters averaging 3.2 mm. At about 1 day post-hatching, larvae ranged from 9.1 to 10.0 mm TL; larval features were similar to those described for other ictalurids. Stomachs of adults and juveniles contained a variety of benthic organisms, but dipteran, trichopteran, ephemeropteran, coleopteran, and odonate larvae or nymphs composed more than 95% of the total food organisms consumed.

The Carolina madtom, *Noturus furiosus* Jordan and Meek, is a moderate-sized, boldly patterned catfish (Fig. 1) that is endemic to the Tar and Neuse river drainages, North Carolina. It has remained poorly known since its original description. Jordan and Meek (in Jordan 1889) noted that "numerous specimens were taken" of *N. furiosus* (actually fewer than 20), but did not comment further on its abundance. Bailey et al. (1977) assigned *N. furiosus* a conservation status category of special

concern but made no further comment. Cooper and Braswell (1982) stated: "Based on the very small numbers of specimens taken in recent years, despite intensive sampling at many localities in both rivers, the species seems to have experienced a serious decline." They added, "Its endemism and apparent rarity make it vulnerable to extinction." Recently, Braswell and Cooper found the species to be relatively common in October at two sites on the Tar River (Cooper and Ashton 1985).

*Noturus furiosus* was originally allied with *N. miurus* and *N. eleutherus* (Jordan 1889). It is currently allocated to the subgenus *Rabida* (Taylor 1969), which presently contains 14 other species (Taylor 1969, Douglas 1972, Etnier and Jenkins 1980). Taylor (1969) considered *N. furiosus* to be a member of the *furiosus* species group including *N. placidus*, *N. stigmosus*, and *N. munitus*. In an analysis of chromosomal evolution of the genus *Noturus*, LeGrande (1981) did not include *N. furiosus*. There has been some question regarding the taxonomic status of *N. furiosus* because even Taylor (pers. comm.) has suggested that it might be a geographic subspecific population of *N. stigmosus*. An analysis of allozymes of all extant members of *Noturus* by James M. Grady demonstrates that the species has several fixed alleles and can be distinguished electrophoretically from other members of the *furiosus* group.

The historical range of *N. furiosus* included varied habitats in two physiographic provinces comprising all major tributary systems of the Tar and Neuse rivers: Piedmont (Tar River and Neuse River [including Eno River]) and Coastal Plain (Tar River [including Fishing Creek and other minor streams] and Neuse River [including Little and Trent rivers, Contentnea Creek, and other minor streams]). However, since 1963, *N. furiosus* has been taken at fewer than 12 localities. Use of ichthyocides, electrofishing gear, and trapping in madtom habitat has revealed few specimens of *N. furiosus*, although *N. insignis* and *N. gyrinus* are encountered frequently.

Presented here is a report on the distribution, biology, and conservation status of *N. furiosus* based on museum specimens and field work through the summer of 1985. This paper is extracted from a report to the Office of Endangered Species, U.S. Fish and Wildlife Service.

## PROCEDURES

*Collecting Methods.* The field work accomplished from 1982 through 1984 was performed in most cases by two people with small-mesh, 10-foot minnow-seines and dip nets. Both day and night collecting were attempted at two sites. Locations where *N. furiosus* formerly had been collected in relatively high numbers (5 to 10 individuals) were most frequently visited. During May 1985, intensive collecting at nearly all

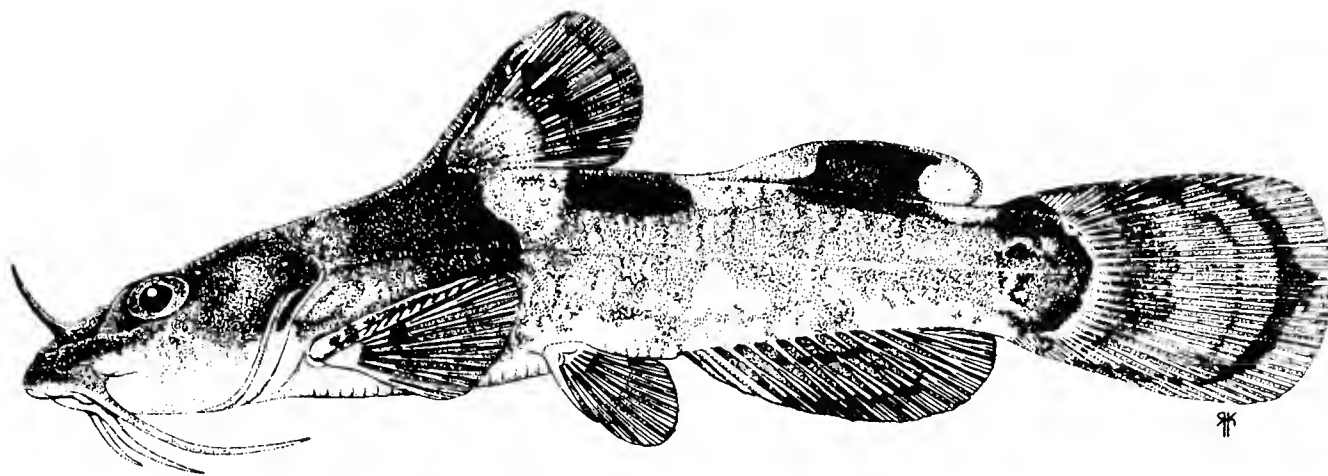


Fig. 1. *Noturus furiosus*, 67 mm SL, Tar River, 5.5 airmiles NE Franklinton, Franklin County, North Carolina, 17 October 1984 (NCSM 11089). Drawing by Renaldo Kuhler.

previous sites of occurrence was performed using seines, 25-cm aquarium nets, and snorkeling gear.

*Field Surveys.* A total of 66 visits to 16 sites within the Neuse River drainage and 15 sites within the Tar River drainage were made with the specific purpose of trying to locate extant populations of *N. furiosus*. Little River, near Goldsboro, Wayne County, was visited almost monthly during fall and spring, 1983 and 1984, to obtain baseline data on habitat and life history. Unfortunately, extremely high water during several months prevented field work.

Other information in this report has been obtained from museum specimens in a number of research collections (see MATERIALS).

*Geochronographic Figures.* These figures, modified after Cashner and Jenkins (1982), are maps showing locations, years, numbers of collections, and results of collections in the Neuse and Tar rivers. Locality data for all records are given under MATERIALS.

*Reproductive Parameters.* Specimens were sexed by examination of gonads. GSI refers to the gonadosomatic index, calculated by total weight of both ovaries or testes divided by eviscerated (= adjusted) body weight X 1000. Weights of gonads and bodies were determined after blotting, to the nearest 0.01 g, with a Mettler analytic balance. Numbers of ova were determined by direct count from both ovaries. Ova diameters were measured with dial calipers to the nearest 0.1 mm. Ten randomly selected ova from each female were measured.

*Nesting.* Collecting sites were searched for potential nest sites (i.e., cans, bottles, mussel shells, boards, flat rocks, logs). Potential nest sites were surrounded by a net, removed from the stream, and examined for guardian adults, embryos, and larvae. If a nest was found, the parent(s)

and young were preserved for subsequent examination. In most cases, mated pairs were returned to their nest sites if they were not guarding embryos or larvae.

*Aging.* Age of some specimens in breeding condition was determined by counting the number of annuli on cross sections of pectoral spines as outlined by Clugston and Cooper (1960) and modified by Mayden and Burr (1981). Many specimens were assigned to age classes based on length-frequency analysis, although neither method of aging provided satisfactory results. Lengths of juveniles and adults are expressed in mm standard length (SL); lengths of larvae in mm total length (TL).

*Food.* Diet was determined from examination of the contents of the stomach.

*Substrate.* Size ranges in centimeters of certain substrate types mentioned herein are: sand, less than 0.3; pea or small gravel, 0.3-3.0; medium gravel, 3-5; large gravel, 5-8; small rubble, 8-15; medium rubble, 15-22; large rubble, 23-30; and boulder, greater than 30.

## MATERIALS

A virtually complete record of repository is given. Institutional acronyms are: ANSP, Academy of Natural Sciences of Philadelphia; DU, Duke University; CAS-SU, Stanford University (now at California Academy of Sciences); NCSM, North Carolina State Museum of Natural Sciences; SIUC, Southern Illinois University at Carbondale; UF, University of Florida, Florida State Museum; UMMZ, University of Michigan Museum of Zoology; UNCC, University of North Carolina at Charlotte; and USNM, National Museum of Natural History. Numbers of specimens (in parentheses) follow the catalog number or the acronym.

A total of 326 specimens (70 collections) were examined. Within each drainage, collections are listed alphabetically by county. Collections from the same site are listed in chronological order. An asterisk preceding a locality denotes collections made by personnel of the North Carolina Wildlife Resources Commission (NCWRC). To our knowledge, these collections were not deposited in a recognized museum or university collection, but are reported in Bayless and Smith (1962) and Smith and Bayless (1964).

*Neuse River System.* CRAVEN COUNTY: NCSM 9939(1) Neuse River near Streets Ferry, 8.7 airmi. NW New Bern, 28 January 1981. DURHAM COUNTY: NCSM 1930(1) Eno River at SR 1004 bridge, 3 August 1961. GREENE COUNTY: \*NCWRC(22) Contentnea Creek, 3 mi. S Scuffleton at Edwards Bridge, 6 September 1960. JOHNSTON COUNTY: DU uncat.(3) Mill Creek, 1 mi. N Cox Mill, SR 1200 bridge, 8 June 1961; NCSM 13838(1) Little River at SR 1002 bridge, 1 mi. N

Princeton, 19 May 1985; NCSM 8780(2) Little River at SR 1001 bridge, 4.25 airmi. SSW Kenly, 25-29 March 1979; NCSM 3420(5) Swift Creek, 3 mi. SW Smithfield, 18 July 1961; NCSM 13839(4) same site as preceding, 19 May 1985; NCSM 1794(7) Little River, 1 mi. W Raines Crossroads, 20 June 1961; DU uncat.(18) same site as preceding, 20 July 1961; NCSM 632(1) Middle Creek, at NC 210 bridge, 3 airmi. S Smithfield, 20 July 1961; UNCC uncat.(?) Little River above SR 1001 bridge, 10.4 mi. E Smithfield, 16 May 1982. JONES COUNTY: NCSM 8245(5) Trent River at SR 1300 bridge, 4.75 airmi. NW Trenton, 25-26 September 1978; NCSM 13840(1) same site as preceding, 22 May 1985; NCSM 8223(3) Trent River at SR 1129 bridge, 6 airmi. W Trenton, 25 September 1978; NCSM 8204(1) Trent River below NC 58 bridge, 4.75 airmi. NW center of Trenton, 25 September 1978; \*NCWRC(10) Trent River at NC 58 bridge, 3 mi. E Phillips Crossroads, 22 July 1960. LENOIR COUNTY: SIUC 11730(22) Neuse River at NC 903 bridge, 5.5 mi. SSW LaGrange, 20 May 1985; NCSM 13841(1) Neuse River at Kinston at Business NC 58-US 70 bridge, 22 May 1985; DU uncat.(5) Neuse River, 5 mi. N Liddell, ca. 17 mi. W Kinston, 11 August 1960. PITT COUNTY: NCSM 758(1) Little Contentnea Creek, at NC 102 bridge, 9 September 1960. WAKE COUNTY: USNM 48475(1) Crabtree Creek, near Raleigh, July 1897; UMMZ 165885(1) Neuse River, near Raleigh, 22 August 1897; NCSM 243(1), probably from Neuse River near Raleigh, no date; USNM 67937(1) Neuse River, Raleigh, 27 August 1888; UMMZ 165884(1) Neuse River, 18 August 1902; CAS-SU 1380(2), USNM 39932(1), USNM 164109(2) Neuse River, at Millburnie, near Raleigh, summer 1888. WAYNE COUNTY: NCSM 485(1), NCSM 486(1) Beaverdam Creek, 0.5 mi. upstream from jct. with Neuse River, 6 June 1961; NCSM 1242(1), NCSM 2715(2) Neuse River below Quaker Neck Dam at Goldsboro, 7 June 1961; UF 31453(2) Neuse River, 2 mi. downstream from H. F. Lee Plant, 9 August 1977; NCSM 2209(3) Little River, 1 mi. W Goldsboro at NC 581 bridge, 13 June 1961; UF 23768(1) same site as preceding, 25 April 1977; SIUC 5541(7) same site as preceding, 22 May 1982; SIUC 8693(16) same site as preceding, 17 September 1983; SIUC 8960(3) same site as preceding, 14 October 1983; SIUC 9754(1) same site as preceding, 30 April 1984; NCSM 13836(2), NCSM 13837(2), SIUC 11685(1), SIUC 11777(1), same site as preceding, 19 May 1985; SIUC 11683(2) same site as preceding, 20 May 1985. USNM 40572(1) Little River, near Goldsboro, 1888. WILSON COUNTY: DU 851(9) Contentnea Creek, 3 mi. W Stantonsburg, 8 September 1960; \*NCWRC(39) Contentnea Creek at NC 42 bridge, 4 July 1961.

*Tar River System.* EDGECOMBE COUNTY: ANSP 71335(1), CAS-SU 3435(2), UMMZ (Indiana Univ. 7246)(1), UMMZ 167076(1), USNM 20926(6) Tar River, near Tarboro, ca. 1877; NCSM 11087(1)

Tar River, 0.9 airmi. SE Tarboro, 3 October 1984; SIUC 11760(6) Tar River at NC 44 bridge, N edge of Tarboro, 16 May 1985; NCSM 13832(2), SIUC 11776(1), SIUC 11679(8) same site as preceding, 17 May 1985; SIUC 11775(1) same site as preceding, 22 May 1985; NCSM 11090(11) Tar River, at NC 42 crossing, 4.9 airmi. E Pinetops, 30 October 1984; USNM 40398(1) Tar River, below Rocky Mount, 1888; NCSM 13833(2), SIUC 11778(1) Tar River at SR 1252 bridge, 7.5 mi. E Rocky Mount, 17 May 1985; USNM 191110(44), USNM 191071(15), UMMZ 187094(8) Fishing Creek, below bridge at SR 1500, ca. 4.5 mi. SW Lawrence, 19 September 1959; \*NCWRC(37) same site as preceding, 12 August 1963; USNM 191099(8) Swift Creek, just above NC 97, W Leggett, 19 September 1959; \*NCWRC(16) Swift Creek at SR 1253 bridge, 1 mi. SSW Leggett, 9 July 1963; SIUC 4194(1) same site as preceding, 21 May 1982; NCSM 13830(4), NCSM 13831(7) same site as preceding, 16 May 1985; \*NCWRC(9) Town Creek, 2 mi. upstream from mouth, 10 June 1963. EDGECOMBE-HALIFAX COUNTY: \*NCWRC(17) Fishing Creek at SR 1418 bridge near Enfield, 13 June 1963. EDGECOMBE-NASH COUNTY: USNM 191057(8), UMMZ 187097(4) Tar River, at railroad line, Rocky Mount, 19 September 1959; SIUC 11684(1) same site as preceding, 17 May 1985. FRANKLIN COUNTY: \*NCWRC(7) Tar River at SR 1003, W Louisburg, 26 June 1963; NCSM 11089(10) Tar River, upstream from bridge at SR 1003, 5.5 airmi. NE Franklinton, 17 October 1984; SIUC 11749(15) same site as preceding, 15 May 1985; \*NCWRC(17) Tar River at SR 1611 near Bunn, 26 June 1963; \*NCWRC(?) Sandy Creek at NC 58 bridge, 11 June 1963; NCSM 13834(1) Tar River at Louisburg, 18 May 1985. FRANKLIN-VANCE COUNTY: NCSM 3077(1) Tar River, 4 mi. N Franklinton at US 1 bridge, 7 July 1966; NCSM 13828(2) same site as preceding, 15 May 1985; NCSM 13829(2) Tar River at SR 1203 bridge, 4.75 mi. NNW Franklinton, 15 May 1985. HALIFAX COUNTY: \*NCWRC(18) Little Fishing Creek at SR 1343 bridge near White Oak, 22 July 1963; \*NCWRC(1) Beech Swamp at SR 1100 bridge, 13 June 1963. NASH COUNTY: \*NCWRC(29) Swift Creek at SR 1003 bridge near Red Oak, 10 July 1963; NCSM 13835(1) Tar River at NC 581 bridge, 0.5 mi. N Floods Chapel, 18 May 1985. NASH—HALIFAX COUNTY: \*NCWRC(18) Fishing Creek at SR 1506 bridge near Aventon, 12 June 1963. VANCE COUNTY: \*NCWRC(20) Tar River at SR 1101 bridge near Franklinton, 15 August 1963.

## RESULTS

### HABITAT

All records of *N. furiosus* are from free-flowing streams. Permanent occupation of lentic habitat is highly unlikely, and sampling in pools



generally does not yield specimens. Gradients are moderate and stream temperatures in summer are warm (diurnal maxima greater than 20°C). Submersed macrophytes are generally absent; the Carolina madtom does not appear to be strongly associated with emergent vegetation, although small patches of vegetation may occasionally be present in prime habitat. Water is generally clear to coffee-colored.

A large majority of records are from medium to large streams, i.e., the Neuse and Tar rivers proper and the lower reaches of their major tributaries. Most records from small streams are within a few kilometers of the mouth and may represent forays of individuals, or populations largely reliant upon recruitment from main rivers.

Stream sections inhabited have riffles, runs, and pools with *N. furiosus* found during warm months in or near swift current; depth usually 0.3 to 1.0 m. Young and juveniles tend to occupy shallower riffles and runs in slower current than adults, although overlap is typical. Habitat during cool months is unknown, but there is no reason to suspect it would be strikingly different from that occupied during the warm months. Common substrates in well-populated streams are leaf litter, sand, gravel, and small rubble. The Carolina madtom occupies all these substrates, but is most frequently taken over sand mixed with pea- or medium-sized gravel and in leaf litter. In the lower Tar and Neuse rivers, the species is frequently taken from debris piles in sandy areas.

The habitat of adult madtoms during the nesting season (May-July) is in areas of moderate to slow flow where there is an abundance of cover for nesting sites (e.g., beer and soda cans, bottles, mussel shells, flat rocks, and stick piles). Because guardian males usually have empty stomachs (Table 2), it is assumed they rarely leave a nest site to forage. This may, in part, explain why collections made during the breeding season often miss adult madtoms unless nesting sites are found or ichthyocides are used.

Taylor (1969) noted that specimens taken from near the Fall Line were collected in swift water about 1 m in depth over a gravel-rubble bottom, whereas those taken on the Coastal Plain were in very shallow water with little or no current over sand and small gravel. Our observations of habitat agree closely with those of Taylor.

#### DISTRIBUTION, ABUNDANCE, AND POPULATION STATUS

*Noturus furiosus* is known from the Neuse and Tar river drainages of North Carolina (Fig. 2), occurring both above and below the Fall Line. Extant populations of the fish are presently known with certainty from 17 localities (Fig. 3-4). Generally, the species is rare or uncommon, but this may relate to inadequate sampling of appropriate habitat and lack of collections made after dusk. It has been taken with regularity in

Table 1. Characteristics of female *Noturus furiosus* in reproductive condition from the Tar and Neuse river drainages, North Carolina.

Date of collection	SL (mm)	Age in years	Adjusted body weight (g) <sup>a</sup>	Weight of ovaries (g)	GSI <sup>b</sup>	Mature ova: total no. (right ovary, left)	No. ova per gram adjusted body weight
17 May	72.2	3	6.46	0.40	62	79 (41,38)	12.2
19 May	68.6	3	5.52	1.37	248	125 (67,58)	22.6
19 May	69.5	3	5.90	1.52	258	142 (68,74)	24.1
20 May	70.0	3	5.60	0.79	141	120 (75,45)	21.4
22 May	74.3	3	7.46	1.27	170	100 (55,45)	13.4
22 May	73.0	3	5.87	1.02	174	123 (63,60)	21.0
22 May	—	—	—	—	—	89 (47,42)	—
6 June	69.5	3	5.52	0.34	62	102 (57,45)	18.5
8 June	73.0	3	8.30	1.75	211	125 (70,55)	15.1
8 June	73.0	3	7.31	1.64	224	118 (55,63)	16.1

7 July	97.5	4	17.85	1.07	60	298 (164,134)	16.7
20 July	61.0	2	4.82	0.59	122	82 (42,40)	17.0
20 July	75.4	3	6.83	0.59	86	114 (57,57)	16.7
20 July	75.8	3	6.75	0.82	121	112 (53,59)	16.6
20 July	78.5	3	7.94	0.72	91	105 (46,59)	13.2
20 July	79.4	3	8.55	0.34	40	110 (52,58)	12.9
20 July	86.0	4	10.85	2.34	216	166 (79,87)	15.3

<sup>a</sup> The specimen's weight after removal of ovaries, stomach, intestine, and liver.

<sup>b</sup> Equals weight of ovaries x 1000/adjusted body weight.

Table 2. Variables of nests with guardian males and embryos or larvae of *Noturus furiosus* from the Tar and Little rivers, North Carolina.

Locality, date	Habitat	Nesting site	Description of nest site	Water depth (cm) and temp (°C)	Size (mm SL),		Size of embryos (mm) or larvae (mm TL): mean, range, and (N)
					age (years), stomach contents of guardian male	No. embryos or larvae collected	
Tar River 17 May 1985	Moderate current over sand/gravel	Quart milk jar	Opening facing downstream; no substrate in jar	80:23.5	99:4 Digested white material	171 (brood complete)	4.0 3.8 - 4.1 (15)
Tar River 17 May 1985	Above riffle; moderate current over sand/gravel	Half of an antique crock pot	Nest depression ca. 3 cm deep; opening facing downstream	40:23	101:4 empty	200+ larvae (none captured)	
Tar River 17 May 1985	Moderate current over sand	Broken antique whiskey bottle	Opening facing downstream; no substrate in bottle	66:24	93:4 Digested white material	147 (brood complete)	3.6 3.4 - 3.8 (15)
Little River 19 May 1985	Moderate current over sand/gravel	355 ml beer can	Opening facing upstream; little substrate in can	26:22	63:3 1 chironomid 1 odonate	139 (brood complete)	4.2 4.0 - 4.4 (15)
Tar River 22 May 1985	Swift current over sand/gravel	Broken antique wide-mouth jar	Opening facing downstream; no substrate in jar	120:25	93:4 Digested white material, sand	16 larvae (brood incomplete)	9.5 9.1 - 10.0 (16)

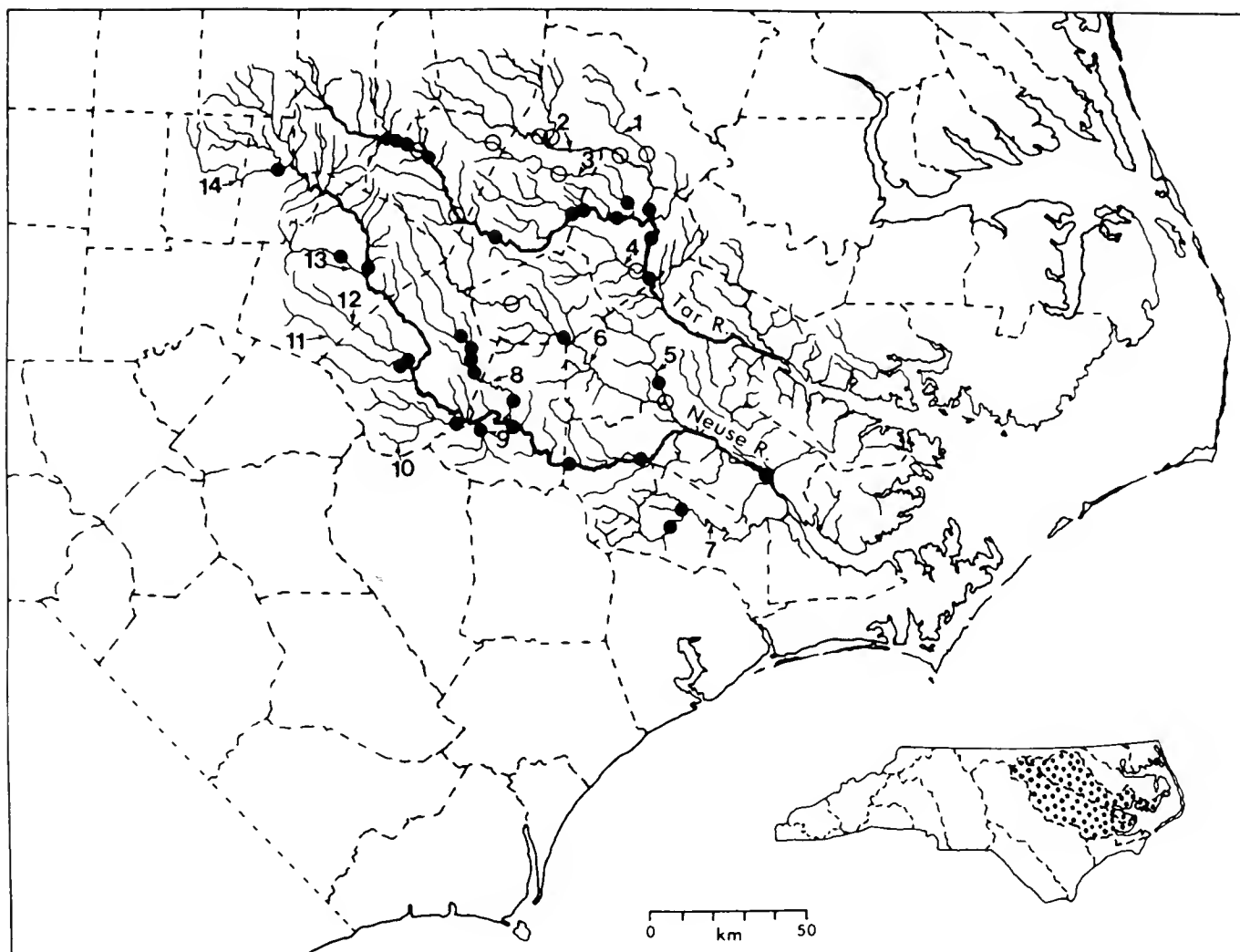


Fig. 2. Distribution of *Noturus furiosus*, showing all known extant and extirpated populations. Some dots cover more than one record locality. Solid dots represent localities with extant voucher material; open circles represent localities reported by Bayless and Smith (1962) and Smith and Bayless (1964) for which voucher material is presumably not available. 1. Beech Swamp Creek, 2. Fishing Creek, 3. Swift Creek, 4. Swamp Creek, 5. Little Contentnea Creek, 6. Contentnea Creek, 7. Trent River, 8. Little River, 9. Beaverdam Creek, 10. Mill Creek, 11. Middle Creek, 12. Swift Creek, 13. Crabtree Creek, 14. Eno River.

only a few streams in recent years, the Little River system (Neuse drainage), the lower Neuse River proper, Swift Creek (Neuse drainage), the Tar River proper, and Swift Creek (Tar drainage).

Reviewed here are the status of madtom populations and their distributions and habitats within tributary systems. Order of presentation is from upstream to downstream, Neuse drainage first.

### *Neuse Drainage*

Eno River system.—Only a single specimen of *N. furiosus*, captured in 1961 (using rotenone), is known from the Eno River. Our collection on the Eno River was made at night in May 1982 but did not reveal additional specimens, although a typical variety of Piedmont fishes was represented in our sample. Appropriate madtom habitat appeared scarce,

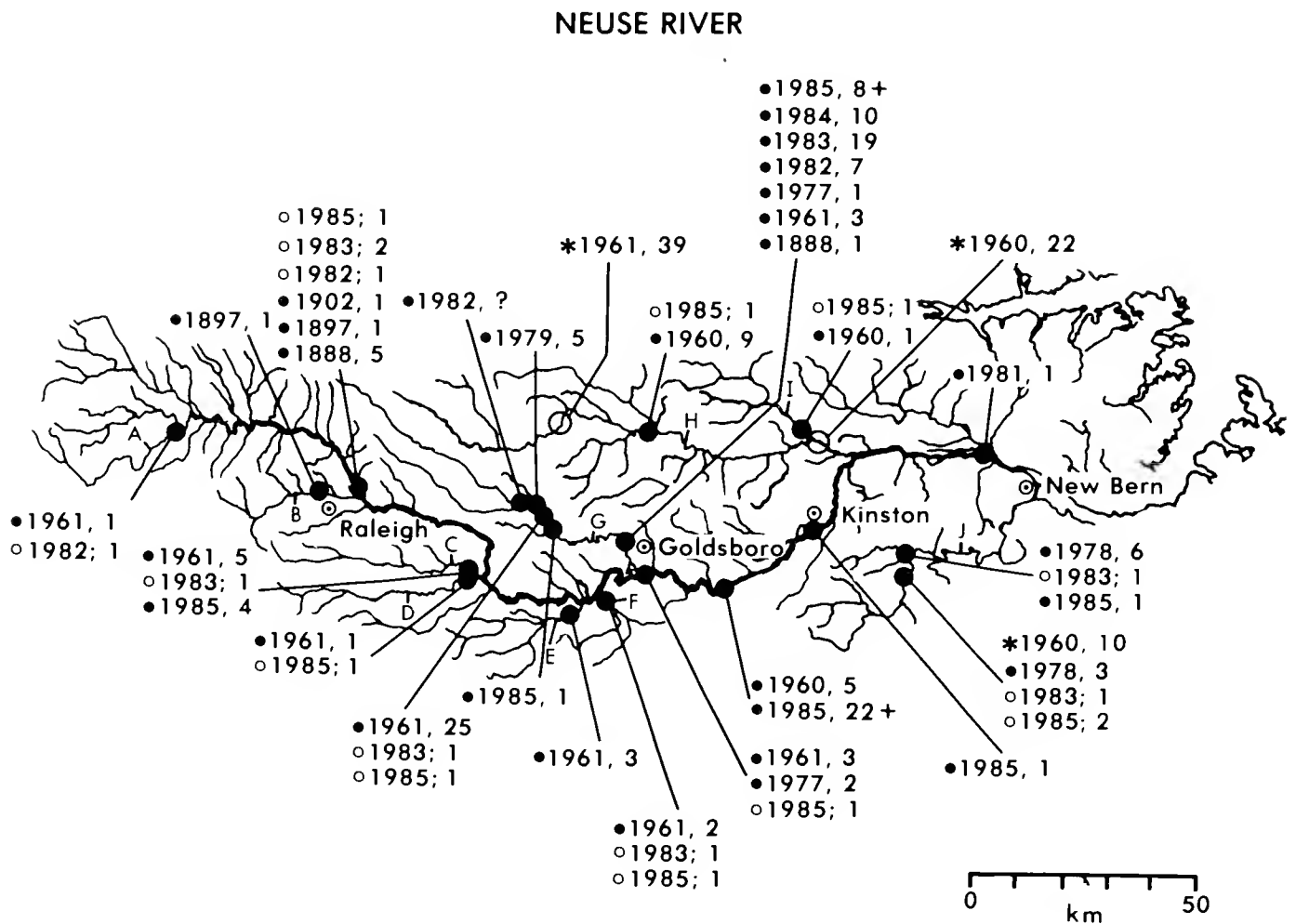


Fig. 3. Geochronography of *Noturus furiosus* in the Neuse River drainage, North Carolina. Map shows virtually all known records of capture. Solid dots indicate capture sites, but not necessarily extant subpopulations. Offriver data are: year of collection(s) preceded by (1) solid dot if *N. furiosus* taken, (2) open circle if not taken, (3) asterisk if voucher material not available; following the year are (4) number of specimens taken (this number is separated by a comma), (5) the number of collections not yielding specimens (this number is separated by a semicolon), (6) a “?” indicating number of specimens unknown, and (7) a “+” sign indicating many individuals were returned to the stream. Numbers refer to collection of juvenile and adult specimens only. A. Eno River, B. Crabtree Creek, C. Swift Creek, D. Middle Creek, E. Mill Creek, F. Beaverdam Creek, G. Little River, H. Contentnea Creek, I. Little Contentnea Creek, J. Trent River.

with much of the stream bottom consisting of bedrock and large rubble. Capture of *N. furiosus* above the Fall Line is rare, and the Eno River record is at the extreme northwestern edge of the species’ range.

Neuse River near Raleigh.—This is the type locality of *N. furiosus* where approximately seven specimens were taken in 1888, 1897, and 1902. Four daytime visits to the Neuse River near Raleigh in 1982, 1983, and 1985 revealed large expanses of suitable habitat, but no madtoms were collected. The changes in the river near this site include the construction of a major reservoir (Falls Lake) upstream and pollution

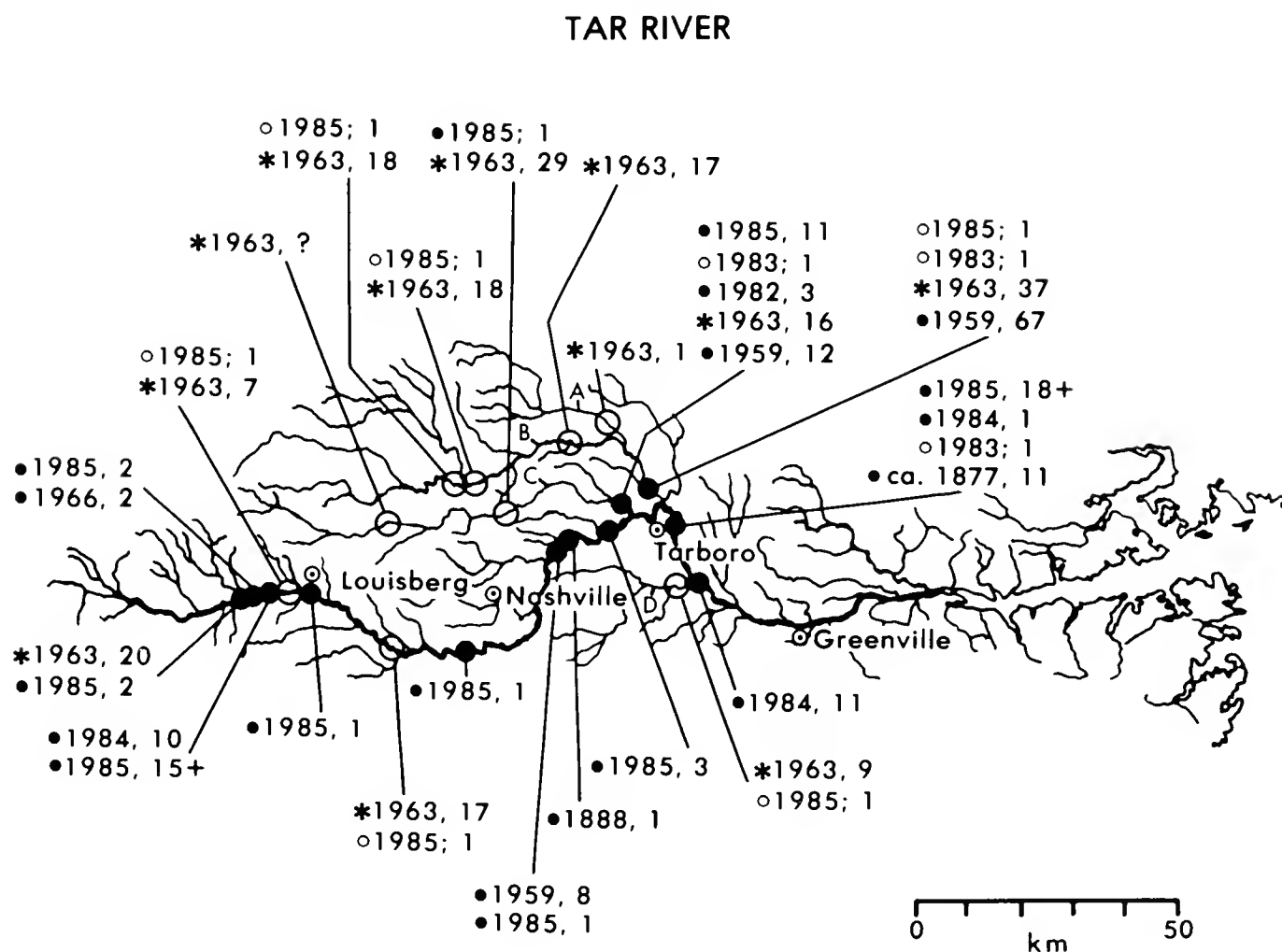


Fig. 4. Geochronography of *Noturus furiosus* in the Tar River drainage, North Carolina. Map shows virtually all known records of capture. Data format explained in Figure 3. A. Beech Swamp Creek, B. Fishing Creek, C. Swift Creek, D. Swamp Creek.

from the city of Raleigh. A large fish kill in July 1980 did not reveal any Carolina madtoms (Alvin L. Braswell, pers. comm.). The temperature in the Neuse River below Falls Lake dam was 18°C in mid-May 1985, about 6 degrees cooler than surrounding streams, and perhaps too low for madtom reproduction. Dead mussels abounded, but no other invertebrates were seen. Few fishes were collected, and all but an eel, *Anguilla rostrata*, were introduced sport fishes. It is unlikely that the Carolina madtom occurs in the reservoir or near the polluted waters of the city anymore.

Swift, Middle, Mill, and Beaverdam creeks.—A total of 11 specimens were taken in 1961 from these four creeks. Upon re-collecting all these creeks during the day in October 1983 and May 1985, we obtained five specimens, all from Swift Creek. Suitable madtom habitat is present, although limited, and the streams are relatively small, perhaps too small to support large, viable populations of *N. furiosus*. Potential nest sites in Swift Creek were occupied only by juveniles, although some nesting probably occurs in the stream. Records from these streams may

represent forays of a few individuals from the nearby Neuse River proper. We know of no substantial, long-term ecological perturbations that have occurred in these streams since 1961.

Little River system.—Without question this stream harbors the single largest extant population of the Carolina madtom known from within the entire Neuse drainage. As many as 20 individuals have been collected at any one time, and one of the largest series of males and females in breeding condition was taken from the Little River in 1961. Our several visits to Little River just west of Goldsboro from 1982 through 1985 revealed abundant madtom habitat, both for nonbreeding and breeding individuals, and numerous mated pairs were found in cans and bottles and returned to their nest sites. Substantial populations of *N. insignis* and *N. gyrinus* are also known from the Little River. Except for a small dam and impoundment, the Little River appears to be relatively undisturbed.

Neuse River, Lenoir County.—In 1960, five specimens of *N. furiosus* were collected in the Neuse River proper near the Lenoir County line. We revisited this site in May 1985 and found *N. furiosus* to be the most common benthic fish species. Water was low (<1 m) about 300 m downstream of the bridge, and from two to eight specimens were obtained from nearly every stick/detritus pile found in moderate current over sand. The fish was so common that many individuals were returned (22 were preserved) to the river. No nesting sites were found here, although a few scattered mussel shells were examined. A much smaller population of *N. furiosus* is present on the lower Neuse River near Kinston.

Contentnea Creek system.—Sampling activity in this stream has been limited in recent years, but four collections using rotenone in 1960 and 1961 yielded a total of 71 *N. furiosus*. We resampled two of the Contentnea Creek sites in May 1985, but found no *N. furiosus*. During our visits, suitable madtom habitat was found to be limited. In fact, one site was essentially a swamp rather than a flowing stream. We assume the fish still occurs in the Contentnea system, but probably in limited numbers owing to lack of adequate habitat.

Trent River system.—In 1960 and 1978, ten and nine specimens, respectively, of *N. furiosus* were taken from three sites on the Trent River. These were the first records of the species that far downstream in the Neuse. Collection methods included ichthyocides, which are very effective in securing madtoms. We revisited all three sites on the Trent River in September 1983 and May 1985. Only one *N. furiosus* was found even though adequate habitat was available. *N. insignis* was common. About 75 potential nest sites were examined here, but they were either empty or were being used by other fishes (e.g., *N. insignis*, *A. rostrata*) and the Neuse River waterdog, *Necturus lewisi*.



Extreme lower Neuse River, Craven County.—Probably the most surprising record of the Carolina madtom from the Neuse is an individual that was trawled from the main river near New Bern in 2 to 3 m of water over sand in 1981. Extremely heavy rain in December (the highest in 15 years) preceded the capture of this fish in January; it had apparently been swept downstream with the heavy flooding that followed the rain. The collection should probably be considered a stray from typical areas of occurrence upstream.

### *Tar Drainage*

Tar River proper.—Both historically and recently the Tar River proper has harbored the most substantial populations of *N. furiosus* known anywhere. Six collections on the mainstream have yielded 45 specimens since 1877, and three large populations are known to be extant. Searches by us, some U.S. Fish and Wildlife Service personnel, and North Carolina State Museum employees in October 1984 and May 1985 revealed four new sites for the Carolina madtom in the Tar River. In addition, several old sites were re-collected (e.g., Tarboro and Rocky Mount). All sites had an abundance of madtom habitat, and numerous additional specimens were observed but not preserved. Numerous mussel shells, cans, bottles, jars, and other litter in the Tar River provide an abundant variety of nesting sites and undoubtedly contribute to successful reproduction in most summers. It should be noted that the recent successful collections in the Tar River were made under ideal conditions of extremely low, clear water and during peak recruitment or spawning periods. The Tar River remains one of the finest large streams in North Carolina and will probably continue to be the stronghold for the species.

Swift and Fishing Creek systems.—Both of these streams offer abundant habitat for *N. furiosus* and are physically similar to the Little River near Goldsboro. The largest series ever taken of this species (67 individuals) was collected in 1959 from Fishing Creek during a combined day and night sampling period. Re-collection of these sites between 1982 and 1985 yielded 14 specimens (all from Swift Creek), but sampling was impossible in Fishing Creek because of extremely high water. Re-collection of Fishing Creek under optimum conditions is especially warranted because this stream may harbor one of the largest extant populations of *N. furiosus*. Several large collections of *N. furiosus* were made by NCWRC personnel in 1963 in Swift and Fishing creeks (Fig. 4) after application of rotenone. To our knowledge, no voucher specimen is extant for any of these collections, but the large number of specimens taken (Fig. 4) is evidence that these two streams support, or did support, large populations of *N. furiosus*.

## LIFE HISTORY

*Age, Maximum Size, and Weight-Length Regression.* Specimens (32-99 mm SL; N = 10) aged from pectoral spines were 1 to 4 years old. Accurate readings of other pectoral-spine cross sections could not be made. The largest specimen aged was 99 mm SL and 4 years old. The largest male examined was 101 mm; the largest female 98 mm. Few individuals reach 85 mm. The largest specimen recorded by Taylor (1969) was 100 mm SL.

Length-frequency histograms of 248 specimens were difficult to interpret, although several age classes appear to be represented (Fig. 5). Populations seem skewed towards younger age classes as would be expected in a healthy population experiencing normal recruitment. The relatively large number of individuals collected in May under 40 mm SL indicates that growth is slow in winter and early spring. In September (N = 92), age 0 fish ranged in SL from 17 to 47 mm, age 1 from 49 to 67 mm, age 2 from 71 to 76 mm, and ages 3 to 4 from 79 to 86 mm. There was considerable overlap in length of older age classes. Lack of adequate sample sizes in most months precludes more meaningful comparisons of age classes and sexual differences in growth.

Regression of body weight on length of specimens was similar for both sexes. The relationship between adjusted body weight in grams (W) and SL for males was  $\text{Log } W = -5.098 + 3.198 \text{ Log SL}$  ( $r = 0.99$ ; N = 56) and for females was  $\text{Log } W = -4.631 + 2.918 \text{ Log SL}$  ( $r = 0.99$ ; N = 77).

*Age and Size at Maturity.* Females of *N. furiosus* reached reproductive maturity in a minimum of 2 years, although a vast majority of gravid females were 3-year-olds ( $\bar{x} = 3.1$  years; Table 1). Other species of *Noturus* about the same size as *N. furiosus* reached reproductive maturity in 1 to 2 years (e.g., *N. exilis*, Mayden and Burr 1981; *N. miurus*, Burr and Mayden 1982a; *N. nocturnus*, Burr and Mayden 1982b). Mature females ranged in SL from 61 to 98 mm ( $\bar{x} = 74.8$ ; N = 16 for individuals 2 to 4 years old) and in adjusted body weight from 4.82 to 17.85 g ( $\bar{x} = 7.60$ ; N = 16). No females older than 4 years or longer than 98 mm SL were seen.

Age at first spawning for males was not ascertained, although all males found guarding nests or nest sites were 2 to 4 years old and longer than 60 mm SL. Adjusted body weights of all males in breeding condition ranged from 3.81 to 18.24 g ( $\bar{x} = 8.46$ ; N = 24).

*Reproductive Condition in Males.* In gross appearance, testes were opaque white and fimbriate as in other ictalurids (see Sneed and Clemens 1963; Mayden and Burr 1981). Weight of testes was positively correlated with increasing body weight. For combined samples of immature and mature males, linear regression of testes weight in

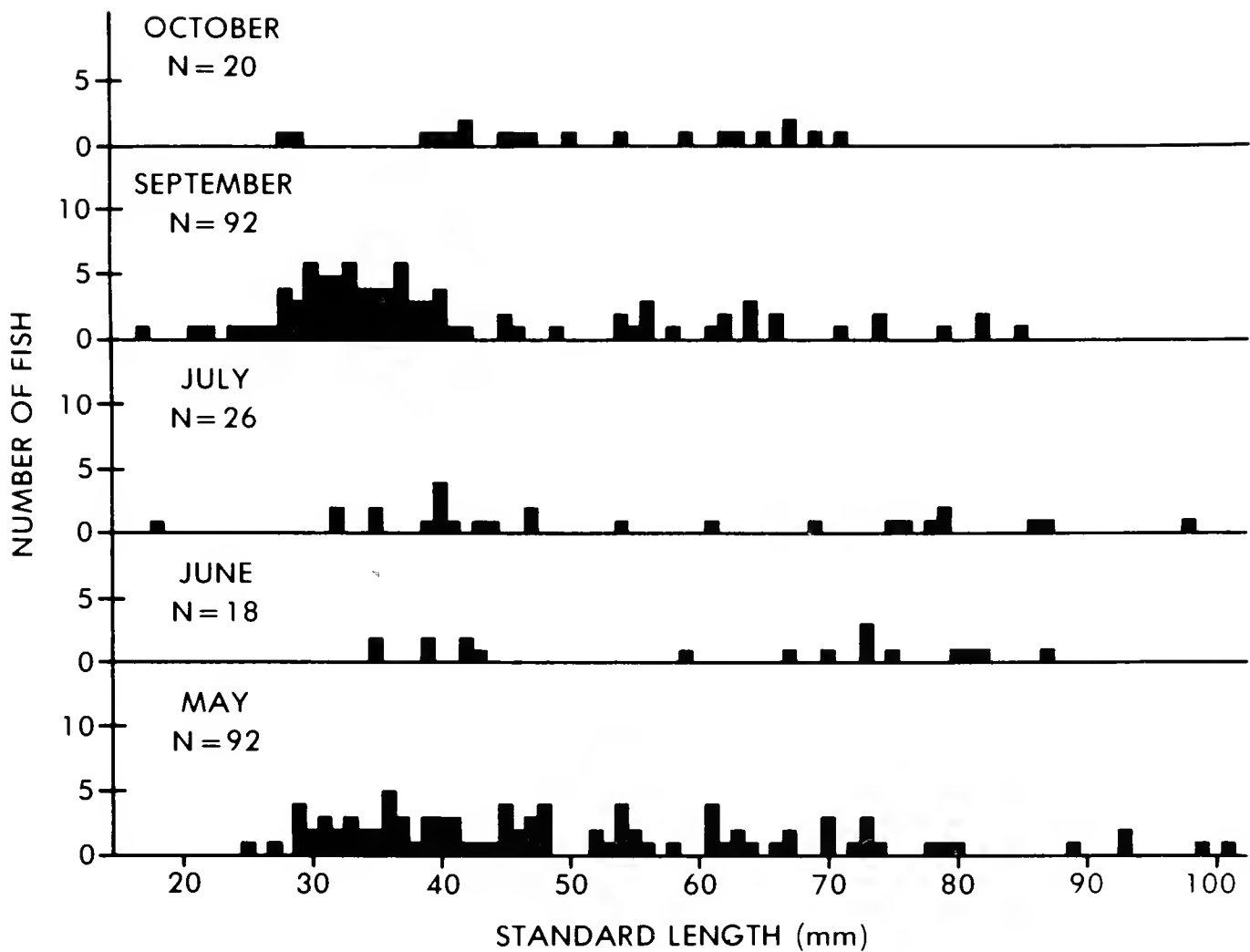


Fig. 5. Length-frequency distribution of *Noturus furiosus* in spring, summer, and fall seasons. At least four age classes are represented.

milligrams (T) on adjusted body weight in grams (W) was  $T = -0.001 + 0.004W$  ( $r = 0.52$ ;  $N = 17$ ).

In 11 mature males collected from May to July, the GSI ranged from 0.001 to 0.007 ( $\bar{x} = 0.003$ ). The largest relative testes weight (equaling 0.7% adjusted body weight) was that of an 82-mm specimen collected 8 June. The GSI of immature males was usually less than 0.002.

As in other species of the genus, there was no marked sexual dimorphism outside the breeding season. Reproductively mature males of *N. furiosus* had enlarged cephalic epaxial muscles, swollen lips, and swollen genital papillae (Fig. 6). The male papilla was much like that described for other species of *Noturus* in the subgenus *Rabida* (see Burr and Mayden 1982a). The swollen heads of males are presumed to function in nest guarding and perhaps in nest preparation.

*Reproductive Condition in Females.* Throughout the summer there was little change in GSI for immature females (range = 0.001 to 0.008;  $\bar{x} = 0.005$ ;  $N = 11$ ). Lack of adequate numbers of specimens from the remainder of the year prevented a comparison of GSI throughout fall, winter, and spring. Ovarian growth in immature *N. furiosus* is

presumably similar to the variable, slight seasonal increase in other species (Mayden and Burr 1981; Burr and Mayden 1982a,b).

GSI of mature females reached a peak in May ( $\bar{x}$  GSI = 176) and June ( $\bar{x}$  GSI = 166) and began to taper off in July ( $\bar{x}$  GSI = 105). Peak GSI in May and June presumably corresponds to accelerated ovarian recrudescence and oocyte vitellogenesis. Sixteen gravid females had a mean adjusted body weight of 7.60 gm and a mean ovarian weight of 1.04 g (range = 0.34 to 2.34). The proportionally heaviest ovaries (equaling 25.8% adjusted body weight) were those of a 70-mm female collected from the Little River on 19 May (Table 1). GSI ratios from gravid females of other medium-size to large madtoms collected May through July were: 79 (N = 4) in *N. nocturnus* (Burr and Mayden 1982b), 107 (N = 7) in *N. flavater* (Burr and Mayden 1984), 145 (N = 12) in *N. miurus* (Burr and Mayden 1982a), 149 (N = 33) in *N. gyrinus* (Whiteside and Burr 1986), 175 (N = 3) in *N. flavipinnis* (Shute 1984), and 211 (N = 11) in *N. exilis* (Mayden and Burr 1981).

Externally, gravid females appeared similar to immature specimens except in having distended abdomens and swollen genital papillae (Fig. 6).

*Oocyte Diameter and Fecundity.* As in congeners, ovaries of gravid females contained two size classes of oocytes. Large, vitellogenic oocytes were amber, ranged in diameter from 1.7 to 3.0 mm ( $\bar{x}$  = 2.5; N = 130), and were assumed to be the only oocytes spawned during one season. Immature oocytes were small (0.2 to 1.8 mm;  $\bar{x}$  = 0.9; N = 12) and opaque white or yellow. In 17 gravid females there was a positive correlation ( $r = 0.97$ ) between mean oocyte diameter in mm (D) and increasing GSI, with  $D = 1.46 + 0.006\text{GSI}$ .

Vitellogenic oocytes in 17 gravid females ranged in number from 79 to 298 ( $\bar{x}$  = 126.3). Asymmetry in oocyte number between right and left ovaries occurred in several females, but the differences were not statistically significant at the 0.05 level (Table 1). Skewed distributions of oocytes have also been reported for *N. exilis* (Mayden and Burr 1981), *N. flavus* (Walsh and Burr 1985), and *N. flavater* (Burr and Mayden 1984). As suggested by Walsh and Burr (1985), these differences probably reflect individual variation since other gravid *N. furiosus* had nearly equal numbers of oocytes between ovaries (Table 1).

The total number of mature oocytes in a female was positively correlated with increasing SL, adjusted body weight, and age. For 17 gravid females, the regression of number of mature oocytes (F) on SL was  $F = -248.60 + 5.01\text{SL}$  ( $r = 0.81$ ), of the number of mature oocytes on adjusted body weight in grams (W) was  $F = 16.37 + 14.47\text{W}$  ( $r = 0.90$ ), and of the number of mature oocytes on age in years (A) was  $F = -140.30 + 87.04\text{A}$  ( $r = 0.77$ ). The number of mature oocytes per gram adjusted body weight ranged from 12.2 to 24.1 ( $\bar{x}$  = 17.1; N = 16).

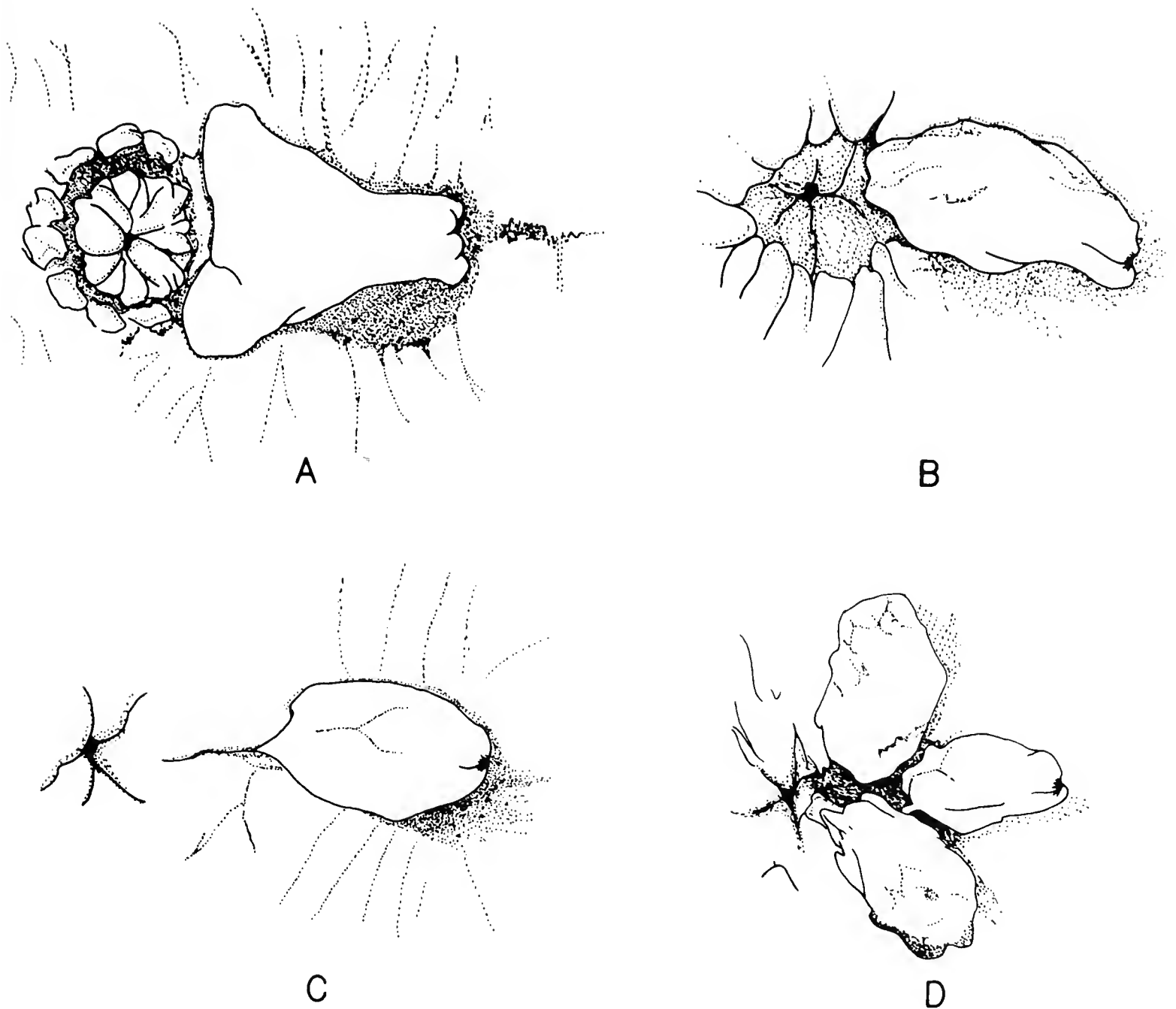


Fig. 6. Genital papillae of *Noturus furiosus*. (A) 82-mm SL nonbreeding male, 19 September 1959, Tar River, Edgecombe-Nash counties (USNM 191057). (B) 79-mm SL breeding male, 20 May 1985, Little River, Wayne County (SIUC 11683). (C) 55-mm SL nonbreeding male, same as A. (D) 73-mm SL breeding female, same as B. Left is anterior. 25X. Drawing by Karen L. Fiorino.

*Sex Ratio.* There was no significant deviation from a 1:1 sex ratio in the total sample from North Carolina (126 males:114 females), nor in any of the monthly samples containing more than 10 individuals. In a preliminary review, skewed sex ratios in other species of *Noturus* (Mayden and Burr 1981) were thought to result from sampling bias, particularly in older age classes.

*Nesting.* As judged from females with mature ova and males in reproductive condition, the nesting season of *N. furiosus* extends from about mid-May to the third week of July (Tables 1 and 2). The first evidence of nesting *N. furiosus* was the discovery of a reproductively

mature pair in Little River, west of Goldsboro, in a 355-ml beer can on 22 May 1982; water temperature was 20°C in the shallow run where the can was found. From 16 to 22 May 1985, in water ranging in temperature from 22 to 25°C, we found two primary and two secondary areas of nesting for *N. furiosus*. Both the Little River, west of Goldsboro, and the Tar River in Tarboro contained substantial nesting populations of the species. At the former site, in an area about 300 m in length, seven solitary males in breeding condition were found in 355-ml cans and bottles, or under shells (about 50 potential nesting sites were examined); one female swollen with eggs was in a 355-ml can; three pairs in reproductive condition were in cans; and one male with embryos was in a beer can (Table 2). At Tarboro, in an area about 100 m in length, 11 solitary males in reproductive condition were found in cans and bottles and under mussel shells (about 200 potential nest sites were examined); two males, each with embryos, were found in glass containers (Table 2). Subadults were numerous at both these sites, in containers and other situations similar to those occupied by adults.

Secondary nesting areas for the species were found in the Tar River in Rocky Mount and northwest of Heartsease. At both sites, we found one breeding male with embryos or larvae in water ranging from 23 to 23.5°C. Only two other individuals, both juveniles, were found at each of these sites. Potential nesting sites were uncommon at both areas.

Nests, pairs, and solitary adults in breeding condition were all found in similar habitat; medium- to large-sized streams with pea- to medium-sized gravel/sand substrates and moderate-to-swift warm water (22 to 25°C). Most nest sites were in runs above riffles or in pools with current. Water depth varied from 26 to 120 cm ( $\bar{x}$  = 66.4). All nests with embryos or larvae were guarded by solitary males, 3 to 4 years old and ranging in SL from 63 to 101 mm ( $\bar{x}$  = 89.8). The stomachs of guardian males were mostly empty or contained well-digested, unidentifiable material.

Only three clutches captured were complete with 139, 147, and 171 embryos ( $\bar{x}$  = 152). One clutch, containing more than 200 larvae and guarded by the largest male, could not be captured (Table 2). A brood of 16 larvae, considered incomplete, was captured with the guardian male. Larvae were negatively phototactic, and in one case dispersed rapidly when nest cover was removed, precluding capture of the complete brood.

Nest cans and bottles were generally free of substrate material, but if present, it was tightly packed against the bottom of the container. Nest containers or cover usually were partially buried in the substrate. Nests were found as close as 5 m apart and ranged from a few centimeters from the bank to the center of the stream.

Cans or bottles with small openings are probably favored as nest sites by large males because they are easy to protect. Head width in eight reproductively mature males ranged from 15.1 to 29.0 mm ( $\bar{x}$  = 22.4) and head depth ranged from 7.8 to 16.0 mm ( $\bar{x}$  = 12.3). Pop-top beer and soda can openings ranged from 18.5 to 28.0 mm in length ( $\bar{x}$  = 23.7) and from 13.0 to 20.0 mm in width ( $\bar{x}$  = 16.2). Thus, there is little room to spare at the opening of a can once a male is inside. Guardian males with their swollen heads generally face the opening of the container, presumably blocking the entry of most potential predators. It is not known whether a male enters a can with his head muscles and lips already swollen or if these changes take place after he has selected his nest site.

During May we found no instances of syntopic species of *Noturus* nesting in areas with *N. furiosus*. Both *N. gyrinus* and *N. insignis* were uncommon or not found in *N. furiosus* nesting habitat. Crayfishes, juvenile madtoms, *A. rostrata*, and *Necturus lewisi* may compete for nest or hiding sites with *N. furiosus*. The waterdog and *N. furiosus* are sympatric, and one nest of the former has been found under a flat rock (Ashton and Braswell 1979). Although we did not find any *N. furiosus* nests under rocks, the species may use such sites at least occasionally, especially since close relatives of the species have been found to do so (see Burr and Mayden 1982a, 1984). Like other ictalurid catfishes, *N. furiosus* is a member of the speleophil reproductive guild as defined by Balon (1975).

Clearly, *N. furiosus* has taken advantage of human litter as potential nest sites, but the presence of several adults in reproductive condition under mussel shells (mostly *Elliptio complanata*) and bark indicates that before the advent of modern man these were perhaps the only form of adequate-sized cover available. Our survey work indicates that the number of artificial nest sites (i.e., cans and bottles) far exceeds the number of adequate-sized natural sites in the streams we intensively sampled.

*Larval Development.* As in other species of *Noturus*, embryos adhere to each other in a mass, but not to other surfaces. Chorion diameters of 45 pre-hatchling embryos ranged from 3.8 to 4.4 mm ( $\bar{x}$  = 3.9 mm). Yolk sacs of developing embryos were cream to light yellow, similar to yolks of *N. flavus* (Walsh and Burr 1985), but in contrast to the darker yellow or nearly orange yolks in *N. albater* (Mayden et al. 1980), *N. exilis* (Mayden and Burr 1981), *N. miurus* (Burr and Mayden 1982a), and *N. nocturnus* (Burr and Mayden 1982b). Yolk diameters averaged 3.2 mm (range = 2.5 to 4.0; N = 45).

At about 1 day post-hatching, larvae ranged in TL from 9.1 to 10.0 mm ( $\bar{x}$  = 9.5; N = 16), had well-developed maxillary and mandibular

barbels, rudimentary nasal barbels, and darkly pigmented retinæ; small pectoral and pelvic fin buds; and a continuous posterior fin fold heightened in the regions of the anal and dorsal fins, and with rudimentary caudal and anal rays (Fig. 7). A sprinkling of melanophores occurred on the head and along the dorsal myomeres. Hatchlings of *N. furiosus* exhibited tightly cohesive schooling behavior. Larvae in later stages of development were not found. Early post-hatching larvae of *N. furiosus* closely resembled *N. nocturnus* (Burr and Mayden 1982b) and *N. miurus* (Burr and Mayden 1982a) in shape, pigmentation, and overall developmental features. Early post-hatching larvae of other species of *Noturus* are more heavily pigmented when compared with *N. furiosus* (e.g., *N. exilis*, Mayden and Burr 1981; *N. flavater*, Burr and Mayden 1984).

The smallest juveniles known are 17 mm SL, and they have the body shape and pigmentation pattern typical of adults.

*Diet.* A total of 200 stomachs of *N. furiosus* were examined; 88 were empty, 18 had unidentifiable digested material, and 94 contained some food. The large percentage of empty stomachs is probably a sample bias resulting from many daytime collections. Madtoms feed primarily during the evening with peaks at dawn and dusk (Mayden and Burr 1981).

Dipteran, ephemeropteran, trichopteran, coleopteran, and odonate larvae or nymphs compose more than 95% of the total food organisms (Table 3). Dipteran larvae and ephemeropteran nymphs were the most commonly eaten food source. Chironomid larvae accounted for 91% of the dipterans eaten, with the remainder being culicid and simuliid larvae. Ephemeropteran nymphs included members of the families Baetiscidae, Heptageniidae, and Caenidae. Larvae of Hydropsychidae were the predominant (69%) representatives of Trichoptera. Elmids larvae made up 95% of the coleopterans, and almost all of the elmids were members of the genus *Stenelmis*, with only one individual of *Dubiraphia* represented. Odonates included nymphs of the genus *Hagenius*, in the family Gomphidae, and one representative of Coenagrionidae. Nematodes found in the stomachs were possibly parasitic. Four individuals had large fish scales in their stomachs, probably indicating benthic scavenging activities. Individual madtoms ate a variety of organisms; one had representatives of six different taxa in its stomach. Several individuals had sand grains and plant material mixed in with their food, which probably was ingested incidentally.

Larger individuals ate larger food items (Table 3). The relatively small-sized dipteran larvae decreased in the diet with increasing size of the madtom. Percentages of larval dipterans in the diet of the three size groups of madtoms listed in Table 3 varied from 35.5 to 26.8 to 0. In



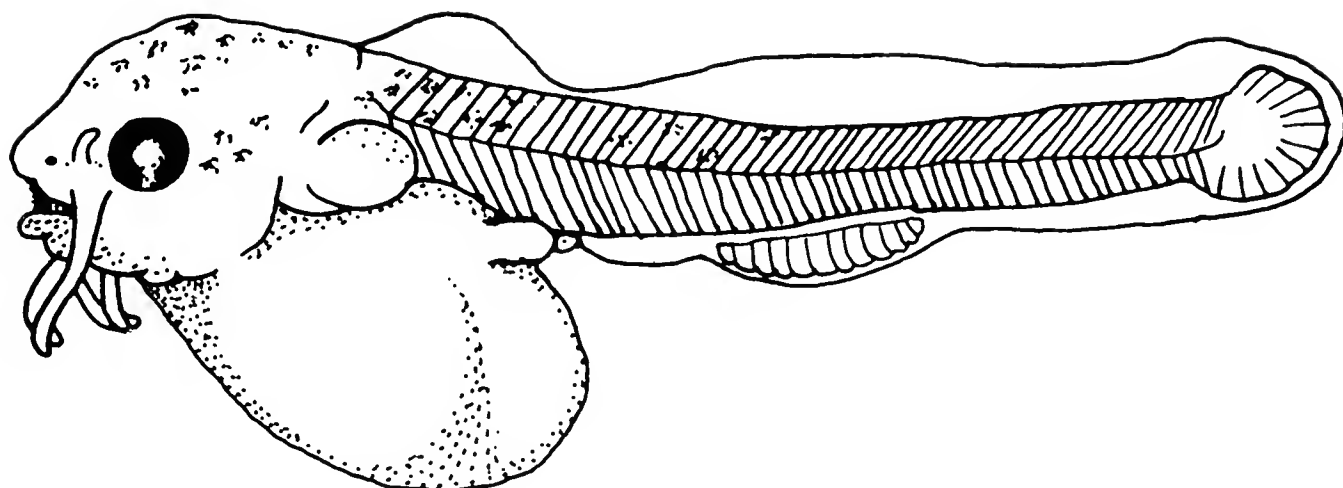


Fig. 7. Lateral view of 9.5-mm TL larva of *Noturus furiosus* (SIUC 11775). Drawing by Karen L. Fiorino.

contrast, percentages of the larger-sized odonate nymphs in the diet increased from 5.1 to 6.6 to 30.4 with increasing size of the madtom.

Comparisons of spring and summer diets are shown in Figure 8. Elmids larvae were a significant food organism in the spring, but were negligible in the summer samples. Simuliid larvae were present only in summer collections, and the percentages of ephemeropteran nymphs and trichopteran larvae increased in the madtom's diet in summer. The abundance of chironomid larvae and odonate nymphs in the diet of *N. furiosus* was unaffected by the changing seasons.

It appears that *N. furiosus*, like other madtoms, is a nocturnal, benthic insectivore. All madtoms studied to date are taste feeders and are morphologically equipped for taste feeding with numerous gustatory structures.

## DISCUSSION

Historically, at least 24 distinct localities of occurrence of *N. furiosus* have been recorded based on extant voucher material. Additional literature records (Bayless and Smith 1962, Smith and Bayless 1964) bring the total to 36. We have revisited all but ten of these sites since 1982. Nine sites in the Neuse River drainage and six in the Tar River drainage have not yielded specimens. Several of these sites were too flooded for adequate sampling and may harbor extant populations (e.g., Fishing Creek). In addition, we discovered seven new populations of *N. furiosus* in the Tar and Neuse River drainages in 1984 and 1985, indicating that successful and substantial reproduction has taken place in recent years.

Prior to our field work in 1985, *N. furiosus* was considered to be a rare species. This judgement was the general consensus of several ichthyologists who had tried to collect the species in the 1970s and

Table 3. Stomach contents of *Noturus furiosus* from the Tar and Neuse river drainages, North Carolina, by size class of madtom. Figures to the left are percentages of diet derived from each food organism; parenthetical figures are percent of stomachs in which food organism occurred.

Food Organism	Size Class		
	≤40 mm (N = 60)	41-70 mm (N = 26)	≥71 mm (N = 8)
Nematoda	—	0.8 (3.8)	4.3 (12.5)
Annelida			
Oligochaeta	0.4 (1.7)	2.5 (11.5)	—
Hirudinea	0.9 (1.7)	—	—
Insecta			
Ephemeroptera	26.9 (58.3)	16.0 (23.1)	47.8 (25.0)
Heptageniidae	0.9 (3.3)	0.8 (3.8)	—
Caenidae	—	0.8 (3.8)	—
Baetiscidae	5.1 (11.7)	0.8 (3.8)	—
Odonata	4.7 (8.3)	5.0 (7.7)	17.4 (50.0)
Anisoptera	0.4 (1.7)	0.8 (3.8)	—
Gomphidae	—	—	8.7 (12.5)
Zygoptera	—	—	4.3 (12.5)
Coenagrionidae	—	0.8 (3.8)	—
Plecoptera	0.4 (1.7)	—	4.3 (12.5)
Pteronarcyidae	—	0.8 (3.8)	—
Hemiptera	—	0.8 (3.8)	—
Coleoptera	0.9 (3.3)	—	—
Elmidae	2.6 (8.3)	27.7 (15.4)	4.3 (12.5)
Trichoptera	3.4 (10.0)	8.4 (19.2)	8.7 (25.0)
Hydropsychidae	17.9 (35.0)	5.0 (15.4)	—
Brachycentridae	—	0.8 (3.8)	—
Lepidostomatidae	—	0.8 (3.8)	—
Diptera			
Culicidae	—	2.5 (7.7)	—
Chironomidae	32.5 (46.7)	23.5 (30.8)	—
Simuliidae	3.0 (11.7)	0.8 (3.8)	—

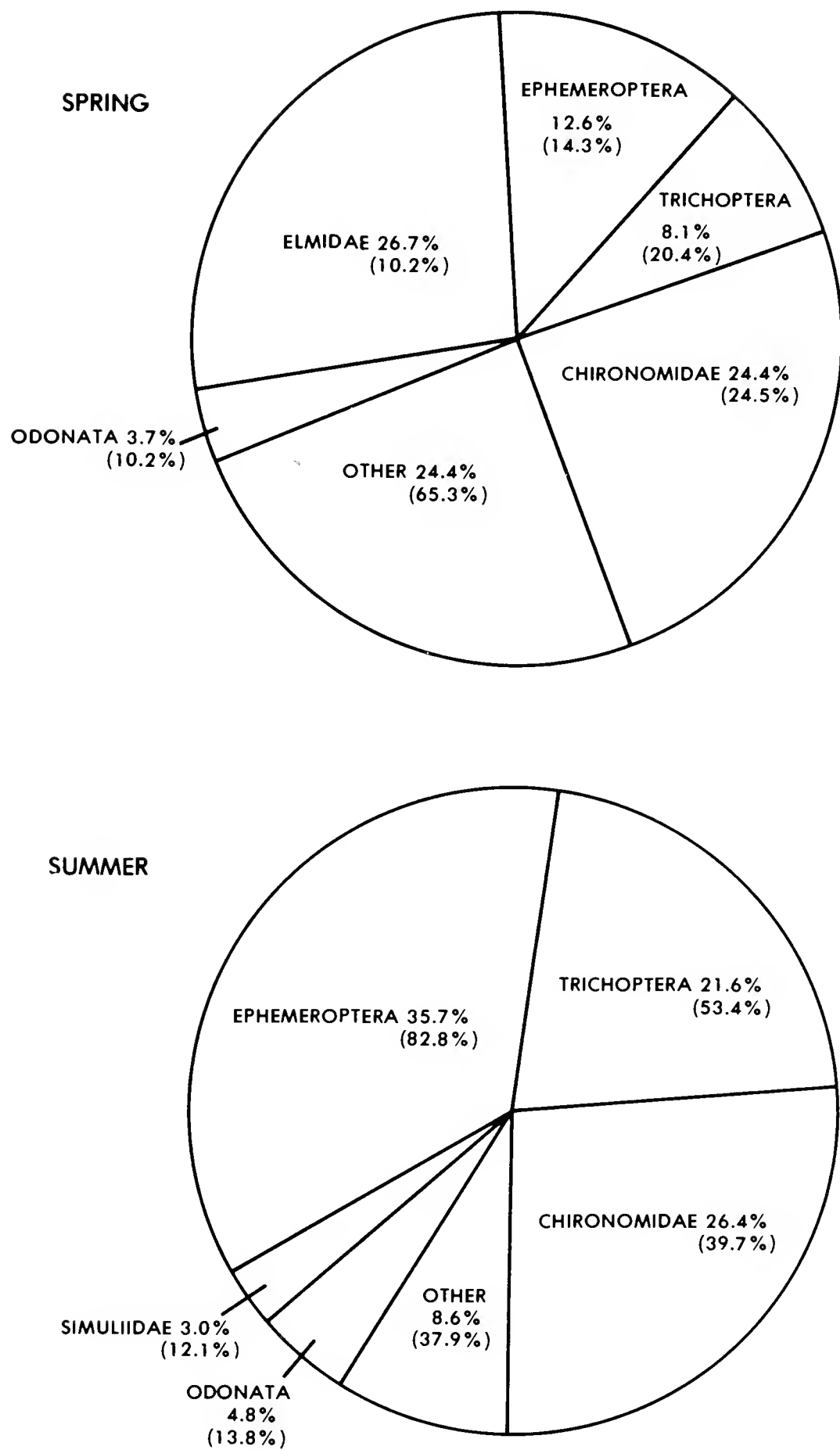


Fig. 8. Composition of the diet of *Noturus furiosus* by spring and summer seasons. Top figures are percentages of total number of food organisms consumed; parenthetical figures are percentages of stomachs in which food organisms occurred.

1980s. Further, the extensive trap data involved in collecting biological information on *Necturus lewisi* (Braswell and Ashton 1985) did not reveal a single specimen of the sympatric and syntopic *Noturus furiosus*. Collecting conditions were ideal during our field work in May 1985 and we concentrated our field efforts on locating only *N. furiosus*. These factors probably contributed to our success. Because we found that *N. furiosus* primarily inhabits medium- to large-size streams, it is clear that the species would be difficult to collect except when water levels are low.

Although *N. furiosus* is relatively common at some sites, the species appears to have experienced a decline and loss of habitat in other areas. The greatest losses of *N. furiosus* habitat have occurred in the Neuse drainage. Reservoir construction (Falls Lake), outflow of cold waters below Falls Lake, and general pollution problems around Raleigh have reduced habitat in the upper Neuse. A toxic chemical spill into the Neuse River near Raleigh on 10 July 1980 caused a large fish kill, but no *N. furiosus* were found. The Tar drainage seems to have experienced fewer cases of severe habitat degradation. However, the Tar River from below Rocky Mount to about 20 km downstream showed evidence of extensive municipal and industrial effluents. We did not find *N. furiosus* in that region, and *Necturus lewisi* is also absent there (Braswell and Ashton 1985).

A number of federal and state projects are presently being completed or are in the planning phase for both the Neuse and Tar drainages. Most of these projects call for (1) removal of stream cover, (2) denuding of stream banks, (3) dredging, (4) channelization, or (5) reservoir construction at a number of localities (e.g., Fishing Creek, Tar River near Tarboro, Contentnea Creek, Trent River) where *N. furiosus* is known to occur. We predict that these activities will have a detrimental effect on the quality of the habitat of *N. furiosus*, either by changing the habitat altogether (e.g., reservoir construction), or by severely modifying it (e.g., dredging).

Natural factors affecting the continued existence of *N. furiosus* include a potential increase in predation owing to desiccation of streams during drought. During late summer and fall most streams in the Neuse and Tar drainages are reduced to low flow because of little rainfall. The riffle habitat of the Carolina madtom is thus restricted in size, and the species may be subject to increased predation by fish-eating birds and snakes. Adults of other madtoms are eaten only rarely by piscivorous fish, and in laboratory experiments they are usually eaten as a last choice, probably because of their stout spines and the toxin-producing glands associated with the spines (Case 1970). Predators we have observed eating other species of adult *Noturus* on several occasions are

water snakes of the genus *Nerodia*. However, most predation on *N. furiosus* probably takes place during the larval stage. In other madtoms, removal of guardian males from nest sites results in rapid loss of young to fishes and crayfishes (Mayden et al. 1980, Mayden and Burr 1981).

Presently, *N. furiosus* is placed in the category of special concern on North Carolina's list of endangered and threatened animals (Bailey et al. 1977); it is only being considered for listing by the Department of the Interior. Nonetheless, fisheries biologists need to be aware of the vulnerability of the species to sampling techniques. In the early 1960s, numerous collections of *N. furiosus* were made from the Tar and Neuse drainages using the ichthyocide rotenone (Bayless and Smith 1962, Smith and Bayless 1964). Unfortunately, a majority of these rotenone collections were made in June and July, during the breeding season of *N. furiosus*. Because ichthyocides are extremely effective in killing madtoms, we believe that the indiscriminate use of rotenone in North Carolina stream surveys should be discouraged. Careful regulation and monitoring may even be justified.

The general biology of *N. furiosus* as outlined here is similar to that in previous reports of other species in the genus. There are, however, two important aspects of reproduction in *Noturus* that remain unresolved. Several authors (Menzel and Raney 1973, Mayden and Burr 1981, Walsh and Burr 1985) have presented circumstantial evidence that females in some species of *Noturus* may spawn with more than one male in a breeding season. In several species, the mean number of vitellogenic oocytes is about twice the mean number of embryos found in complete broods. In this study, the mean number of vitellogenic oocytes (126.3) was somewhat less than the mean number of embryos (152.0) from complete broods of *N. furiosus*. Because of the positive correlation of female body size with fecundity, we assume that polyandry does not occur in this species. This assumption is supported by the results Blumer (1985a) reported from field and laboratory experiments with a related species, the brown bullhead, *Ictalurus nebulosus*.

One additional aspect of reproduction that remains unresolved in *Noturus* is the contribution of females to parental care of embryos and larvae. In all known studies of *Noturus*, including this one, only males have been found guarding embryos or larvae. Because males generally do not feed during the nesting and care-giving period they sustain a greater cost of care giving (starvation and therefore reduced future reproduction) than do males aided by their mates (Blumer 1985b).

Although a great deal has been learned about the natural history of madtoms in the last five years, we still lack basic knowledge of (1) spawning behavior, (2) nest construction (if any), (3) social behavior, (4) contribution of females in parental care of embryos and larvae,

(5) number of clutches spawned per year by a single female, (6) behavior and distribution of young after leaving the nest, (7) critical diurnal habitats, (8) movements or migrations, (9) nocturnal behaviors, and (10) winter habitat occurrence. Because none of this information is known for *N. furiosus*, further research is needed to ensure our ability to preserve and protect the species. Until propagation techniques have been developed for madtoms, we recommend that spawning sites of *N. furiosus* be protected and that collectors be discouraged from sampling prime nesting areas.

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# Pelagic and Near-shore Plankton Communities of a North Carolina Coastal Plain Reservoir

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**ABSTRACT.**— The plankton community of Sutton Reservoir, an estuarine-influenced cooling reservoir in the coastal plain of North Carolina, was sampled monthly throughout 1985. Phytoplankton densities were low to moderate and dominated by the Chlorophyceae and Cryptophyceae, with chlorophyll *a* values indicating a mesotrophic state. The zooplankton community was unusual compared with other area reservoirs and reflected the estuarine influence of the lower Cape Fear River and the reservoir's geographic location. Crustacean zooplankton were dominated by *Diaptomus dorsalis*, *Eurytemora affinis*, *Daphnia ambigua*, and *Bosmina coregoni*; and the rotifers were dominated by members of the Brachionidae. Zooplankton densities, which exhibited a bimodal peak, were high relative to area reservoirs and dominated by rotifers. Biomass was comparatively low and dominated by crustaceans. Correlation analysis indicated a strong, inverse relationship between crustacean zooplankton and phytoplankton, and zooplankton grazing is suggested as the primary controlling force in phytoplankton temporal population dynamics.

Sutton Reservoir, in New Hanover County, North Carolina, is one of several water bodies located in the coastal plain of the southeastern United States. These systems comprise both man-made reservoirs and natural lakes (the Carolina bays). Most of these systems are very important to wildlife, particularly migratory waterfowl; and bay lakes often contain rare or endemic species (Sharitz and Gibbons 1982).

Sutton Reservoir is ecologically interesting in that it is subject to both chemical and biological influence from the lower Cape Fear River and displays characteristics of both fresh and brackish waters. The objectives of this study were to describe the zooplankton community of this unusual ecological system, compare the pelagic and near-shore communities, discuss the relationship of the zooplankton community with the reservoir's chemical and physical characteristics and phytoplankton, and compare the Sutton Reservoir zooplankton with those of other Southeastern systems.

Little has been reported in the literature regarding the plankton communities of coastal-plain lakes and impoundments. Stoneburner and Smock (1980) reported on the plankton community of an acid,

brownwater lake on a south Georgia barrier island. They found a sparse phytoplankton community dominated by *Chlamydomonas* sp., *Melosira varians*, and *Peridinium pusillum*. The zooplankton community maintained high densities and was dominated by *Diaptomus floridanus*, *Polyarthra vulgaris*, *Keratella cochlearis*, and *Daphnia ambigua*. The Great Dismal Swamp ecosystem in Virginia and northeastern North Carolina was investigated by Anderson et al. (1977). They found that the system was dominated by rotifers with high densities of *Polyarthra vulgaris* and *Conochiloides dossuarius*. Dominant crustaceans were *Bosmina longirostris*, *Diaphanosoma leuchtenbergianum*, *Mesocyclops edax*, and *Tropocyclops prasinus*. Casterlin et al. (1984) studied the algae of Lake Waccamaw, a large North Carolina bay lake, and found increasing eutrophication occurring. The North Carolina Department of Environmental Management has reported data concerning the mid-summer algae and chlorophyll of several coastal-plain lakes (NCDEM 1984). The scarcity of plankton information about coastal-plain systems leaves mainly inland water systems for comparisons.

#### SITE DESCRIPTION

Sutton Reservoir (Catfish Lake) is a 445-ha impoundment located 4.8 km northwest of Wilmington, N.C., adjacent to the Cape Fear River. It was constructed in 1972 to provide cooling water for the L. V. Sutton Steam Electric Plant, a 677-MWe closed-circulation, coal-fired generating facility operated by Carolina Power & Light Company (CP&L). The reservoir is U-shaped with a series of baffle dikes and has a mean depth of about 2 m and a maximum depth of about 12 m (Fig. 1). It has a retention time of approximately 140 days, and the circulation time around the reservoir is about 4 days. Power plant discharge has caused midsummer reservoir water temperatures of 32 to 35 °C in recent years (CP&L 1986).

The reservoir has no constant influent stream but receives intermittent makeup water from the Cape Fear River, particularly during the summer. The ionic composition of the water reflects the estuarine influence (Table 1). The lake is well oxygenated, well mixed, and circumneutral in pH (CP&L 1986). The fish community is dominated primarily by typical Southeastern freshwater species such as largemouth bass (*Micropterus salmoides*), gizzard shad (*Dorosoma cepedianum*), bluegill (*Lepomis macrochirus*), and several other sunfish. Estuarine influence is indicated by the presence of species such as mullet (*Muzil cephalus*), flounder (*Paralichthys* spp.), and blue crabs (*Callinectes sapidus*). Between 1972 and 1980 infestations of bladderwort (*Utricularia vulgaris*) were common in Sutton Reservoir, with growth dense enough in 1979 to cause a plant shutdown. Introduction of the redbelly tilapia

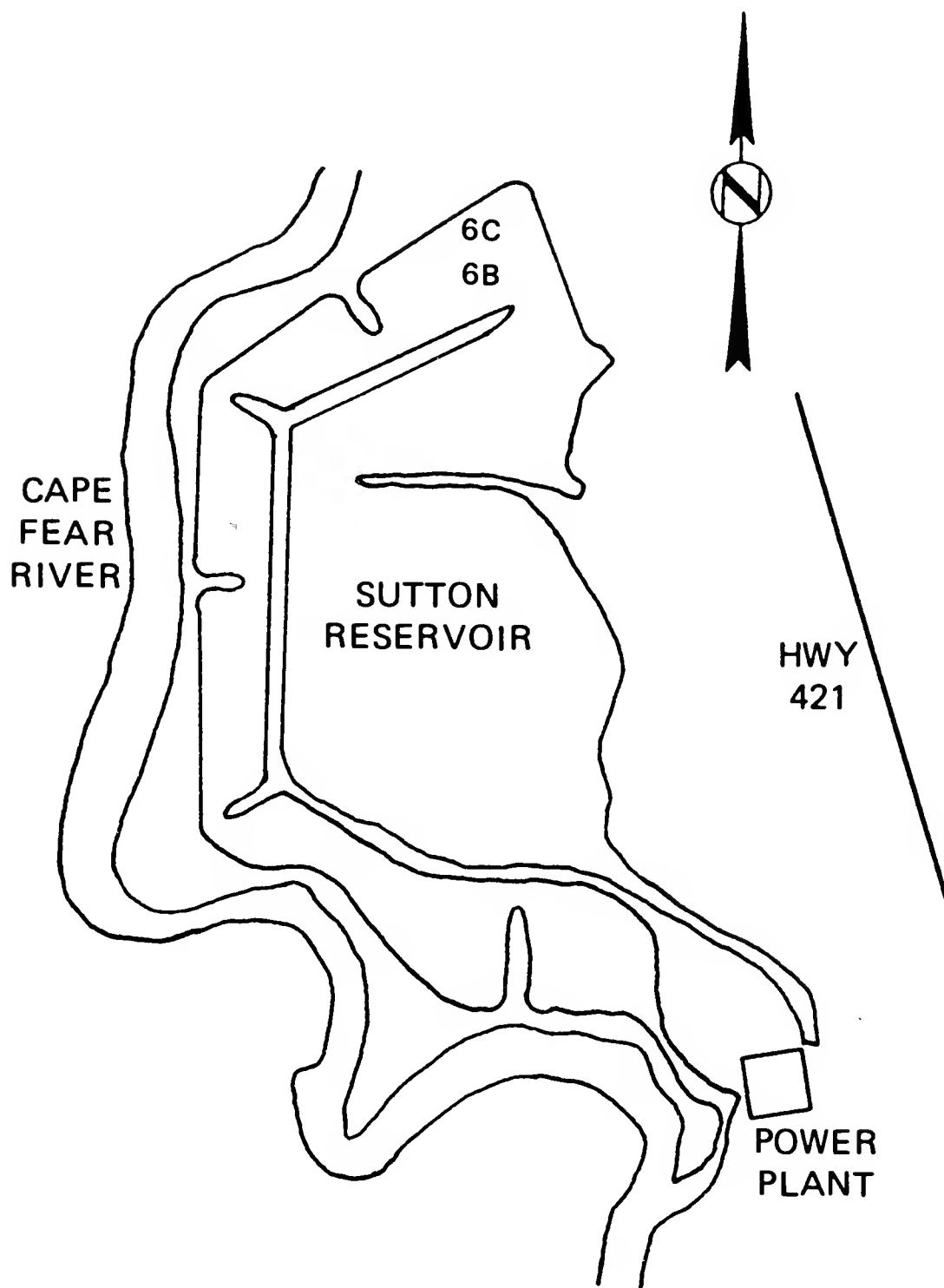


Fig. 1. Map of Sutton Reservoir, New Hanover County, N.C., showing sampling stations and baffle dikes.

(*Tilapia zilli*) in 1980 subsequently controlled the bladderwort (CP&L 1984b). In 1982 dense growths of pondweed (*Potamogeton berchtoldii*), southern naiad (*Najas guadalupensis*), and coontail (*Ceratophyllum demersum*) supplanted the bladderwort and were not effectively controlled by the tilapia. A dense blue-green algal bloom occurred during the summer of that year as well (CP&L 1984a). The macrophytes were controlled and nearly eliminated by the use of herbicides in subsequent years (Schiller 1985). Increased densities of blue-green algae still occur during summer, but nuisance blooms have not occurred since the macrophytes were eliminated in 1983.

## MATERIALS AND METHODS

Zooplankton samples were collected monthly from January 1985 through December 1985 at two locations using a 10.5-liter Juday-style closing plankton trap fitted with a 75- $\mu\text{m}$  mesh net. Traps have been found to be more efficient than nets for zooplankton samples, especially for smaller forms (Kankaala 1984). The 75- $\mu\text{m}$  mesh is more efficient than a larger size for capturing microzooplankton (Evans and Sell 1985). Station 6B was a midreservoir station over deep water (10 m), and Station 6C was a near-shore station in about 1 m of water. Three replicate samples were taken at each station at about the 0.5-m depth. Samples were field preserved with formalin to 2% of volume.

In the laboratory the samples were mixed, and an aliquot containing at least 100 organisms was removed and placed in a circular counting chamber. Copepods, cladocerans, rotifers, and protozoans were counted using a dissecting microscope and identified to the lowest practical taxon using a compound microscope. Taxonomic keys included Pennak (1953), Brooks (1957, 1959), Voigt (1951), Edmondson (1959), and Wilson and Yeatman (1959). Biomass of zooplankton was determined using literature biomass values for piedmont reservoir zooplankton (Horton and Carter 1980). Biomass of species not listed was determined by applying dry-weight regression equations (Dumont et al. 1975) to specimens measured for length in the laboratory. A two-way analysis of variance blocked on months was used to compare various  $\log_e (X + 1)$  transformed zooplankton population density and biomass variables between stations. A Type I error significance level of  $\alpha = 0.05$  was used in the analyses. Densities are reported as number/ $\text{m}^3$  and biomass as  $\text{mg}/\text{m}^3$ . Correlation analyses were run to detect linear relationships between water temperature and selected zooplankton and phytoplankton variables.

Phytoplankton and chlorophyll *a* were sampled monthly at a single midwater station by combining whole water samples from the surface, Secchi depth, and twice Secchi depth. Fifty ml of field-preserved sample were sedimented in Utermohl settling chambers and examined for phytoplankton taxonomic composition and density at 400X using an inverted microscope. Chlorophyll *a* analysis was conducted spectrophotometrically using the method described in Strickland and Parsons (1972).

Monthly surface water samples were collected and analyzed for nutrients and other chemical constituents by the CP&L Analytical Chemistry Laboratory according to standard methods (USEPA 1979, APHA 1981). Field measurements of water temperature, dissolved oxygen, pH, and conductivity were also taken on a monthly basis concurrent with the plankton samples.

Table 1. Surface water characteristics of Sutton Reservoir during 1985.

Parameter	Mean	Range
H <sub>2</sub> O temperature (°C)	20.6	5.6-32.2
Secchi depth (m)	2.1	1.5-2.9
pH	6.6	6.2-7.5
Conductivity (μS/cm)	792	510-935
PO <sub>4</sub> - P (mg/l)	0.003	0.001-0.008
NO <sub>2</sub> + NO <sub>3</sub> - N (mg/l)	0.054	0.01-0.17
Total alkalinity (mg/l CaCO <sub>3</sub> )	15.1	4.7-32.6
Sodium (mg/l)	125.8	89-250
Chloride (mg/l)	206.5	160-260
Chlorophyll <i>a</i> (μg/l)	5.7	1.6-13.2

## RESULTS AND DISCUSSION

Phytoplankton densities in Sutton Reservoir ranged from 480 units/ml in March to 7260 units/ml in June during 1985 (Fig. 2). Densities and chlorophyll *a* values were moderate compared with other lakes in the North Carolina coastal plain (NCDEM 1984). The Chlorophyceae and Cryptophyceae were the two most important phytoplankton classes, followed by the Bacillariophyceae and Cyanophyceae, respectively. Nuisance blue-green algal blooms observed during 1982 and 1983 were not manifested in 1985. Biomass as chlorophyll *a* was greatest in June when densities of *Cryptomonas ovata*, *Peridinium* spp., or larger diatom taxa such as *Melosira* were high (Fig. 2). Mean chlorophyll *a* levels (5.7 μg/l) suggest a mesotrophic state for Sutton Reservoir (Wetzel 1983).

Thirty-five zooplankton taxa from the Copepoda, Cladocera, and Rotifera were identified from Sutton Reservoir samples collected during 1985 (Table 2). A great majority of the taxa were rotifers, with the Brachionidae particularly well represented. Few of the crustaceans were numerically dominant in the reservoir. Those which were dominant included the copepods *Diaptomus dorsalis* and *Eurytemora affinis* and the cladocerans *Daphnia ambigua* and *Bosmina coregoni* (Table 3). Crustacean zooplankton densities displayed a bimodal peak in early spring and again in fall and winter, with a minimum from May through August. The rotifers generally maintained high densities from May through the end of the year, with various species of *Brachionus* and *Keratella* usually dominating. Other rotifers with high densities at various times included *Ascomorpha* sp. and *Conochiloides natans*.

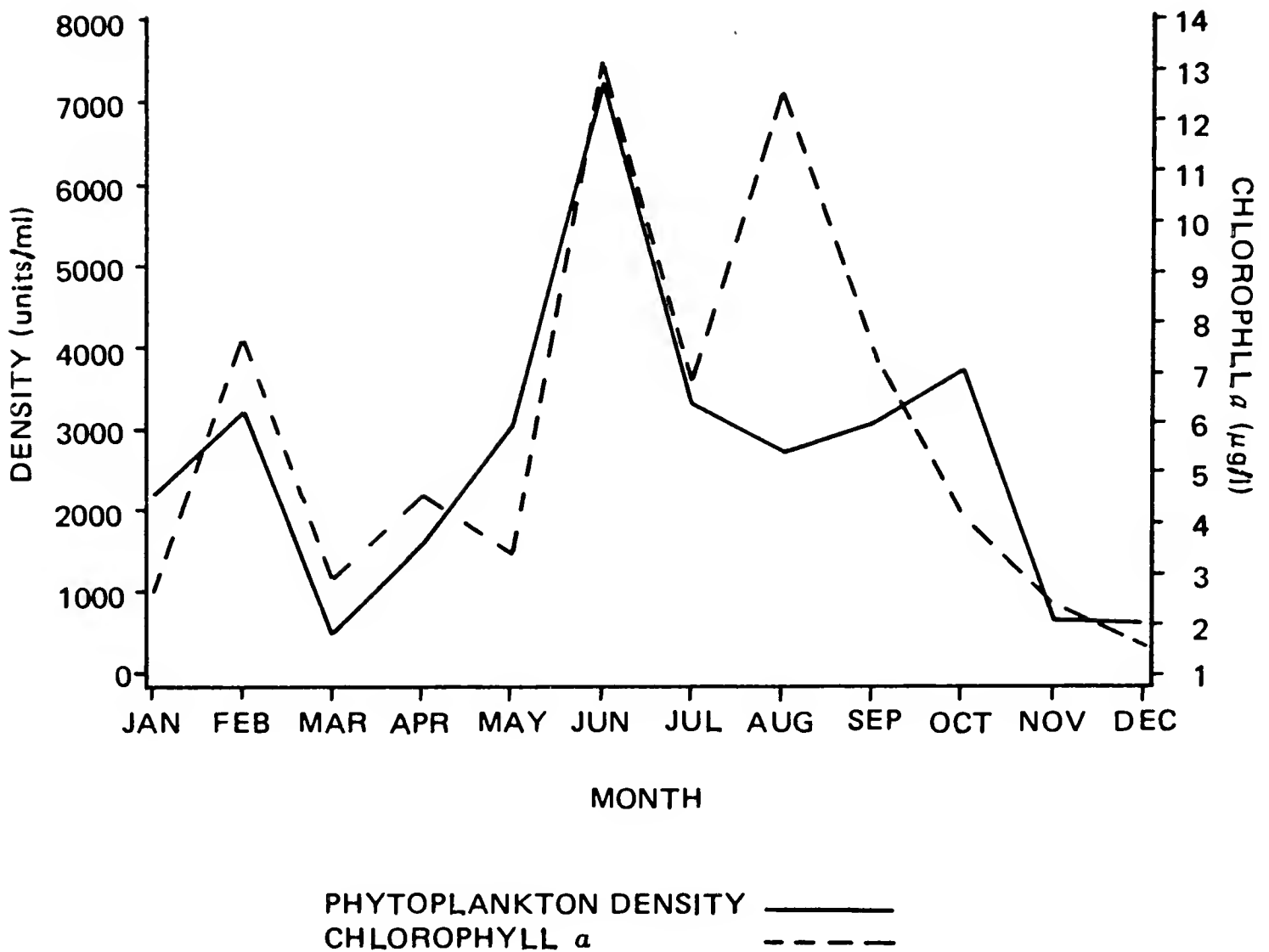


Fig. 2. Total phytoplankton densities and chlorophyll *a* values in Sutton Reservoir during 1985.

Zooplankton densities (Table 4) were dominated by rotifers and were high relative to other North Carolina reservoirs (Weiss et al. 1975, DPC 1977, Mallin 1986). Zooplankton biomass values (Table 4) indicated biomass dominance by copepods followed by cladocerans and then rotifers. Zooplankton biomass in Sutton is low compared with other North Carolina impoundments (Mallin 1986).

Temporal changes in dominance by organism density are illustrated by the percent composition over time of the total density by the major taxa groups (Fig. 3). Rotifers comprised large percentages of the densities in all seasons except spring. When the composition of biomass in Sutton Reservoir is examined over time (Fig. 4), it is evident that rotifers constitute a very small percentage of the zooplankton biomass, which has two notable peaks each year. In spring the major contributors to biomass were the copepod *Eurytemora affinis* followed by the cladocerans *Daphnia ambigua*, *Ceriodaphnia quadrangula*, *Diaphanosoma brachyurum*, *Bosmina coregoni*, and *B. longirostris*. In the fall,

Table 2. Zooplankton taxa identified from Sutton Reservoir during 1985.

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Copepoda

*Diaptomus dorsalis* Marsh  
*Eurytemora affinis* (Poppe)  
*Cyclops vernalis* Fischer  
*Mesocyclops edax* (Forbes)  
*Eucyclops agilis* (Koch)

Cladocera

*Daphnia ambigua* Scourfield  
*Daphnia parvula* Fordyce  
*Ceriodaphnia quadrangula* (O. F. Müller)  
*Bosmina longirostris* (O. F. Müller)  
*Bosmina coregoni* Baird  
*Ilyocryptus spinifer* Herrick  
*Alona* sp.  
*Chydorus sphaericus* (O. F. Müller)  
*Diaphanosoma brachyurum* (Lievin)

Rotifera

*Brachionus havanaensis* (Rousselet)  
*Brachionus quadridentatus* (Hermann)  
*Brachionus plicatilis* (O. F. Müller)  
*Keratella americana* (Carlin)  
*Keratella cochlearis* (Gosse)  
*Keratella valga* (Ehrenberg)  
*Keratella* sp.  
*Platylabus patulus* (O. F. Müller)  
*Lecane* sp.  
*Monostyla* sp.  
*Trichocerca longiseta* (Schrank)  
*Ascomorpha* sp.  
*Asplanchna* sp.  
*Synchaeta* spp.  
*Polyarthra* spp.  
*Filinia longiseta* (Ehrenberg)  
*Pompholyx sulcata* (Hudson)  
*Hexarthra* sp.  
*Conochilus unicornis* (Rousselet)  
*Conochiloides natans* (Seligo)  
*Collotheca* sp.

---

Table 3. Mean densities (no./m<sup>3</sup>) of important zooplankton taxa groups in Sutton Reservoir during 1985.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Copepods													
Nauplii	10980	20939	34000	72551	3991	33698	5649	22527	13613	10866	57338	16206	25196
<i>Diaptomus dorsalis</i>	0	0	0	0	0	0	0	4364	1835	479	47248	16174	5842
<i>Eurytemora affinis</i>	10028	6418	27556	546	105	238	37	0	0	0	0	0	3744
Copepodites	119	617	6829	7890	0	0	0	73	67	38	1399	16	1421
<i>Mesocyclops edax</i>	0	0	107	3991	0	0	0	0	0	0	444	466	417
Cladocerans													
<i>Daphnia ambigua</i>	252	1547	24797	3199	0	0	0	0	0	0	2278	7693	3314
<i>Ceriodaphnia quadrangula</i>	256	1094	2284	133	16	56	43	0	0	0	0	132	335
<i>Bosmina longirostris</i>	0	0	3436	1863	311	135	705	0	0	0	0	0	537
<i>Bosmina coregoni</i>	1717	1560	6290	1685	111	0	0	91	530	1654	31981	360	3832
<i>Chydorus sphaericus</i>	0	69	105	0	19	873	86	0	0	43	0	63	105
<i>Diaphanosoma brachyurum</i>	0	0	0	2955	0	167	0	0	76	0	159	333	308
Rotifers													
<i>Brachionus havanaensis</i>	0	0	0	0	194	64897	12559	362	857	299	7314	0	7207
<i>B. quadridentatus</i>	0	0	0	0	0	3079	0	0	0	0	0	0	257
<i>B. plicatilis</i>	0	0	0	0	0	32786	736	283	17289	1396	5762	0	4854
<i>Keratella americana</i>	161	45	0	0	1302	11278	6148	28268	5511	1067	66108	4257	10345
<i>K. cochlearis</i>	14448	7906	224	1597	22836	0	0	102	641	101	65175	6082	9926
<i>K. valga</i>	397	37	0	45	195	45167	1195	7373	219	17995	61186	1733	11295
<i>Platytas patulus</i>	0	0	0	0	27	3222	0	167	0	0	0	0	285
<i>Ascomorpha</i> sp.	662	85338	0	7116	38	0	0	0	0	0	0	0	7763
<i>Synchaeta</i> spp.	325	27178	1234	0	435	0	0	0	0	0	0	0	2431
<i>Polyarthra</i> spp.	0	130	0	792	170	3071	2024	181	0	0	0	0	531
<i>Pompholyx sulcata</i>	421	732	0	278	819	0	6424	0	1190	132	1268	656	993
<i>Conochiloides natans</i>	0	0	0	0	0	45627	6556	20520	72752	1262	3379	0	12508
All Zooplankton*	40172	153609	107565	105060	32549	246143	42328	84567	114942	35557	351039	54272	113986

\*Columns do not equal totals because taxa that are rare or found in low densities are excluded from table.



Table 4. Yearly mean densities (no./m<sup>3</sup>) and biomass (mg/m<sup>3</sup>) of major zooplankton taxa groups at Sutton Reservoir during 1985.

Taxa Group	Densities	Biomass
Total copepods	36,701	51.0
Total cladocerans	8,512	14.0
Total rotifers	68,773	3.0
Total zooplankton	113,986	68.0

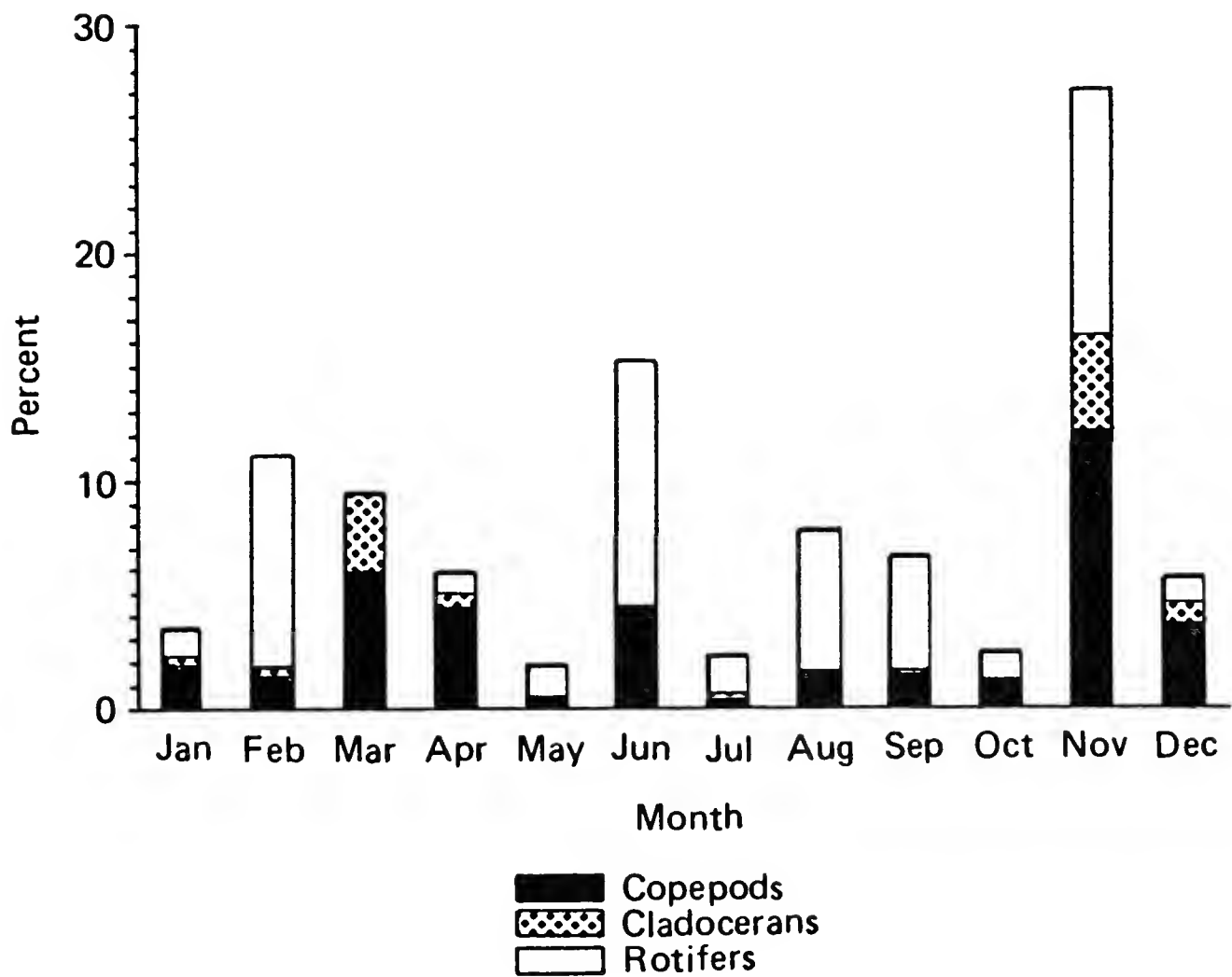


Fig. 3. Percent composition of total zooplankton density by major taxa groups for Sutton Reservoir during 1985.

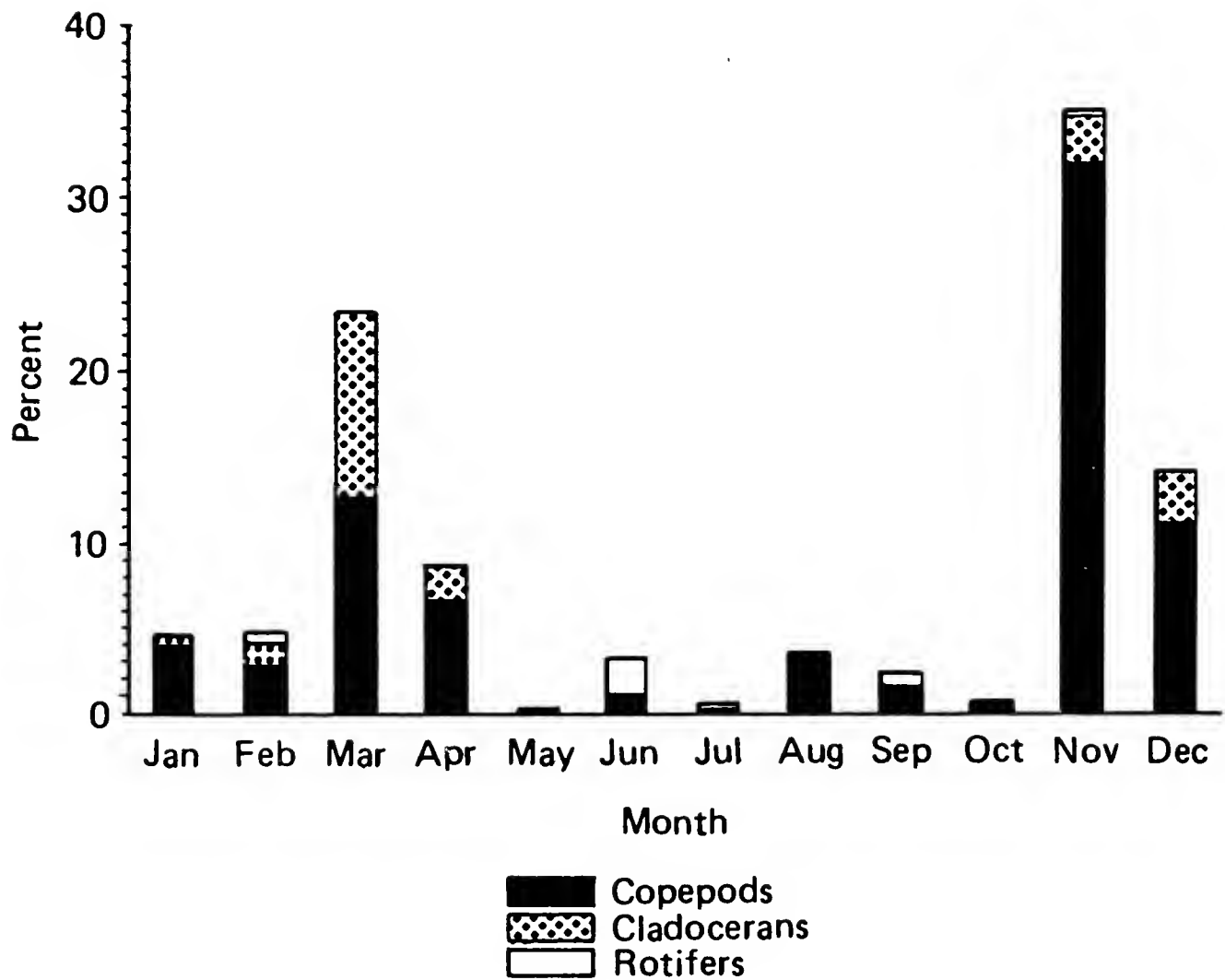


Fig. 4. Percent composition of total zooplankton biomass by major taxa groups for Sutton Reservoir during 1985.

biomass was composed mainly of *Diaptomus dorsalis*, *Daphnia ambigua*, *B. coregoni*, and *Mesocyclops edax*.

Comparisons were made to determine if there were differences between the pelagic and near-shore zooplankton communities. The trap sampling method was designed to capture typical planktonic species, and therefore the common littoral taxa associated with the benthos or littoral zone were not sampled. The results indicated that significantly greater densities of copepods and rotifers were captured at Station 6B, the pelagic location, than at 6C, the near-shore sampling station (Fig. 5). These differences were a result of greater densities of the copepods *Eurytemora affinis* and *Diaptomus dorsalis* and the rotifers *Brachionus havanaensis*, *B. plicatilis*, *Keratella americana*, *K. cochlearis*, and *K. valga* in midwater as opposed to near shore.

The interesting ecological situation of Sutton Reservoir is illustrated by its zooplankton taxonomic composition. The taxonomic composition of the zooplankton is probably a result of the estuarine influence from the makeup water and the reservoir's coastal geographical location. The two principal copepods, *D. dorsalis* and *E. affinis*, have not been

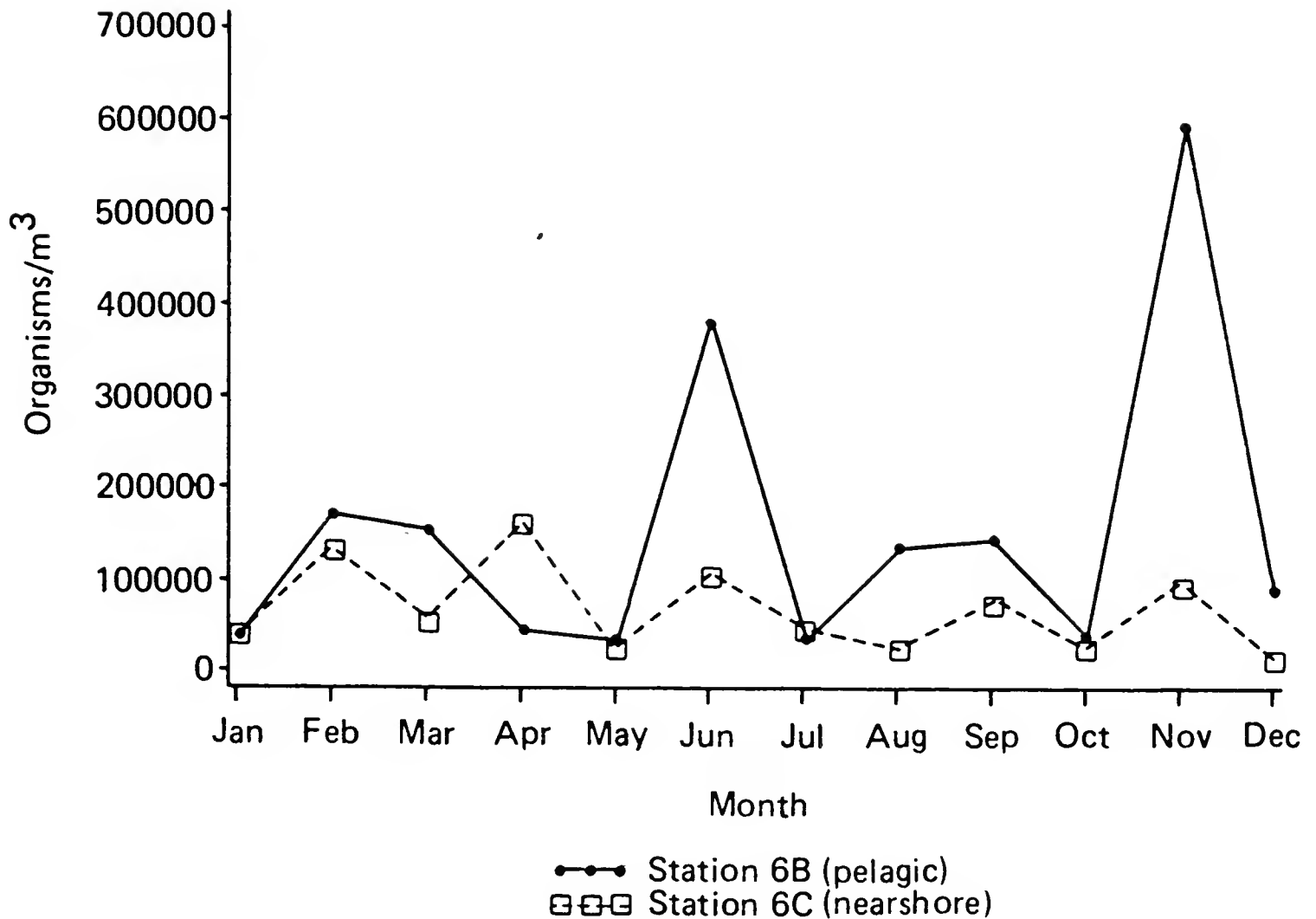


Fig. 5. Total zooplankton densities by station for Sutton Reservoir during 1985.

described in the literature from North Carolina reservoirs. *Diaptomus dorsalis* is typically found in states in the Gulf of Mexico region (Wilson and Yeatman 1959). *Eurytemora affinis* is a variable marine form found in North Carolina estuaries (Peters 1968), and its presence in Sutton Reservoir is undoubtedly related to the estuarine influence of the lower Cape Fear River. The cladocerans were mostly typical species of North Carolina reservoirs with the exception of *Ceriodaphnia quadrangularis*. *Ceriodaphnia reticulata* or *C. lacustris* are usually the members of that genus reported from reservoir surveys of this area (Coker 1928, Weiss et al. 1975, DPC 1977, Mallin 1986).

The taxa of rotifers found in Sutton Reservoir are normally present in North Carolina reservoirs, but there were differences in the dominant taxa. Members of the genus *Brachionus* have been noted in low densities in several impoundments, but in Sutton Reservoir this genus was dominant in the rotifer community. Some species of this genus found in Sutton Reservoir, *B. quadridentatus* and *B. plicatilis*, are abundant in salt or brackish water (Edmondson 1959). The appearance of these two taxa coincided with an increase in chloride from 160 mg/l

in April to 260 mg/l in July. The lack of taxonomic information in the literature regarding other coastal-plain systems makes comparisons difficult.

A strong phytoplankton-zooplankton interaction was suggested by temporal population dynamics in Sutton Reservoir during 1985 (Fig. 2, 3, and 4). Based on the apparent inverse relationship shown on the density figures, zooplankton grazing appeared to be a major factor regulating the phytoplankton. To test this relationship, correlation analyses were determined between important zooplankton and phytoplankton taxa groups (Table 5). Copepods, cladocerans, and selected individual filter-feeding cladoceran taxa displayed significant linear inverse relationships with total phytoplankton, Chlorophyceae, and Cyanophyceae. These inverse relationships, along with the taxa of phyto- and zooplankton present, suggest grazing was a controlling factor in phytoplankton population dynamics. The chlorophyceae was dominated by small, naked cells or flagellates such as *Chlamydomonas*, *Chlorella*, and *Selenastrum*, which are considered easily accessible food for filter-feeding crustaceans and are suppressed during grazing (Porter 1977, Vyhnalek 1983). The Chlorophyceae increased from 175 units/ml in April to 995 units/ml in May, concomitant with a major crustacean zooplankton decline (Table 2). The Cyanophyceae also showed a major summer increase, but grazing is probably not a major controlling factor for blue-greens, as members of this group are often difficult for zooplankton to ingest and digest (Porter 1977). Increased water temperatures (Tilman and Kiesling 1984, Lamberti and Resh 1985) or nutrient availability (Tilman et al. 1986) are more probable Cyanophyte controls in Sutton Reservoir.

#### SUMMARY

Sutton Reservoir is an estuarine-influenced coastal-plain system. Phytoplankton densities in 1985 were low to moderate and dominated by the Chlorophyceae and Cryptophyceae. A mean chlorophyll *a* value of 5.7  $\mu\text{g/l}$  suggests a mesotrophic state for this system.

The zooplankton taxonomic composition was unusual compared with other North Carolina reservoirs and was probably a result of the estuarine influence of makeup water from the lower Cape Fear River and the reservoir's geographic location. Dominant crustacean taxa were *Diaptomus dorsalis* and *Eurytemora affinis* of the copepods and *Daphnia ambigua* and *Bosmina coregoni* of the cladocerans. Rotifers were dominated by various members of the Brachionidae. Densities were high relative to other North Carolina impoundments and were dominated by rotifers. Zooplankton biomass was comparatively low and dominated by the crustaceans.

Table 5. Results of correlation analyses between biomass of selected zooplankton taxa, densities of selected phytoplankton taxa, and water temperature, at Sutton Reservoir during 1985.

	Total phytoplankton	Chlorophyceae	Cyanophyceae	Water temp.
Copepoda	-0.72 0.008	-0.60 0.038	-0.60 0.037	-0.57 0.04
Cladocera	-0.75 0.005	-0.76 0.004	-0.77 0.003	-0.65 0.020
Rotifera	0.57 0.051	0.62 0.032	0.45 0.139	0.26 0.415
<i>D. ambigua</i>	-0.82 0.001	-0.75 0.005	-0.73 0.007	-0.57 0.054
<i>B. coregoni</i>	-0.66 0.018	-0.36 0.253	-0.45 0.14	-0.37 0.228
Water temp.	0.43 0.159	0.71 0.009	0.93 0.001	1.00 0.000

\*Results listed as correlation coefficients (r)/probability (p)

Significantly greater densities of copepods and rotifers were captured at a pelagic station as opposed to near shore. This was a result of greater densities of *E. affinis* and *D. dorsalis* of the copepods and *Brachionus havanaensis*, *B. plicatilis*, *Keratella americana*, *K. cochlearis*, and *K. valga* at the pelagic station.

Correlation analyses indicated a strong, inverse relationship between crustacean zooplankton (copepods and cladocerans) and phytoplankton. Zooplankton grazing is suggested as a major controlling factor for phytoplankton population dynamics with water temperature or nutrient availability probably controlling the cyanophyceae.

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# Reproductive Biology of the Brown Water Snake, *Nerodia taxispilota*, in Central Georgia

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**ABSTRACT.**— The brown watersnake, *Nerodia taxispilota*, is a large, conspicuous, aquatic snake that occurs over much of the southeastern Coastal Plain of the United States. At sexual maturity, females are considerably larger in body length and mass than males. Males are sexually mature at 2½ years of age and approximately 58 cm SVL. Females mature a year later at 85 to 90 cm SVL. Courtship occurs in late April and early May, and may involve more than one male per female. The young are born from late August to early September. Litter size varied from 14 to 45 and was positively correlated with the SVL of the female.

The natural history of many North American snakes remains poorly known. Reasons for this include their relatively low population densities, their secretive behaviors, and the seasonality of their activity patterns. The brown water snake, *Nerodia taxispilota* (Holbrook), occurs in the southeastern United States from Virginia to southern Alabama (Conant 1975). The species is one of the largest members of the genus and occurs in relatively high densities along many of the river-swamps of central Georgia. These characteristics coupled with strong arboreal basking tendencies make it an ideal subject for life history studies. This report describes the growth and reproductive biology of *N. taxispilota* in central Georgia.

## MATERIALS AND METHODS

The study was conducted in two parts. From July 1976 through July 1977, specimens (n = 59; 33 males, 26 females) were collected from the Oconee, Ogeechee, and Flint river drainages. Snakes were sexed, measured (snout-vent length = SVL, tail length = TL) to the nearest mm, and weighed to the nearest 0.1 g; their reproductive tracts were examined following dissection. Reproductive data recorded for males were the size and wet weight of the testes ( $\pm 10$  mg). A testis and ductus deferens were fixed in a 10% formalin solution, embedded in paraffin, sectioned at 6 to 8 ( $\mu$ m), and stained with Harris's hematoxylin and eosin (Luna 1968). Sections were examined microscopically (100-400X) for the presence of spermatozoa and stage of spermatogenesis. Female reproductive tracts were examined with a dissecting microscope; the number and length of ovarian follicles, embryos, or both were recorded.

Between March 1977 and May 1981, I monitored a separate population of *N. taxispilota* by mark-recapture techniques. The study area was along a 900-m section of Commissioner Creek (Oconee River tributary), 0.5 km N of Toombsboro, Wilkinson County, Georgia. At this location, the creek is approximately 20 m wide and has a maximum depth of 3 m. Numerous shallow oxbows and water-filled depressions occur adjacent to the study area. The predominant woody vegetation bordering the creek consists of tupelo (*Nyssa aquatica*), sweet gum (*Liquidambar styraciflua*), bald cypress (*Taxodium distichum*), and alder (*Alnus serrulata*).

I visited this site approximately four times per month from March through October during 1977 and 1978. The frequency of visits was reduced to monthly during 1979 and continued at this rate through May 1981. Using a canoe, I attempted to capture each specimen sighted. Once captured, snakes were sexed, measured (SVL and TL), and individually marked by clipping subcaudal scales (Blanchard and Finster 1933). Adults were examined for evidence of recent courtship activities by swabbing the interior of the cloaca (Fukada 1959). I palpated adult females for enlarged ovarian follicles or embryos and checked for the presence of cloacal plugs (Devine 1975). Most snakes were released near the point of capture within 24 hours.

Eleven adult females captured outside the study area were maintained in captivity for up to 6 months, and five of these produced litters. Newborn snakes were measured and weighed as described above, and released in the study area. Growth rates were determined from recaptures and were calculated on the basis of an 8-month (240-day) annual growth period, assuming no growth occurred during hibernation.

Where statistical treatment of data is provided in the text, the mean value is followed by  $\pm 1$  standard deviation. Statistical comparisons were made using the student's *t* test (Steel and Torrie 1980).

## RESULTS AND DISCUSSION

*Body size.* The ratio of TL/total length was significantly greater in males ( $\bar{x} = 0.257 \pm 0.002$ ,  $n = 50$ ) than in females ( $\bar{x} = 0.235 \pm 0.001$ ,  $n = 59$ ,  $t = 6.2$ ,  $p < 0.01$ ). However, at maturity females are longer (SVL and total length) and heavier than males (Fig.1). I calculated allometric equations separately for each sex in the form of  $y = ax^b$ , where  $y$  = body weight (kg),  $x$  = SVL (m), and  $b$  = a derived constant. These equations were  $0.47 \times 3.12$  and  $1.47 \times 2.89$ , for males and females, respectively. These compare favorably to the equation  $y = 0.50 \times 3.13$  derived by Kaufman and Gibbons (1975) for combined sexes of *N. taxispilota* from western South Carolina. Semlitsch and Gibbons (1982) suggest that there is strong selection in females for increased body size to allow production

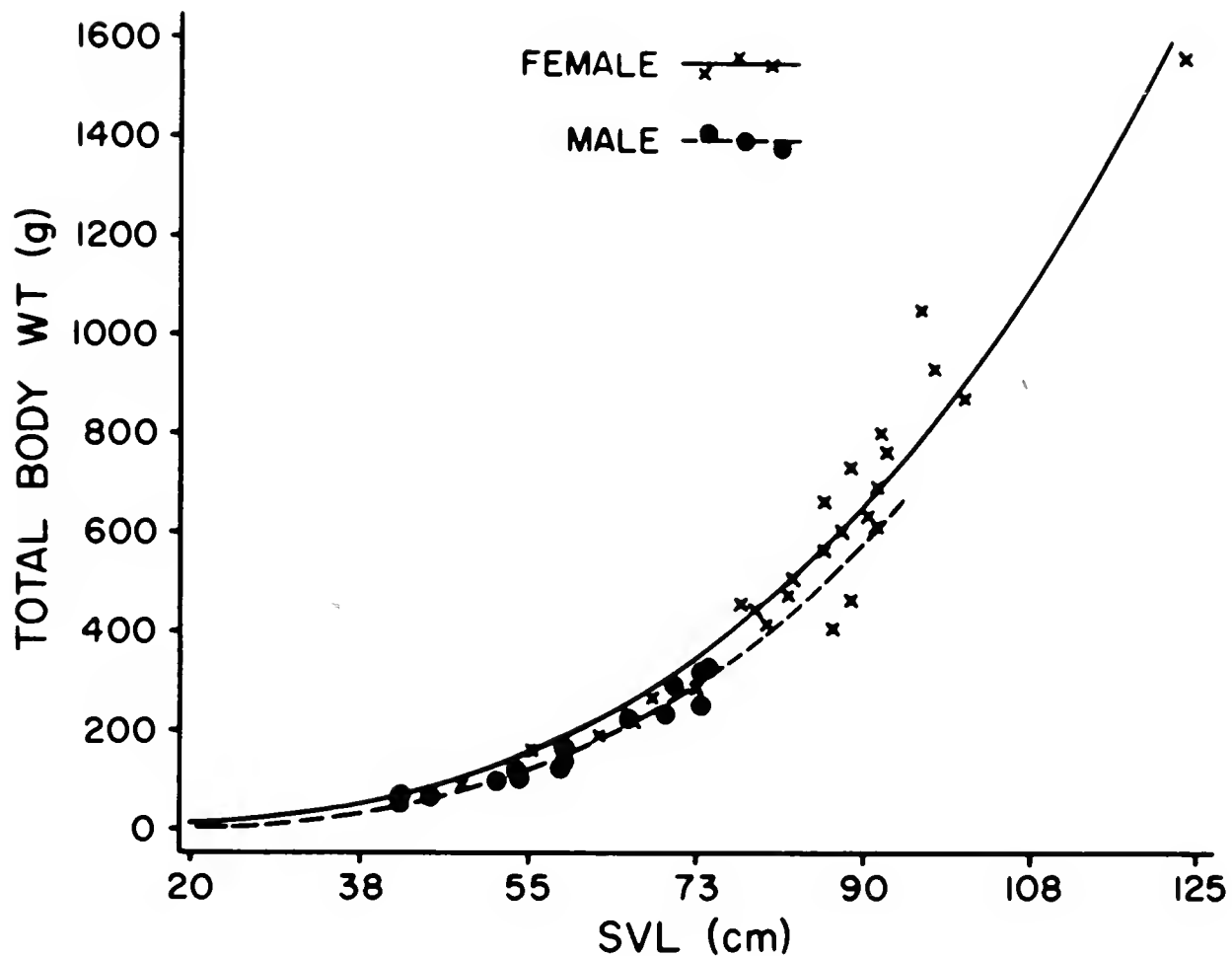


Fig. 1. Relationship between SVL and total body weight for male (solid circles) and female (x) *Nerodia taxispilota* from central Georgia.

of larger clutches, but selection for increased body size in males is weak or absent. My data are consistent with this hypothesis, but other hypotheses such as partitioning of food resources by prey size are possible. The largest male and female examined from central Georgia were 86 and 124 cm SVL, respectively, and six of 74 females (8.7%) exceeded 100 cm SVL.

*Growth.* The age/size-class structure of the mark-recapture population was determined by plotting the SVL of all specimens collected during April and May as a histogram (Fig. 2A) and transforming these values onto probability paper as described by Harding (1949). Because only mark-recapture data can positively age individual specimens, Figure 2B indicates the most likely age/size-class assignments based on the probability plot.

Five litters of *N. taxispilota*, totaling 83 individuals, were born in captivity. Newborn snakes had a mean SVL of  $23.3 \pm 0.1$  cm and weighed  $10.9 \pm 0.1$  g. Under natural conditions little growth occurred before hibernation, and the following spring this group emerged from hibernation with SVLs from 23 to 26 cm. One newborn snake marked on 14 September 1976 had grown only 0.4 cm (SVL) when recaptured on 16 March 1977.

Snakes in their first full season of activity were better represented in spring samples because they became progressively more difficult to locate as vegetation density increased from spring to summer. However, during 1977, specimens from 23 to 33 cm SVL were collected between March and August and are considered to represent first-year individuals. Growth rates from recaptures ( $n = 4$ ) averaged  $9.6 \pm 4.1$  cm per season (range 3.8 to 13.6 cm).

An additional cohort was apparent in the spring with SVLs ranging from 39 to 53 cm. These snakes were approximately 19 months old and beginning their second full season of activity. Growth appears to be rapid during this period, but no recaptures were recorded for this size group.

Specimens in their third full season of activity emerged with a modal SVL of 62 cm. Recaptured males ( $n = 2$ ) grew at a rate of 4.0 to 19.1 cm SVL per season (mean = 13.0 cm). Two females in this size class were recaptured; one had increased only 0.2 cm after 6 weeks, whereas the second had grown 3.8 cm SVL in 7 weeks (21.7 cm per season).

Males in the next larger size class ( $n = 6$ ) increased in SVL from 2 to 4 cm per season (mean =  $3.2 \pm 1.8$  cm), while females in the same cohort ( $n = 3$ ) maintained growth rates that averaged  $12.2 \pm 2.8$  cm per season. A reduction in female growth rates with the attainment of sexual maturity is suggested by data on recaptures. Growth of three measured in their fourth season of activity ranged from 8.8 to 13.6 cm SVL per season (mean =  $11.0 \pm 2.4$  cm). In the next larger size class ( $n = 4$ ) growth was reduced to 3.2 to 6.4 cm SVL per season (mean =  $5.7 \pm 2.0$  cm).

*Reproduction.* In central Georgia, males are sexually mature when they emerge from their third period of hibernation and are approximately 58 cm SVL. All males in this or larger size classes ( $n = 13$ ) had spermatozoa present in the ductus deferens irrespective of the month in which they were collected. Spermatozoa were much more numerous in late fall and spring than at other times of the year. This agrees with observations of Mitchell and Zug (1984) for *N. taxispilota* in Virginia. Two slightly smaller males (53 and 56 cm SVL) collected during September had traces of sperm in their ductus deferens. Thus, size at maturity of males from central Georgia is comparable to the 50.3-cm size at maturity in Virginia (White et al. 1982).

Females are sexually mature between 85 and 90 cm SVL. The largest immature female (92.5 cm SVL) was collected during August, and the smallest mature female (86.0 cm SVL) gave birth in captivity. The minimum size at maturity observed during this study (86 cm SVL) is larger than that reported by White et al. (1982) for this species in Virginia (72.5 cm SVL). During late summer a total of 12 females (70-80

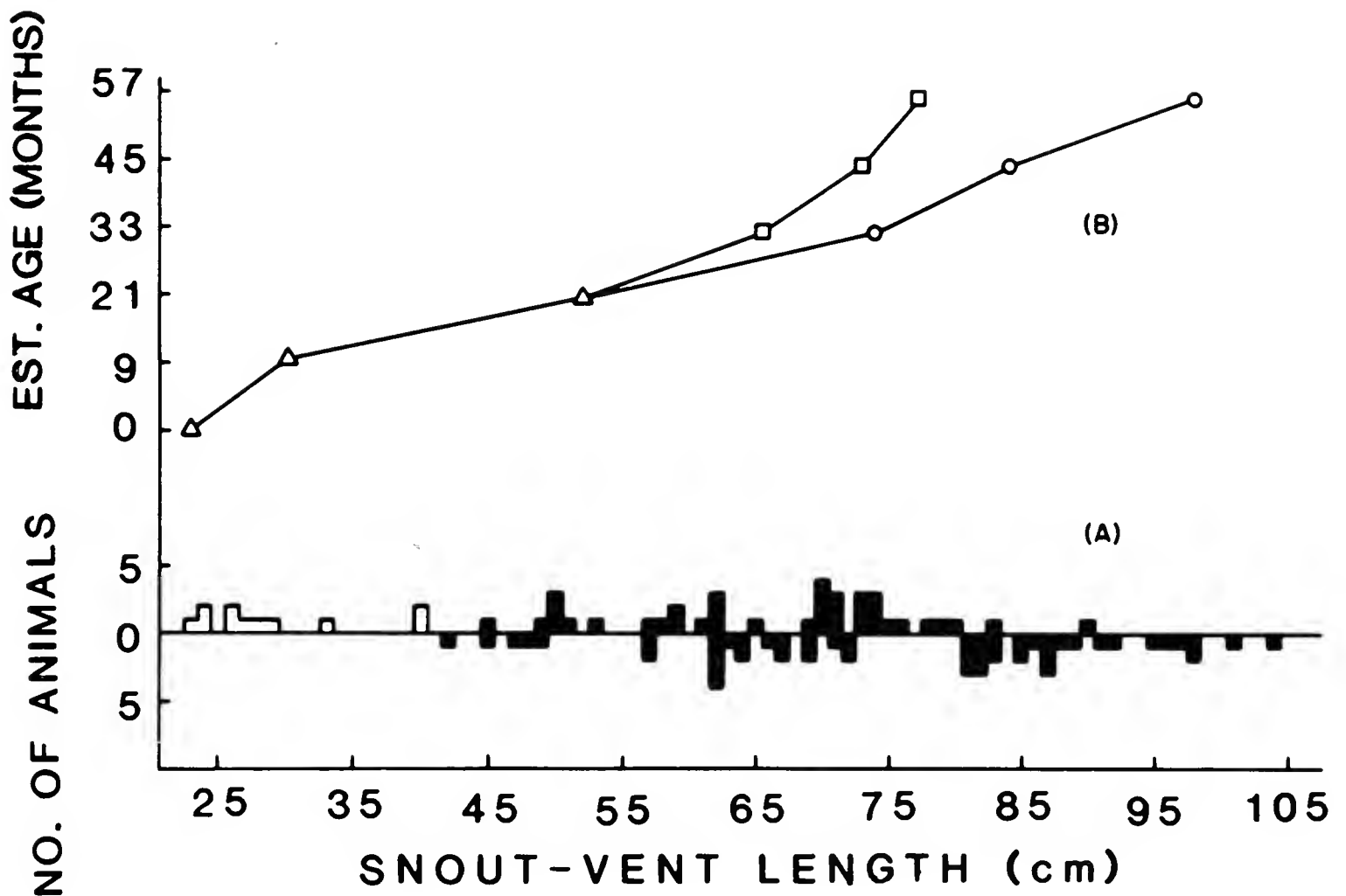


Fig. 2. Size-class structure for spring (April-May) *Nerodia taxispilota* population: (A) Histogram of SVLs: males (solid bars) and juveniles (open bars) above the line and females (solid bars) below the line. (B) Probable age-class assignments for the same population, redrawn from a cumulative percent plot on probability graph paper: juveniles = triangles, males = squares, and females = open circles.

cm SVL) were either dissected or palpated in the field, and none contained enlarged follicles or embryos. The larger size at maturity for Georgia females may be the result of differences in growth rate or in the age at maturity.

Macroscopic changes in the ovaries of *N. taxispilota* from central Georgia are similar to those described by Betz (1963) for *N. rhombifera*, by Bauman and Metter (1977) and Aldridge (1982) for *N. sipedon*, and by White et al. (1982) for other populations of *N. taxispilota*. Ovarian follicles gradually enlarge with increasing SVL in immature snakes. Females in the second full season of activity had ovarian follicles less than 3.0 mm in length. The following year follicles had increased to between 5 and 9 mm in length. Females are sexually mature at the beginning of their fourth full season of activity (approximately 43 months old). Vitellogenesis occurs rapidly, with follicle lengths often exceeding 20 mm prior to ovulation. Ovulation apparently occurs from

late May to early June, but no adult females were available for dissection during this period. However, ovulation did not begin earlier than late May and was completed by early July. White et al. (1982) found that ovulation occurred during late June in Virginia.

No observations have been reported concerning courtship in *N. taxispilota*. Between 24 April and 5 May 1979, four instances of courtship activities were observed. In three of these, single females were observed in close association with two to three males. All groups were located on tree limbs that were 33 to 63 cm above the water surface. Three of the four females were collected, and each had abundant sperm in cloacal smears. Two of these females and three additional specimens collected during May had in their cloacas gelatinous, semirigid structures resembling sperm plugs (Devine 1975). These observations suggest that multiple male courtship may be common in *N. taxispilota*. Multiple male courtship was reported for *N. sipedon* by Mushinsky (1979).

Mating activities were centered between late April and early May. No sperm were detected in cloacal smears of 18 mature females before mid-April; however, between mid-April and mid-May, eight of ten mature females contained sperm in cloacal smears. Six adult females collected prior to 15 April and maintained in captivity failed to produce young that year, presumably because mating had not occurred prior to capture. No evidence of fall matings was observed in cloacal smears taken from 29 adult females sampled during September and October.

Parturition occurred in captivity between 27 August and 9 September. Litter size was 16, 14, 26, 13, and 14, for females that were 86, 88, 94, 95, and 101 cm SVL, respectively. The earliest appearance of a newborn specimen in the field was on 21 August 1977. Fecundity, including the number of fetuses as well as the number of enlarged ovarian follicles, ranged from 14 to 45 and was positively correlated with the female SVL ( $r = 0.77$ ), with SVL explaining 59% of the variation. This agrees with the corresponding correlation coefficient of  $r = 0.78$  reported by Semlitsch and Gibbons (1978) for *N. taxispilota* from western South Carolina.

Females apparently produce litters annually once sexual maturity is reached. All females that were at least 92 cm SVL had either enlarged ovarian follicles or embryos present, and at least four females were known to have been gravid in consecutive years.

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# Movements of Land-based Birds Off the Carolina Coast

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*ABSTRACT.*— Although the occurrence of land-based birds at sea during migration periods is well known, relatively little information is available on the species composition of the flocks detected by radar. This paper lists 96 species documented from the offshore waters of North and South Carolina, offers evidence for offshore movements by groups of birds other than nocturnal migrants, and suggests temporal changes in flock composition.

It is well known that land-based birds regularly occur at sea during migration periods, when flocks of birds or individual birds deliberately or accidentally take oceanic routes. Various authors have demonstrated (through personal observation and radar studies) that offshore movement of nocturnal migrants occurs in the North Atlantic on a regular basis (Scholander 1955; Drury and Keith 1962; Williams et al. 1977; Davis 1978; McClintock et al. 1978; Richardson 1978, 1980; Larkin et al. 1979; Cherry et al. 1985; Williams 1985). Nisbet (1970) and others have proposed that a long, over-water flight crossing the Atlantic directly to South America is a normal and deliberate route for some species (e.g., Blackpoll Warbler). Although fall movements over the western North Atlantic Ocean have been documented, there is relatively little information on the species composition of the migrant clouds detected. Furthermore, individual records of land-based birds found at sea generally have gone unrecorded and unreported. Here we identify some of the offshore migrants, present evidence for offshore movements by groups of birds other than nocturnal migrants, and suggest temporal changes in flock composition.

Our sightings of land-based birds were for the most part recorded incidental to studies of seabirds during the 10-year period from 1975 to 1986. They were made primarily 10 to 55 miles (16-88 km) off the North Carolina coast between 30° and 35°N. Sightings were made without optical aids, but identifications were often made with binoculars. It should be emphasized that many land-based birds observed at sea could not be specifically identified because of distance, boat movement, atypical flight postures resulting from strong winds, and other adverse conditions. We estimate that 55% of the land-based birds seen in flight disappeared from the field of vision before they could be identified.

Therefore, we are unable to present data indicative of the actual numbers of birds encountered or of the species' relative abundance, and comparison of tallies between trips is meaningless.

In the species list given below, observations are from off coastal North Carolina unless otherwise indicated (SC = South Carolina). Most records are from Lee's 130 survey trips conducted in charter fishing boats off Oregon Inlet, Dare County, N.C., but additional published and unpublished records are included. Reports with incomplete data are mentioned only when no other evidence is available to document the species' occurrence off the Carolina coast. Sightings for each species are arranged by day and month. When more than a single bird was seen, the number observed is presented in parentheses. Precise latitude and longitude as determined by LORAN instruments are available for most of Lee's records, but these data have been omitted in the interest of brevity. For selected species, distances from shore have been provided.

#### LAND-BASED BIRDS SEEN OFFSHORE

##### PODICIPEDIFORMES

Pied-billed Grebe (*Podilymbus podiceps*): 19 July 1977 (NCSM 6167), 39 miles ESE Oregon Inlet; 10 August 1977, 30 miles E Oregon Inlet.

##### PELECANIFORMES

Brown Pelican (*Pelicanus occidentalis*): Summer 1976. Foraging flocks approximately 50 miles SE Beaufort.

Double-crested Cormorant (*Phalacrocorax auritus*): 3 November 1979 (100 fathom contour).

##### CICONIIFORMES

Great Blue Heron (*Ardea herodias*): 15 October 1979, 16 October 1979, 5 November 1979, 5 December 1985.

Snowy Egret (*Egretta thula*): 4 October 1980 (9), Chat 45:54.

Little Blue Heron (*Egretta caerulea*): 4 October 1980, Chat 45:54.

Cattle Egret (*Bubulcus ibis*): 27 April 1968, Chat 33:102; 9 September 1979 (40); 7 October 1975 (SC).

##### ANSERIFORMES

Northern Pintail (*Anas acuta*): Fall 1983 or 1984 (flock).

Blue-winged Teal (*Anas discors*): 27 August 1979, 1 September 1979 (4), 8 September 1979.

Lesser Scaup (*Aythya affinis*): 5 November 1979.

White-winged Scoter (*Melanitta fusca*): 6 September 1981 (6), Chat 46:47.

Red-breasted Merganser (*Mergus serrator*): 16 March 1984 (12+), 28 April 1983 (4), 19 May 1982 (3).

## FALCONIFORMES

- Osprey (*Pandion haliaetus*): 21 June 1985 (4), 30 September 1979.  
 Northern Harrier (*Circus cyaneus*): 4 October 1980, Chat 45:54.  
 Sharp-shinned Hawk (*Accipiter striatus*): 29 September 1979, 30 September 1979, 1 October 1979 (2), 12 October 1975.  
 American Kestrel (*Falco sparverius*): Fall, Kerlinger et al. 1983.  
 Merlin (*Falco columbarius*): 10 September 1979, 30 September 1979.  
 Peregrine Falcon (*Falco peregrinus*): 28 September 1979; 30 September 1979; 2 October 1979; 4 October 1980, Chat 45:54; 7 October 1985 (SC); 20 October 1982.

## GRUIFORMES

- Clapper Rail (*Rallus longirostris*): 1 September 1979.  
 King Rail (*Rallus elegans*): 9 September 1979, ca. 50 miles E Core Banks.  
 Purple Gallinule (*Porphyryla martinica*): 19 August 1978.  
 American Coot (*Fulica americana*): 12 October 1975, 16 October 1979.

## CHARADRIIFORMES

- Black-bellied Plover (*Pluvialis squatarola*): 27 August 1979 (5).  
 Lesser Golden-Plover (*Pluvialis dominica*): 8 September 1979 (7), 15 October 1979.  
 Semipalmated Plover (*Charadrius semipalmatus*): 1 September 1979, 1 September 1984 (2).  
 Greater Yellowlegs (*Tringa melanoleuca*): 31 July 1984 (flock), 24 August 1979 (9).  
 Solitary Sandpiper (*Tringa solitaria*): 27 August 1979 (SC), 28 August 1979 (2), 1 September 1979 (2).  
 Willet (*Catoptrophorus semipalmatus*): 16 August 1984 (flock).  
 Spotted Sandpiper (*Actitis macularia*): 1 September 1985 (SC).  
 Whimbrel (*Numenius phaeopus*): 19 May 1982.  
 Ruddy Turnstone (*Arenaria interpres*): 16 May 1979, 8 September 1979.  
 Red Knot (*Calidris canutus*): August 1984 (flock).  
 Sanderling (*Calidris alba*): 22 May 1980, 7 September 1979 (4).  
 Semipalmated Sandpiper (*Calidris pusilla*): 1 September 1979, 1 September 1985 (SC).  
 Least Sandpiper (*Calidris minutilla*): 8 May 1980, 24 August 1979, 1 September 1979.  
 Stilt Sandpiper (*Calidris himantopus*): 24 August 1979.  
 Short-billed Dowitcher (*Limnodromus griseus*): 28 August 1979; 4 October 1980, Chat 45:54. [Dowitcher sp.: 24 August 1979 (10)].

## COLUMBIFORMES

Mourning Dove (*Zenaida macroura*): 2 October 1979, (2); 4 October 1980, Chat 45:54; 8 October 1978; 15 October 1979; 16 October 1979 (2); 4 November 1979 (2); 5 November 1979.

## APODIFORMES

Chimney Swift (*Chaetura pelagica*): 29 May 1980.

## CORACIIFORMES

Belted Kingfisher (*Ceryle alcyon*): 12 July 1980, 1 September 1979, 8 September 1979, 23 September 1985 (SC).

## PICIFORMES

Red-headed Woodpecker (*Melanerpes erythrocephalus*): 28 April 1983, 32 miles ESE Oregon Inlet.

Downy Woodpecker (*Picoides pubescens*): 6 August 1981, 30 miles ESE Oregon Inlet.

Northern Flicker (*Colaptes auratus*): 2 October 1979, 12 October 1975, 15 October 1979.

## PASSERIFORMES

Acadian Flycatcher (*Epidonax virescens*): 31 August 1977, 1 September 1979.

Least Flycatcher (*Epidonax minimus*): September, Scholander 1955.

"Tropical" Kingbird (*Tyrannus [melancholicus or couchii]*): 1 September 1985 (SC).

Tree Swallow (*Tachycineta bicolor*): 19 April 1980, 1 September 1979, 12 October 1975.

Bank Swallow (*Riparia riparia*) 30 August 1985.

Cliff Swallow (*Hirundo pyrrhonota*) 24 August 1979.

Barn Swallow (*Hirundo rustica*): 29 April 1980, 8 May 1980, 10 May 1978, 16 May 1979, 18 May 1977, 20 May 1977 (5), 22 May 1980, 5 August 1981, 7 August 1984, 9 August 1983, 9 August 1984, 10 August 1984 (2), 23 August 1979, 24 August 1979 (5), 26 August 1975, 27 August 1979 (3, SC), 29 August 1985.

American Crow (*Corvus brachyrhynchos*): 1 November 1979.

Red-breasted Nuthatch (*Sitta canadensis*): 9 September 1981 (2), Chat 46:74.

Brown Creeper (*Certhia americana*): 15 October 1979.

House Wren (*Troglodytes aedon*): 8 October 1978, 12 October 1985 (3), 15 October 1979, 16 October 1979.

Golden-crowned Kinglet (*Regulus satrapa*): 12 October 1985, 4 November 1979.

Ruby-crowned Kinglet (*Regulus calendula*): 12 October 1985, 15 October 1979.

- Gray Catbird (*Dumetella carolinensis*): 7 October 1985 (SC), 15 October 1979 (2), 16 October 1979.
- Cedar Waxwing (*Bombycilla cedrorum*): 15 October 1979 (4).
- European Starling (*Sturnus vulgaris*): 16 March 1984, 1 November 1979 (2), 4 November 1979 (2).
- Orange-crowned Warbler (*Vermivora celata*): 1 September 1985 (SC).
- Nashville Warbler (*Vermivora ruficapilla*): 24 September 1985.
- Yellow Warbler (*Dendroica petechia*): 1 September 1979, 9 October 1987.
- Cape May Warbler (*Dendroica tigrina*): 1 September 1979 (6); 7 September 1979; 8 September 1979 (8); 10 September 1981 (4), Chat 46:74; 27 September 1979 (2); 15 October 1979; 16 October 1979 (2). The six birds on 1 September 1979 represent early migrants.
- Black-throated Blue Warbler (*Dendroica caerulescens*): 1 September 1979; 10 September 1981 (2), Chat 46:74; 9 October 1987. September first is an extremely early migrant record.
- Yellow-rumped Warbler (*Dendroica coronata*): 12 October 1985 (2), 15 October 1979 (8), 16 October 1979 (5, two different boats), 25 October 1985 (2), 2 November 1979.
- Black-throated Green Warbler (*Dendroica virens*): 10 September 1981 (4), Chat 46:74; 7 October 1985 (SC).
- Yellow-throated Warbler (*Dendroica dominica*): 7 October 1985 (SC).
- Prairie Warbler (*Dendroica discolor*): 2 September 1979.
- Palm Warbler (*Dendroica palmarum*): 24 September 1985; 27 September 1979 (3); 28 September 1979; 2 October 1979; 4 October 1980, Chat 45:54; 7 October 1985 (5, SC); 15 October 1979 (3); 16 October 1979 (2).
- Bay-breasted Warbler (*Dendroica castanea*): 9 October 1987, 15 October 1979, 16 October 1979 (2).
- Blackpoll Warbler (*Dendroica striata*): 15 October 1979 (6), 16 October 1979 (2).
- Black-and-white Warbler (*Mniotilta varia*): October, Scholander 1955.
- American Redstart (*Setophaga ruticilla*): 8 September 1979; 10 September 1979; 10 September 1981, Chat 46:47; 29 September 1979; 4 October 1980, Chat 45:54; 9 October 1987; 15 October 1979. Last date represents rather late migration record for species.
- Prothonotary Warbler (*Protonotaria citrea*): 1 September 1979, 7 September 1979.

- Northern Waterthrush (*Seiurus noveboracensis*): 9 August 1984, 30 August 1985. 1 September 1979, 10 September 1979.
- Kentucky Warbler (*Oporornis formosus*): 1 September 1985 (SC).
- Mourning Warbler (*Oporornis philadelphia*): 1 September 1979.
- Common Yellowthroat (*Geothlypis trichas*): 1 September 1979, 1 September 1984. 7 September 1979, 8 September 1979, 7 October 1985 (2, SC), 15 October 1979.
- Yellow-breasted Chat (*Icteria virens*): 7 September 1979.
- Indigo Bunting (*Passerina cyanea*): 8 May 1980, 18 May 1977 (NCSM 6145).
- Dickcissel (*Spiza americana*): October, Scholander 1955.
- Rufous-sided Towhee (*Pipilo erythrophthalmus*): 23 October 1967, Jensen and Livingstone 1969.
- Chipping Sparrow (*Spizella passerina*): 15 October 1979.
- Tree Sparrow (*Spizella arborea*): 26 April 1985 (SC), Chat 50: 55-56.
- Field Sparrow (*Spizella pusilla*): 15 October, 1979.
- Savannah Sparrow (*Passerculus sandwichensis*): October, Scholander 1955.
- Song Sparrow (*Melospiza melodia*): 15 October 1979 (5), 4 November 1979 (2).
- Swamp Sparrow (*Melospiza georgiana*): 12 October 1985.
- White-throated Sparrow (*Zonotrichia albicollis*): 12 October 1985 (3), 15 October 1979 (3).
- White-crowned Sparrow (*Zonotrichia leucophrys*): 12 October 1985, 15 October 1979 (3), 16 October 1979.
- Dark-eyed Junco (*Junco hyemalis*): 12 October 1985 (5), 15 October 1979 (3), 4 November 1979 (2).
- Lapland Longspur (*Calcarius lapponicus*): 10 May 1978. Late date for species in North Carolina; previously 9 May 1981 (Chat 45:110) was considered an extremely late date.
- Bobolink (*Dolichonyx oryzivorus*): 9 September 1979, 27 September 1979.
- Eastern Meadowlark (*Sturnella magna*): 23 October 1967, Jensen and Livingston 1969.
- Boat-tailed Grackle (*Quiscalus major*): 2 June 1984.
- Orchard Oriole (*Icterus spurius*): 23 August 1979.
- Northern Oriole (*Icterus parisorum*): 1 September 1979; 8 September 1979; 9 September 1979; 10 September 1981, Chat 46:47; 23 September 1985 (SC); 1 October 1979.

## DISCUSSION

Approximately 400 birds belonging to 12 orders and 97 species (including 52 passerine species) were recorded. The absence from our

records of several families of common East Coast migrants (e.g., thrushes and vireos) should be noted. Most of the birds seen were fall migrants (90%), and more than 60% of all activity was recorded in September and October. Only 11 species were recorded during the spring migration period. Figure 1 illustrates the documented monthly occurrence of land-based birds off the Carolinas.

Land-based migrants off the Carolina coast in August and early September are predominantly non-passerine species, primarily shorebirds. These non-passerine species dominate August migrants by 2:1 over passerine species. Passerine species become more numerous during September. Most of these early records were of neotropical migrants (Fig. 2). Furthermore, the 20 passerine species identified over the ocean between 10 August and 10 September were largely different in geographic origin from the 17 species seen between 6 October and 4 November. Among the early passerine migrants were four parulids (Prairie, Prothonotary, and Kentucky Warblers and Yellow-breasted Chat) that originate from breeding grounds restricted primarily to southeastern North America (i.e., the United States east of the Mississippi River). Their median breeding range is about 34°N. These species, which apparently fly from the northern part of their range southward over the Atlantic Ocean, have been recorded as regular, though numerically few, migrants to Bermuda (Drury and Keith 1962). Other early passerine migrants that have a similar breeding range are the Acadian Flycatcher and the Orchard Oriole. In addition, some of the other early-migrant parulids (i.e., Black-throated Blue, Black-throated Green, and Mourning Warblers) are birds that occupy intermediate-latitude breeding ranges, and individuals encountered in all likelihood originated from northern and central Atlantic States.

These early-season species contrast with late-season parulid migrants (i.e., Yellow-rumped, Bay-breasted, and Blackpoll Warblers) from northeastern North America, which occur as late as 15 October or later (Fig. 2). Each of these species comes from intermediate- to northern-latitude breeding grounds (median breeding range ca. 49°N). Also among the late-season encounters are short-distance migrants: Brown Creeper, House Wren, Gray Catbird, Golden-crowned and Ruby-crowned Kinglets, and Chipping, Field, Song, and White-throated Sparrows. Only three species were recorded during both periods: American Redstart and Common Yellowthroat, which have broad-latitude breeding ranges, and the Cape May Warbler, which breeds at the intermediate latitudes. Dates of encounters reported here are generally within the periods reported for the respective species by Sykes (1986) in his study of autumn land-bird migration along the Outer Banks of North Carolina.

Many of the birds encountered, particularly small passerines, were often near the point of exhaustion, and it was not uncommon to have

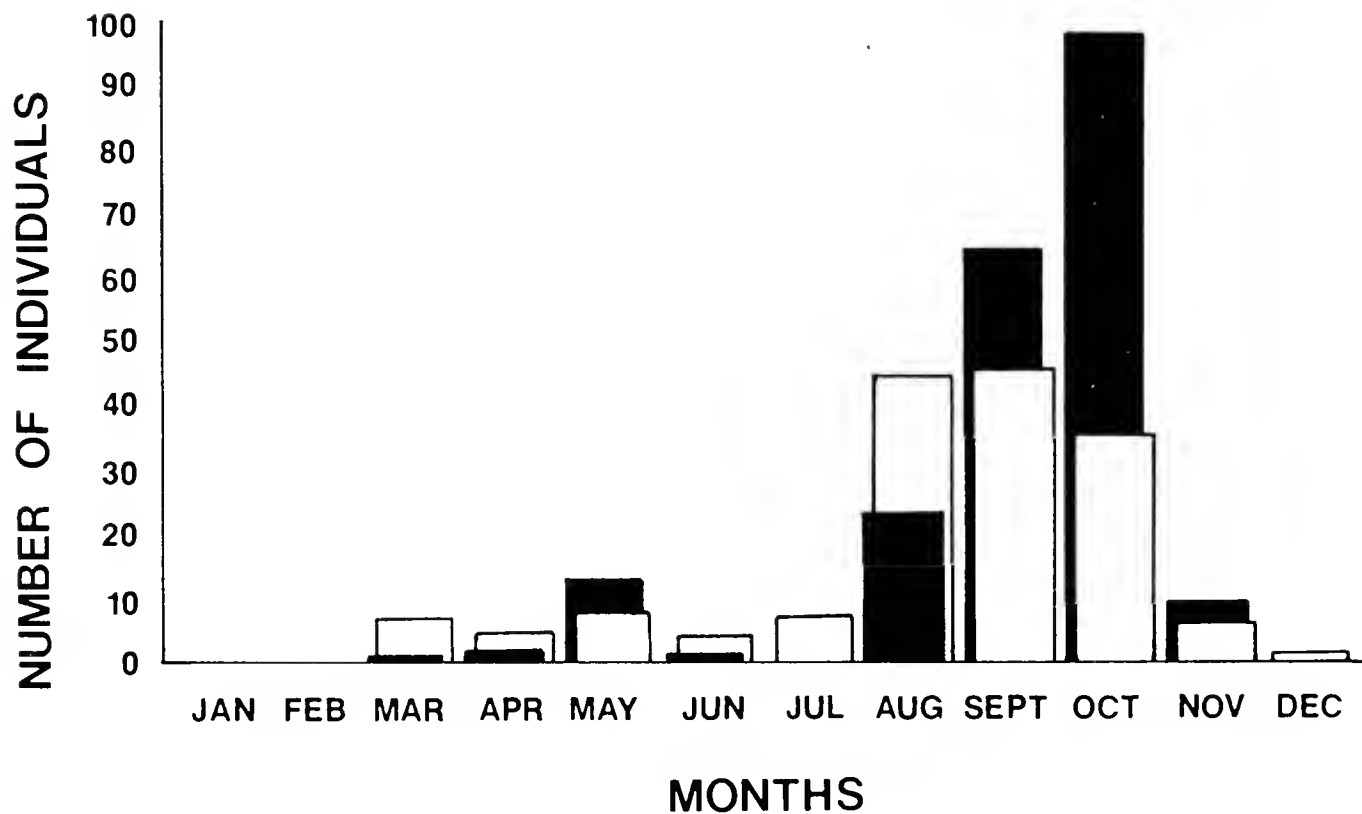


Fig. 1. Monthly occurrence of passerine (dark bars) and land-based non-passerine (light bars) birds off the Carolina coast.

them land on the boat. McClintock et al. (1978) found most of the individuals landing on ships to be emaciated immatures. On several occasions we watched warblers fall into the ocean or get caught in waves. Gulls and jaegers have been seen eating exhausted song birds, and the first Long-tailed jaeger (*Stercorarius longicaudus*) collected in North Carolina had an Acadian Flycatcher in its stomach on 31 August 1977. Once we watched a Laughing Gull (*Larus atricilla*) capture an exhausted Common Yellowthroat on the wing. It is possible that weakened migrating song birds are an important food item for jaegers at sea in fall. Although the mortality rate for offshore land-based birds may be high, scavengers and predators certainly consume most of the evidence quickly.

With the exception of the swallows and a few accidentals, we consider the records of passerines reported here to represent fallout from the offshore migrant clouds.

Our records were obtained on fair-weather days, weather conditions under which radar has often revealed large numbers of birds passing overhead. Radar studies indicate that migrants gain altitude as they move out to sea, normally flying at heights that would keep them out of view. Most passerines reported here were seen as they approached the boat; their small size prohibited our seeing distant or high-flying birds. Therefore, it is not possible to interpret the magnitude of offshore migration based on chance encounters with what probably represent



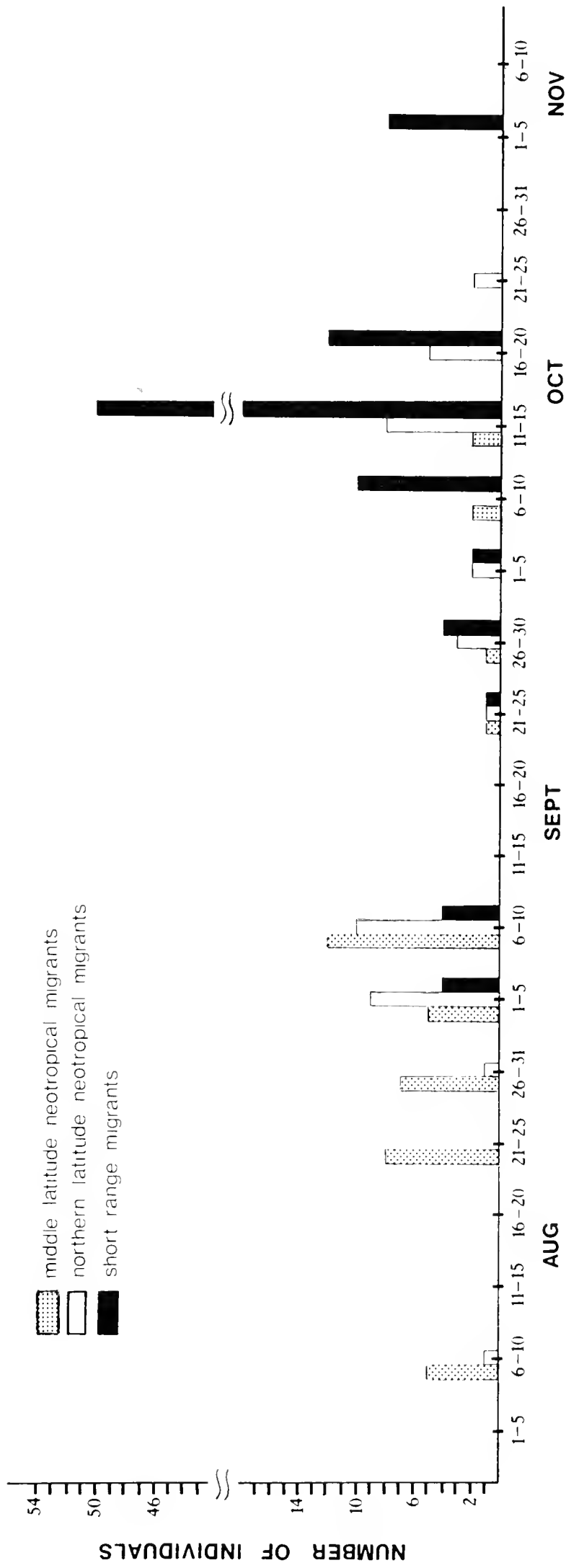


Fig. 2. Occurrence of migrant passerine birds off the Carolina coast based on origin and destination of species.

exhausted individuals or those that were unable to keep up with the migrating flocks.

Some of the hawks were observed at heights that made it difficult to see them without the aid of binoculars. Because of this, we believe that the offshore hawk movement is likely to be much more regular than is suggested here. Kerlinger et al. (1983) discussed raptor migration off the northeastern United States.

The offshore presence of sedentary species (e.g., Downy Woodpecker) is difficult to interpret; certainly, some of these birds should be regarded simply as accidentals. The occurrence of a "Tropical" Kingbird off the South Carolina coast on 1 September 1985 (Koeble, pers. comm.) is noteworthy and at present inexplicable. A tropical storm that was in the Gulf of Mexico at that time may in some way account for the bird's northward displacement. The Tropical Kingbird specimen taken at Scarborough, Maine, early in the twentieth century is of the migratory race *Tyrannus melancholicus chloronotus* (A.O.U. 1957).

Offshore movements of migrants are not limited to birds. Far offshore we have seen butterflies [sulphurs (Pieridae), several species; monarchs (Danidae), *Danus plexippus*], dragonflies [darners (Aeshnidae, *Anax*); skimmers (*Libellula* sp.); the Globe Trotter, *Pantala flavescens*, which is a cosmopolitan species], and bats. Red Bats, *Lasiurus borealis*, were seen on 21 June 1985, 2 September 1984, 9 September 1979, and 4 November 1979.

*ACKNOWLEDGMENTS.*— We thank Wayne Irvin, Steve Platania, and Mary Kay Clark for assistance during offshore trips and Capt. Allen Foreman, Charles S. Manooch III, Richard Rowlett, Paul DuMont, and Tim D. Koeble for sharing unpublished records of land-based birds at sea. Rowlett's records were particularly extensive and useful. Janet M. Williams, Sidney A. Gauthreaux, Jr., and Robert Dickerman reviewed a previous draft of the manuscript. Lee's offshore studies were financed in part by contract #92375-1130-621-16, U.S. Fish and Wildlife Service Laboratory, Slidell, Louisiana.

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*Accepted 27 August 1987*

AUTUMN LAND-BIRD MIGRATION  
ON THE BARRIER ISLANDS OF NORTHEASTERN  
NORTH CAROLINA

by

Paul W. Sykes, Jr.

For three consecutive years Sykes investigated the autumn migration of land birds in the Bodie Island and Pea Island area of coastal North Carolina. During a 102-day period in 1965, he recorded 110,482 individual birds of 148 species. He was able to correlate major influxes of migratory species with specific weather patterns. His data show seasonal peaks of southward movement for the land-bird species that pass along the North Carolina coast in large numbers. In addition, Sykes recorded five species native to the western United States. Three of these vagrants provided the first reports of Swainson's Hawk, Sage Thrasher, and Western Meadowlark for North Carolina.

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Distribution of the Southeastern Shrew,  
*Sorex longirostris* Bachman, in Western Virginia

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*ABSTRACT.*— A two-year study of the distribution and abundance of shrews was conducted in Virginia. Pitfall traps (1508 in all) were placed at 140 localities scattered around the state. *Sorex longirostris* (73 specimens) was caught at 33 of the 107 localities within its potential range (at 65% of Piedmont, 40% of Blue Ridge, 37% of Coastal Plain, and 11% of Ridge and Valley localities). Other specimens were found in museums and in bottles discarded along roadways. Altogether, 48 new localities can be added to the compilation of Pagels et al. (1982) of collecting sites of *S. longirostris* in Virginia. In the eastern lowlands *S. longirostris* frequented all habitats sampled. In the mountains it was caught mostly in fields and borders. Trapping results indicate that the species reached the Valley of Virginia through several gaps in the Blue Ridge, and that it reached southwestern Virginia through the Tennessee Valley. *Sorex longirostris* was captured with five of the other eight shrews known to occur in Virginia. It was not caught with *S. cinereus*, and its distribution west of the Blue Ridge may be limited by the presence of that species. The two exhibit contiguous allopatry, with *S. longirostris* below 457 to 610 m (depending on latitude) and *S. cinereus* above that elevation.

When we (Pagels et al. 1982) summarized the distribution of *Sorex longirostris* in the Mid-Atlantic States, we questioned earlier reports of a nearly statewide distribution in Virginia. We believed that this shrew does in fact occur throughout the Coastal Plain and Piedmont lowlands in Virginia (except on the Eastern Shore), but, although we reported it west of the Blue Ridge in Page and Warren counties, we doubted that it is widespread in the mountainous sections of the state. Specimens from Giles County (Odum 1944) had been shown to have been misidentified (French 1980a), and specimens from other montane counties, Montgomery (Handley and Patton 1947) and Augusta (Bruce 1937),

apparently had been lost and could not be re-examined. Thus, the true distribution of this shrew in western Virginia remained to be determined.

Following our earlier work on *Sorex longirostris*, Pagels conducted a more detailed field study of the distribution and ecology of shrews of all species in Virginia. He collected *S. longirostris* at many localities from which it had not been known and located previously collected specimens that add significantly to our knowledge of the range of this species in Virginia. Although we list and map all of the new localities, as an update of our earlier work (Pagels et al. 1982), our present emphasis is on the distribution of *S. longirostris* west of the Blue Ridge.

### MATERIALS AND METHODS

We placed 1508 pitfall traps (16-oz. aluminum cans) at 140 localities, mostly along highways, to form irregular transects in all five physiographic regions of Virginia (Fig. 1). The cans, partly filled with water early in the study but later with a formalin solution to help preserve the specimens, were checked approximately bimonthly for 24 months between 1983 and 1985.

Four major cover types were sampled: old field, field-forest edge, mixed forest, and hardwood forest. Within a given habitat, traps were set irregularly in the best cover rather than at fixed intervals. Because this study included all species of shrews, collecting effort sometimes was directed toward a particular species. Thus, the intensity of sampling of the various cover types was not the same in all regions.

Although we sampled 140 localities with pitfall traps, only 107 of them (52 in the Coastal Plain and Piedmont, and 55 in the mountains) were within the known range of *Sorex longirostris*. The other 33 localities were above 610 m, the upper limit of *S. longirostris* at this latitude. The boreal habitats of these elevations are not likely to be inhabited by this austral shrew. Thus, in Table 1 we listed these 33 localities as a separate division of the Ridge and Valley Province and did not include them in the distributional totals.

### COLLECTIONS

Altogether we found 115 specimens of *Sorex longirostris* at 48 localities in Virginia not listed in the compilation of Pagels et al. (1982). The 48 new localities are plotted in Figure 1, and are grouped by physiographic province in the following list of specimens (elevations in parentheses were estimated by Pagels from topographic maps).

Because of our collecting technique, the specimens could only be prepared as skulls or kept entire in 70% alcohol (skulls of some of those

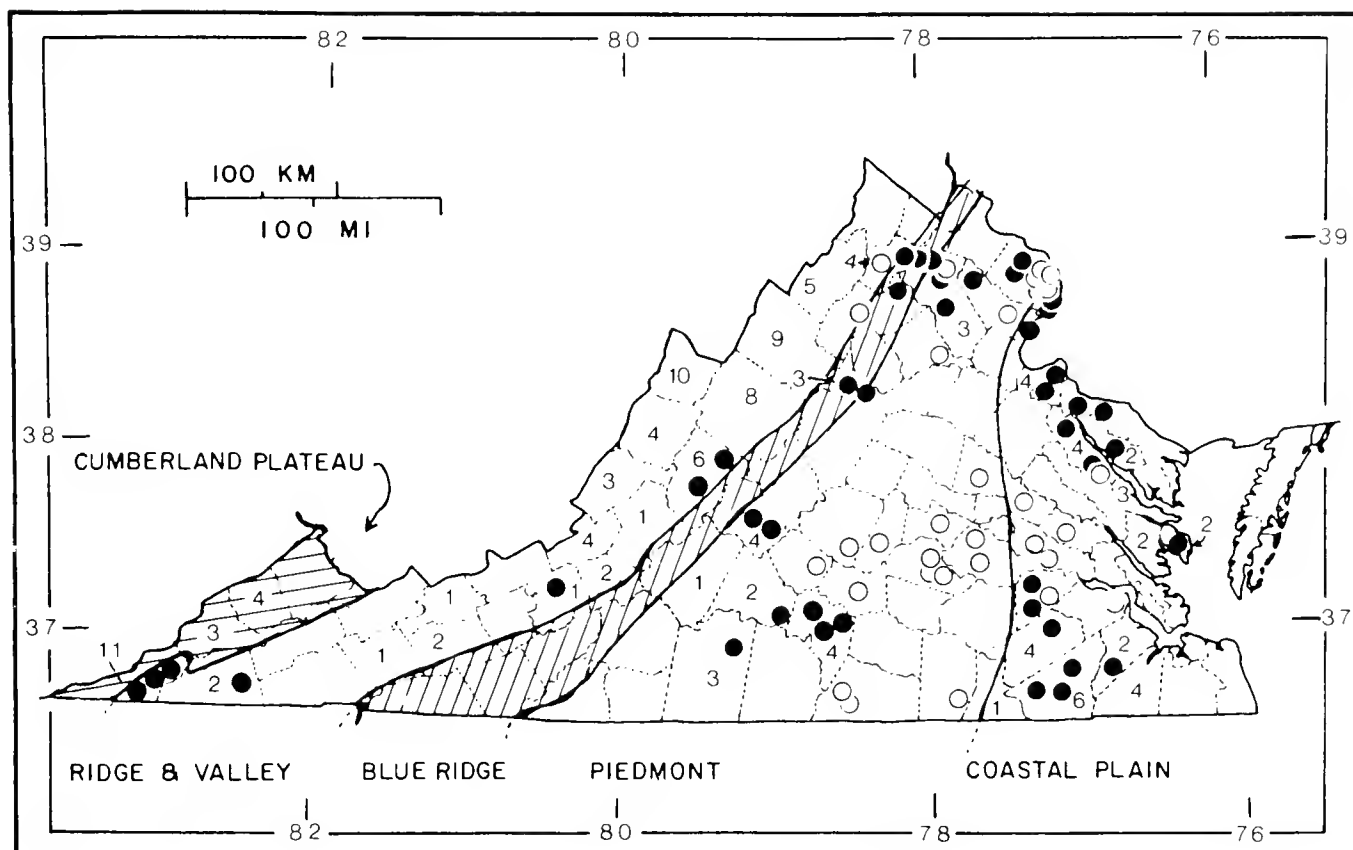


Fig. 1. Collecting localities of *Sorex l. longirostris* in Virginia. Open circles represent localities reported by Pagels et al. (1982). Solid circles represent localities reported in this paper. Where localities are closely spaced, circles may indicate more than one locality. Numerals indicate number of transects in each county.

later were removed and cleaned). Most of the specimens are in the Virginia Commonwealth University Mammal Collection: 73 taken in pitfall traps, 8 found in bottles discarded along the roadsides (these containers are effective deathtraps for shrews: Pagels and French 1987), and 5 contributed by Jack Cranford. The other 29 specimens are in various museum collections: 1 in the U.S. National Museum of Natural History (USNM), 2 in Lord Fairfax Community College (LFCC), 9 in George Mason University (GMU), and 17 at Northern Virginia Community College, Annandale Campus (NVCC-A).

COASTAL PLAIN. *Essex Co.*: 3.2 mi. NW Center Cross, 38 m, 1; 0.8 mi. NW Loretto, 31 m, 3; 2.4 mi. NW Loretto, 15 m, 4. *Fairfax Co.*: Gunston Manor, on Mason Neck, 6.25 mi. SE Lorton, (9 m), 1 (GMU); *Isle of Wight Co.*: 3.4 mi. SE Windsor, 23 m, 1. *King George Co.*: 0.5 mi. E Owens, 9 m, 6; 2.5 mi. S and 1 mi. E. Owens, 17 m, 2; 1.3 mi. N Port Conway, 20 m, 4. *Mathews Co.*: 2.2 mi. NE Hudgins, 5 m, 3. *Prince George Co.*: 1.2 mi. NE Disputanta, 23 m, 1; 2 mi. SSE Hopewell, 37 m, 1. *Prince William Co.*: Woodbridge, Lake Ridge, (46

m), 12 (NVCC-A). *Richmond Co.*: 4 mi. S Warsaw, 5 m, 2; 5 mi. S Warsaw, 5 m, 1. *Southampton Co.*: 8 mi. W Capron, 31 m, 3; 5.7 mi. W Courtland, 21 m, 1; 5 mi. NE Sebrell, 24 m, 1. *Sussex Co.*: Warwick Swamp, 1.4 mi. SE Sussex-Prince George Co. line, 23 m, 1. *Westmoreland Co.*: 2.2 mi. SSW Colonial Beach, 6 m, 1; 1 mi. W Lerty, 47 m, 1. Total 50.

PIEDMONT. *Amherst Co.*: 0.1 mi. NW Amherst, 213 m, 2; Forks of Buffalo, 280 m, 1. *Campbell Co.*: Brookneal, 125 m, 3. *Charlotte Co.*: 2.2 mi. S and 5 mi. W Charlotte, 146 m, 1; Cub Creek, 1 mi. W Phenix, 110 m, 1; 1.3 mi. W Phenix, 116 m, 2; Roanoke Creek, 6 mi. W Keysville, 91 m, 6. *Fairfax Co.*: Dulles Airport, (91 m), 5 (GMU), 5 (NVCC-A); Fairfax (GMU Campus), 137 m, 1 (GMU); Fort Belvoir, North Post, (31 m), 1 (GMU). *Fauquier Co.*: Conde (Rte. 737), 158 m, 1 (LFCC); 4 mi. NNE Marshall, 168 m, 6; 9.4 mi. NNE Marshall, 168 m, 2. *Greene Co.*: 0.6 mi. W Stanardsville, 183 m, 1. *Pittsylvania Co.*: 1 mi. W Mount Airy, 165 m, 4. *Prince William Co.*: Haymarket, (101 m), 1 (GMU). Total 43.

BLUE RIDGE. *Greene Co.*: 4.7 mi. W Stanardsville, 411 m, *Rappahannock Co.*: Chester Gap, 412 m, 4. *Warren Co.*: 1 mi. S Front Royal, National Zoological Park Conservation Center, (305 m), 1 (LFCC); Linden, along branch of Manassas Run, 274 m, 2; 2.4 mi. W Linden, beside Manassas Run, 213 m, 1. Total 9.

RIDGE AND VALLEY. *Lee Co.*: 2 mi. W Ewing, 415 m, 3; 3 mi. W Jonesville, 421 m, 1; 1 mi. N Rose Hill, Poor Valley Branch, 433 m, 1. *Montgomery Co.*: VPI & SU, Blacksburg, 610 m, 5. *Rockbridge Co.*: 1.5 mi. NW Lexington, 305 m, 1; Vesuvius, 460 m, 1 (USNM). *Scott Co.*: ca. 1 mi. E Hiltons, 442 m, 1. Total 13.

#### ASSOCIATED SPECIES

In this study, five of the other eight species of shrews known from Virginia (*Sorex fumeus*, *Sorex hoyi*, *Blarina brevicauda*, *Blarina carolinensis*, and *Cryptotis parva*) were captured at one or more sites with *S. longirostris*. Because of their narrow habitat preferences and limited distribution in Virginia, it is unlikely that *Sorex dispar* or *Sorex palustris* will be found with *S. longirostris*. The masked shrew, *Sorex cinereus*, has been captured with *S. longirostris* in west-central Indiana (Rose 1980), but never in Virginia or elsewhere. In our area, *S. cinereus* and *S. longirostris* exhibit contiguous allopatry. *Sorex cinereus* is common at high elevations, and we found that its lowest elevational limits (between 442 and 594 m) approximated the highest elevations at which the southeastern shrew was collected (457 to 610 m). Mean elevations of captures of the two species were 823 m versus 155 m.



## HABITAT

Habitats in which we found *Sorex longirostris* confirmed earlier observations; the species occurs in a wide range of cover types (French 1980a, 1980b; Wolfe and Esher 1981; Pagels et al. 1982). Frequency of captures of *S. longirostris* in various habitats in each of the physiographic provinces of Virginia are given in Table 1. In the lowlands this shrew was caught with similar frequency in all habitats. In the mountains, however, it was caught more often in fields and field-forest edges than in forest (14 versus 1).

*Sorex longirostris* was caught often in the Piedmont (at 65% of the pitfall localities), Blue Ridge (40%), and Coastal Plain (37%), but infrequently in the Ridge and Valley Province—at only 11% of the localities. The rarity and limited distribution of *S. longirostris* in western Virginia are emphasized by the very few captures there in spite of extensive pitfall sampling (Table 1 and Fig. 2). Regardless of cover type, the actual number of *S. longirostris* captured in pitfalls in the Ridge and Valley Province, 7 vs. 66 in the other provinces, was significantly less than the expected value adjusted for sampling effort ( $X^2 = 50.3$ ,  $P < 0.01$ ).

## DISTRIBUTION IN WESTERN VIRGINIA

Our records extend the known range of *S. longirostris* in western Virginia. Specimens from Scott and Lee counties bring the range of the species to the edge of the Appalachian Plateau Province, where it already is known to occur in Tennessee (French 1980b), Kentucky (Caldwell and Bryan 1983), and West Virginia (French 1976). From the localities in southwestern Virginia, the range of *S. longirostris* is continuous southward along the Powell, Clinch, and Holston rivers into the Tennessee Valley.

The specimens from Blacksburg confirm the occurrence of *S. longirostris* there. This is close to the site where Handley collected a specimen, subsequently lost, that he identified and published as *Sorex longirostris* (Handley and Patton 1947). The external measurements of this specimen, a male, total length 80 mm, tail vertebrae 32 mm, hind foot 11 mm, ear 9 mm, and weight 3.0 g, are close to the mean for *S. longirostris*.

We discovered that a specimen (USNM 521113) that had been found floating dead in a swimming pool in Vesuvius, Rockbridge County, in 1956 is a young *S. longirostris*, not *Microsorex hoyi winnemana* Preble as we previously reported (Handley et al. 1980). This establishes the occurrence of *S. longirostris* in the mid-Shenandoah Valley. Later, we caught another specimen nearby, at Lexington.

In the Appalachians *S. longirostris* seems to be uncommon and to be found only at relatively low elevations. Published records reveal a general south-to-north gradient of the upper limits of its distribution:

North Carolina	Macon Co.	762 m	(Gentry et al. 1968)
Tennessee	Sevier Co.	488 m	(Komarek and Komarek 1938)
Kentucky	Knox Co.	335 m	(Caldwell and Bryan 1983)
West Virginia	Roane Co.	ca. 305 m	(French 1976)

These localities are all on the west slope of the Appalachians, in the Mississippi drainage. Our records from extreme southwestern Virginia, with elevations of 427 to 457 m, fit into this gradient. Apparently a different south-north gradient, displaced a little to the north, operates on the east slope in Virginia:

Montgomery Co.	Blacksburg	610 m
Rockbridge Co.	Vesuvius	457 m
Greene Co.	Stanardsville	411 m
Rappahannock Co.	Chester Gap	411 m
Page Co.	Luray	366 m
Warren Co.	Front Royal	305 m

We did very little sampling in the Blue Ridge, and most of the capture sites there, all in the foothills, were near ones that we had reported earlier (Pagels et al. 1982). Nevertheless, it must be assumed that the Blue Ridge represents a formidable barrier to distribution of *Sorex longirostris*. Gaps at the Roanoke and James rivers, Chester Gap at the head of the Rappahannock River, Manassas Gap at the head of Goose Creek, and the Potomac River Gap provide the only access for this shrew to the lowlands behind the mountain range (Fig. 2).

We now have evidence that all of these passages except the Potomac River Gap actually have been used by *S. longirostris*—the Roanoke River Gap to Blacksburg, the Roanoke or James gaps (or both) to Lexington and Vesuvius, and Chester Gap or Manassas Gap (or both) to Front Royal and Luray. Specimens actually were taken in Chester Gap and in Manassas Gap (at Linden).

Although there can be no doubt that *Sorex longirostris* has used the gaps in the Blue Ridge to gain access to the Valley of Virginia, it is not clear why its distribution in the Valley is so limited. In this area 45 of the pitfall localities were below 610 m, the highest elevation at which *S. longirostris* has been found in Virginia (Fig. 2). Within the elevational limits represented by the highest point where this shrew was found in each basin, there were 23 pitfall localities. *Sorex longirostris* was caught at only 5 (22%) of the 23 localities (2/8 of these were in fields, 3/13 in ecotones, and 0/2 in forest). The species has reached the head of the Roanoke River and crossed over the divide, barely into the extensive

Table 1. Number of sites sampled, frequency expressed as percentage of sites where at least one *Sorex longirostris* was collected, and number of individuals of *S. longirostris* captured in each habitat type and province.

	Meadow		Forest		Total
	Field	Field-forest edge	Mixed	Hardwood	
610 m or below					
Coastal Plain					
No. sites	13	5	11	6	35
Frequency	23.1	60.0	45.5	33.3	37.1
No. individuals	12	4	10	4	30
Piedmont					
No. sites	4	10	3	0	17
Frequency	75.0	60.0	66.6	0	65.0
No. individuals	9	15	4	0	28
Blue Ridge					
No. sites	4	4	0	2	10
Frequency	50.0	25.0	0	50.0	40.0
No. individuals	6	1	0	1	8
Ridge and Valley					
No. sites	18.5	17	1	8.5	45
Frequency	10.8	17.6	0	0	11.1
No. individuals	4	3	0	0	7
Total no. sites	39.5	36	15	16.5	107
Overall frequency	25.3	36.1	43.8	18.2	32.7
Total no. individuals	31	23	14	5	73
Above 610 m					
No. sites	3	3	16	11	33
No. captures	0	0	0	0	0

New River lowlands, but seems to have made no further penetration. Through the James or Roanoke gaps it has reached the head of the Maury River watershed at Vesuvius, but has not been found at all in the main valley of the James (including Cowpasture and Jackson rivers and Craig and Catawba creeks). Similarly, it has been found a little way up the South Fork of the Shenandoah River from Chester and Manassas gaps, but it is unknown in the broad expanses of the Potomac and lower Shenandoah valleys west of the Blue Ridge.

Can it be that the invasion of the Valley of Virginia by *S. longirostris* is relatively recent, and that what we see are merely the early stages of its occupation of habitat suitable for it but too low for *S. cinereus*? Or, has *S. cinereus*, which undoubtedly occupied the whole area during the Pleistocene, only recently withdrawn or begun to

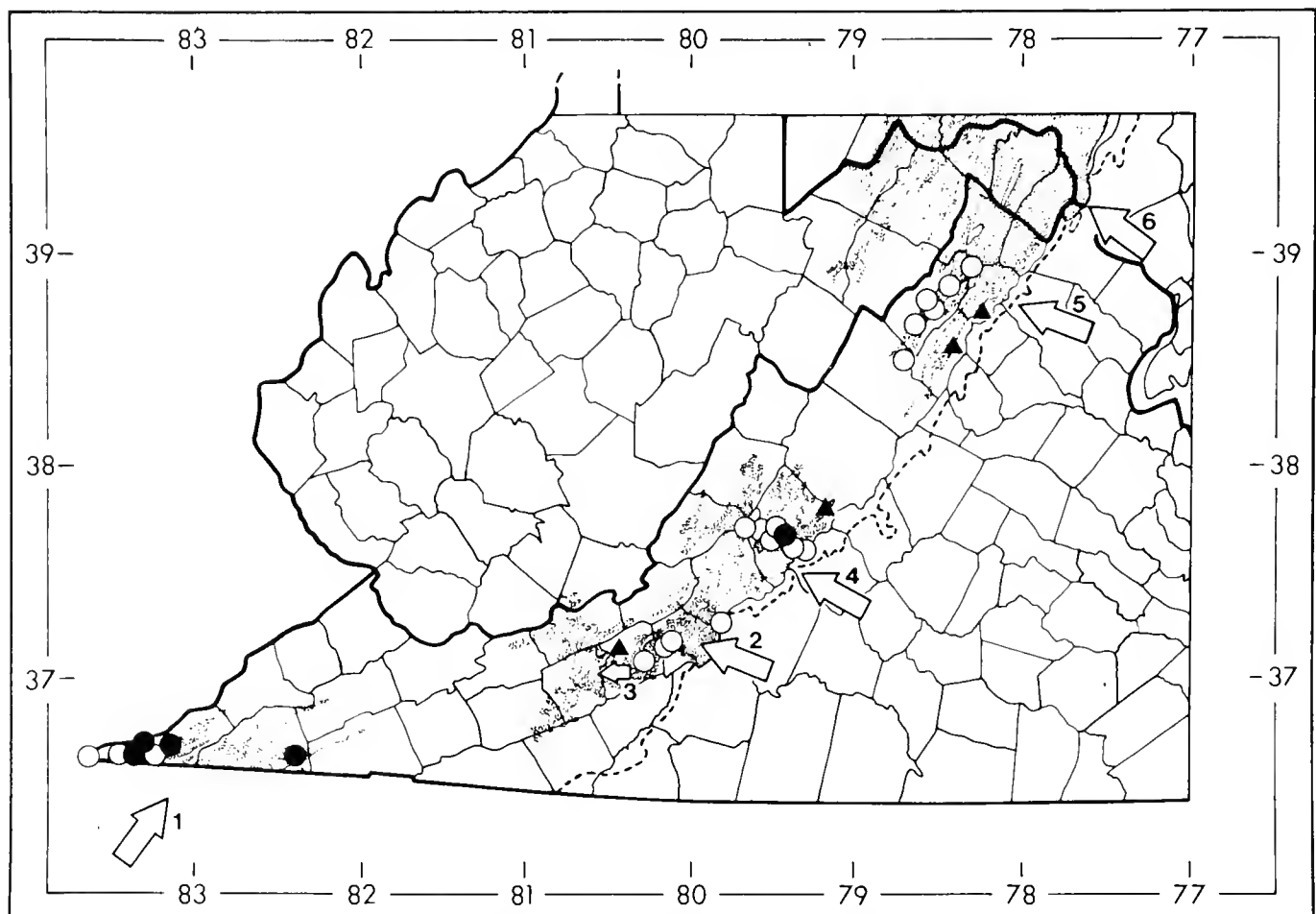


Fig. 2. Distribution of *Sorex longirostris* west of the Blue Ridge in Virginia. The heavy dashed line follows the Blue Ridge front. Arrows indicate low-elevation gaps in the Blue Ridge and access from the Tennessee Valley. Shaded areas represent potential *S. longirostris* habitat in western Virginia and adjacent parts of Maryland and West Virginia: (1) Tennessee River watershed up to 457 m. (2) Roanoke River basin up to 610 m. (3) New River basin from the West Virginia boundary up to 610 m (continuing down to the Ohio Valley in West Virginia). (4) James River watershed up to 457 m. (5) Manassas Gap to Shenandoah River basin up to 305 m. (6) Potomac River basin up to 305 m. Solid circles represent pitfall trap localities where *S. longirostris* was caught; open circles represent pitfall trap localities where *S. longirostris* was not found. Solid triangles represent localities where *S. longirostris* has been taken by means other than pitfall traps.

withdraw from the lower elevations of the Valley of Virginia, clearing the way for *S. longirostris*? Only more collecting can unveil the full extent of details of the distribution of *S. cinereus* and *S. longirostris* and its oddities in western Virginia.

**ACKNOWLEDGMENTS.**— We thank Jack Cranford of Virginia Polytechnic Institute and State University, for donation of specimens. Walter Bulmer of Northern Virginia Community College, Annandale Campus; Carl Ernst of George Mason University; and Robert Simpson of Lord Fairfax Community College allowed us to examine and report on

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THE SEASIDE SPARROW,  
ITS BIOLOGY AND MANAGEMENT

Edited by

Thomas L. Quay, John B. Funderburg, Jr., David S. Lee,  
Eloise F. Potter, and Chandler S. Robbins

The proceedings of a symposium held at Raleigh, North Carolina, in October 1981, this book presents the keynote address of F. Eugene Hester, Deputy Director of the U.S. Fish and Wildlife Service, a bibliography of publications on the Seaside Sparrow, and 16 major papers on the species. Authors include Arthur W. Cooper, Oliver L. Austin, Jr., Herbert W. Kale, II, William Post, Harold W. Werner, Glen E. Woolfenden, Mary Victoria McDonald, Jon S. Greenlaw, Michael F. Delany, James A. Mosher, Thomas L. Merriam, James A. Kushlan, Oron L. Bass, Jr., Dale L. Taylor, Thomas A. Webber, and George F. Gee. A full-color frontispiece by John Henry Dick illustrates the nine races of the Seaside Sparrow, and a recording prepared by J. W. Hardy supplements two papers on vocalizations.

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ENDANGERED, THREATENED, AND  
RARE FAUNA OF NORTH CAROLINA  
PART I.  
A RE-EVALUATION OF THE MAMMALS  
Edited by Mary Kay Clark

This book is a report prepared by a committee appointed in 1985 by the North Carolina State Museum of Natural Sciences to re-evaluate the list of mammals presented in *Endangered and Threatened Plants and Animals of North Carolina* (John E. Cooper, Sarah S. Robinson, and John B. Funderburg, editors. N.C. State Mus. Nat. Hist., Raleigh, 1977), which is now out of print. Committee members were Mary Kay Clark, David A. Adams, William F. Adams, Carl W. Betsill, John B. Funderburg, Roger A. Powell, Wm. David Webster, and Peter D. Weigl. The report treats 21 species listed in the following status categories: Endangered (5), Threatened (1), Vulnerable (6), and Undetermined (9). Most species accounts discuss the animal's physical characteristics, range, habitat, life history and ecology, special significance, and status (including the rationale for the evaluation and recommendations for protection) and provide a range map and an illustration of the animal's external characters. Ruth Brunstetter and Renaldo Kuhler illustrated the book. An introductory section contributed by Ms. Clark discusses the changes in status that occurred in the decade between 1975 and 1985. It also mentions efforts to protect marine mammals and includes a checklist of the cetaceans known from North Carolina.

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ENDANGERED, THREATENED, AND  
RARE FAUNA OF NORTH CAROLINA  
PART II.  
A RE-EVALUATION OF THE MARINE AND  
ESTUARINE FISHES

by

Steve W. Ross, Fred C. Rohde, and David G. Lindquist

This is the second in a series of reports by committees appointed in 1985 by the North Carolina State Museum of Natural Sciences to re-evaluate the faunal lists presented in *Endangered and Threatened Plants and Animals of North Carolina* (John E. Cooper, Sarah S. Robinson, and John B. Funderburg, editors. N.C. State Mus. Nat. Hist., Raleigh, 1977), which is now out of print. The report on marine and estuarine fishes by Ross, Rohde, and Lindquist treats one Endangered species, six Vulnerable species, and four anadromous fishes that, while not formally listed, are of some concern. Five species listed as being of Special Concern in 1977 no longer warrant formal status. The publication includes six original drawings by Renaldo Kuhler.

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