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### IN MEMORIAM

Dr. Joshua Laerm, Professor at the University of Georgia and Curator of Zoological Collections at the University of Georgia Museum of Natural History, died 28 September 1997. He was born and raised in Pennsylvania and received an undergraduate degree from Pennsylvania State University and graduate degrees from the University of Illinois. He joined the faculty at the University of Georgia in 1976.

Dr. Laerm published numerous works in systematics, mammalogy, and natural history. He was particularly interested in rare and threatened or endangered mammals and contributed significantly to understanding their natural history and distribution in the Southern Appalachian Mountains. His enthusiasm for science, his prolific contributions, and his eagerness to help colleagues will be deeply missed.

# Turtles (Reptilia: Testudines) Of The Ardis Local Fauna Late Pleistocene (Rancholabrean) Of South Carolina

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**ABSTRACT-** The Ardis local fauna (late Pleistocene) was collected from a group of interconnecting sediment-filled solution cavities, located in the Giant Cement Quarry near Harleyville, Dorchester County, South Carolina. Fossil material from the lowermost levels and the extreme upper layer of the deposit have been radiocarbon dated at  $18,940 \pm 760$  and  $18,530 \pm 725$  y.b.p., respectively. These dates are considered contemporaneous within present resolution. Approximately ninety vertebrate taxa were collected from the site. Fourteen were species of turtles, including eight not previously reported from the Pleistocene of South Carolina. Among these is the southeastermost occurrence of *Emydoidea blandingii*. This record, in conjunction with other vertebrate fossils from the site, suggests a north-south dispersal route of species along the Atlantic Coastal Plain during interglacial-glacial transitions. Geographically isolated eastern and western populations of *Emydoidea blandingii* may have existed during the maximum advance of the Laurentide ice sheet. Unusually complete fossils of large box turtles recovered from the site corroborate the previously suggested synonymy of the extinct *Terrapene carolina putnami* with *T. c. major*. The fossil turtle community of the Ardis local fauna has no modern analogue. Like the Ardis mammals, it comprises a "disharmonious" fauna which suggests that, during the height of the Wisconsinan glaciation, the region experienced a more equable climate than that of today .

The Ardis local fauna has yielded approximately 90 species of late Pleistocene fossil vertebrates from the Coastal Plain of South Carolina, including a substantial mammalian (Bentley et al. 1994), avian, reptilian, amphibian, and fish faunas currently under study. We present data on the Ardis turtle collection (Appendix I), the largest Rancholabrean fauna reported from the state. Dobie and Jackson (1979) and Roth and Laerm (1980) reported fossils of late Pleistocene age from Edisto Island, the only other Pleistocene fossil turtle fauna from South Carolina described to date. Among the Edisto Island fauna were ten

taxa of turtles, including *Gopherus* sp. and *Malaclemys terrapin* which were not recovered from the Ardis local fauna and possibly three species of *Pseudemys*, *P. floridana* and/or *P. concinna*, and *P. nelsoni*.

The Ardis local fauna was discovered in a large open-pit mine, operated by the Giant Cement Company, located 5 km NNE of Harleyville, Dorchester County, South Carolina (33° 14'N, 80° 26'W). Quarry operations exposed Santee Limestone (middle Eocene) and the clay-rich Harleyville Formation (late Eocene) which underlie Plio-Pleistocene surficial deposits (Ward et al. 1979, Harris and Zullo 1991). Locally, groundwater differentially dissolved the Santee Limestone in its upper portions, so that many solution cavities contacted and penetrated the overlying Harleyville Formation and thereby opened several of the cavities to the Pleistocene surface (Bentley et al, 1994). The radiocarbon dates of the Ardis material place the time of deposition at or near the height of the Wisconsin glacialiation (Bowen 1988, Tushingham and Peltier 1993). Further discussion on the geology, dating methods of the Ardis fossil material, previous fossil collections from the quarry, fossil collection procedures, and a locality map are available in prior publications (Bentley and Knight 1993, Bentley et al. 1994).

#### TAPHONOMY

At least part of the fossil assemblage collected from inside the solution cavities at the Ardis site appears to represent an obrution deposit, the very rapid burial of intact organisms (Brett 1990) in which many of the specimens exhibit incipient decay. Surface openings leading to the cavities varied from a gentle downward slope to a vertical shaft, generally allowing the Pleistocene fauna ease of ingress and egress. This permitted animals to enter the cavities in three different ways: (1) "walk-in" taxa, which may have used the site for estivation/hibernation or as denning sites and hunting grounds, for example muskrats, mink, and woodrats (Bentley et al. 1994); (2) "wash-in" taxa from the surface, either alive or dead, which applies most readily to large animals known only from isolated remains e.g., *Mammot* sp., *Bison* sp., *Equus* sp. (Bentley et al. 1994), that would have been unable to enter the cavities during life; and (3) "fall-in" taxa which fell into exposed verticle shafts, fossil accumulations resulting from this type of natural trap are well documented (e.g., Webb 1974).

Because of the interconnecting "tunnel-like" nature of the cavities, a single episodic event could produce differing water velocities within the cavities and different rates of deposition. Seasonal flooding, depending on the intensity, may have simultaneously smothered living animals within the cavities and buried or reworked those that had died just prior to, or in a preceding, depositional event. Consequently, specimens incompletely or shallowly buried during an event with a low sedimentation rate (low energy) could be completely or partially exhumed and reburied by a succeeding event. This resulted in the preser-

vation of specimens in various orientations to the bedding planes (Fig. 1), various degrees of disarticulation, and the occasional mixing of individual elements. An articulated *Emydoidea blandingii* specimen preserved in its life position with axial skeletal elements inside, indicates little or no decay prior to its final burial (Fig. 2). This preservation suggests the turtle was buried quickly in a high energy, high sedimentation environment (Brett and Speyer 1990), resulting in burial deep enough to avoid reworking during subsequent episodic events. Several articulated turtles were collected with limbs and skulls preserved within the shells in various orientations to the bedding plane. A high energy hydrological environment before or shortly after death would likely explain the various orientations observed in well preserved specimens. Retention and preservation of limb elements, cervical and caudal vertebrae, and skulls inside the shell may reflect a withdrawal by the turtles in response to a catastrophic event.

Fig. 1 *Emydoidea blandingii*, only the carapace (.547) was preserved, ventral side up (side view), among clay clasts from the surrounding Harleyville Formation. This illustrates the hydrodynamic effect upon some specimens prior to final burial.



Fig. 2 Complete *E. blandingii* (.546) *in situ*, with axial skeleton preserved inside the shell, indicating a “withdrawal response” and final burial prior to any significant decay.



#### MATERIALS AND METHODS

Morphological terminology used in this paper is taken from Carr (1952), Ernst and Barbour (1989), Holman (1967, 1977, 1985), Holman and Grady (1987), and Preston (1979). Taxonomy follows Conant and Collins (1991).

Morphological comparisons of Recent skeletons to fossil material were made against available specimens in the Florida Museum of Natural History and the South Carolina State Museum collections. Additionally, specimens from The University of Michigan Museum of Zoology of *Emydoidea blandingii*, UMMZ 155047-155054, *Clemmys guttata*, UMMZ 51235, 51236, 51240-51242, 159219, 155001, 155002, and *Clemmys muhlenbergii*, UMMZ 77140 and, 130840 were studied.

Most of the specimens in the South Carolina State Museum collections are deposited under the base number of S.C. 94.10. and for brevity, are referenced in the text only by the digits following this base number. Specimens accessioned separately are designated by the institutional prefix of SCSM. Fossil specimens deposited in the National Museum of Natural History and the Florida Museum of Natural History are designated by USNM and UF, respectively.

## SYSTEMATIC PALEONTOLOGY

## Testudines

## Kinosternidae

Material: 1 right xiphiplastron (.25); 16 peripherals (.26-.44); 2 humeri (.45-.46); 2 partial jaw rami (.755-.756).

Remarks: These fossil elements could only be identified with confidence to family.

*Kinosternon subrubrum* - Eastern Mud turtle (Lacepede, 1788)

Material: 3 nuchals (.11-.13); 2 right, 3 left hyoplastra (.6-.10); 5 left hypoplastra (.1-.5).

Characters used for identification: The hyoplastron of *Kinosternon subrubrum* can be separated from other North American *Kinosternon* and *Sternotherus* because the axillary notch is narrower, and from *Kinosternon baurii* because the axillary notch is wider and shallower (Holman 1985). *K. subrubrum* hyo- and hypoplastra differ from *Sternotherus odoratus* in that the elements are shorter laterally than medially in *S. odoratus* (Preston 1979). Characters used to identify nuchal material are discussed by Holman (1975). In addition, nuchals of *K. subrubrum* can be distinguished from nuchals of *S. odoratus* because the anterior lip of the nuchal, viewed anteriorly, is nearly straight in *K. subrubrum*. Nuchals of *S. odoratus*, viewed anteriorly, have a decided arc.

Remarks: The eastern mud turtle inhabits a variety of shallow slow to non-moving bodies of water with a soft substrate, such as swamps, ponds, marshes, wet meadows, and lagoons (Ernst and Barbour 1989). *Kinosternon subrubrum* today ranges from southern Massachusetts and Pennsylvania along the Atlantic coast, to the tip of Florida and west into Texas and Oklahoma (Conant and Collins 1991). *K. subrubrum* is common in the area of the Ardis site today and may be sympatric with *K. baurii* (Lamb and Lovich 1990).

This is the first report of this species from the fossil record of South Carolina. Dobie and Jackson (1979) and Roth and Laerm (1980) both reported the same single pygal bone from Edisto Island as "*Kinosternon* sp."

*Sternotherus odoratus* - Common Musk turtle (Latreille, in Sonnini and Latreille, 1802)

Material: 3 nuchals (.22-.24); 2 right hyoplastra (.14-.15); 1 right, 5 left hypoplastra (.16-.21).

Characters used for identification: Identification is based on characters provided in discussion for *Kinosternon subrubrum*. The hyo-hyoplastron of *S. minor* can be separated from the same elements in *S. odoratus* because the area that forms the bridge between the plastron and the carapace is dorsally compressed or flattened in *S. minor*, and not raised as in *S. odoratus*. The nuchals compare most favorably to *S. odoratus*, following the characters used above, and additionally exhibit a strong dorsal medial keel that is generally lacking in *K. subrubrum*.

Remarks: The common musk turtle inhabits areas very similar to that of *K. subrubrum*, preferring slow to non-moving bodies of water with a soft bottom. It has also been collected from fast moving, gravel bottomed, streams (Ernst and Barbour 1989). *S. odoratus* occurs from southern Maine and Canada southward through Florida and as far west as Kansas and central Texas (Conant and Collins 1991), and occurs in the area of the Ardis site today.

#### Chelydridae

##### *Chelydra serpentina* - Snapping turtle (Linnaeus, 1758)

Material: 2 right parietals (.50, .53); 1 left postorbital (.51); 1 right prefrontal (.52); 1 left quadratojugal (.54); 1 partial left mandible (.55); 2 right mandibles (.56-.57); 6 cervical vertebrae (.102-.107); 1 humerus (.63); 2 radii (.69-.70); 1 right scapulo-acromial process (.64); 1 right partial acromial process (.65); 5 femora (.58-.62); 3 ilia (.66-.68); 1 caudal vertebra (.108); 1 nuchal (.95); 1 right 1st peripheral (.71); 16 unassigned peripherals (.72-.83)(2 USNM)(2 UF); 1 left 1st costal (.84); 24 partial costals (.85-.92)(8 USNM)(8 UF); 2 associated costals (.93-.94); 2 neurals (.96-.97); 2 epiplastra (.100-.101); 2 hypoplastra (.98-.99).

Characters used for identification: *Chelydra* shell material is very distinctive and easily separated from other turtles including *Macrolemys*. Preston (1979) provides characters that allow the identification of fragmentary material. All listed fossil elements compare favorably to Recent skeletal materials.

Axial and appendicular skeleton - The large size and diagnostic ornamentation of the *Chelydra* skull roof elements distinguish them from all other turtles. *Macrolemys* lacks the rugose cranial ornamentation of *Chelydra*. A pectoral girdle was assigned to this species based on the 90° angle between the scapula and acromial process and on the heavily striated distal ends (Holman 1966). Femora and humeri could not be separated from Recent material of *C. serpentina*, and are more robust than other genera of fresh water turtles (Holman 1964) except *Macrolemys*, which is generally considerably larger.

Remarks: Snapping turtles are generally found in freshwater to brackish water habitats with soft muddy substrate (Ernst and Barbour 1989) from eastern Canada through the United States east of the Rockies south through Mexico and into Ecuador. *C. serpentina* occurs today in the Ardis area.

Dobie and Jackson (1979), first reported fossil material of *C. serpentina* from Edisto Island with additional material reported by Roth and Laerm (1980).

*Macrolemys temminckii* - Alligator snapping turtle (Gray, 1855)

Material: 1 partial right parietal (.109).

Characters used for identification: The fossil parietal is identical to Recent specimens of this turtle, differing from *C. serpentina* in that the dorsal surface is smooth, i.e. without any of the prominent ornamentation consistently found in *C. serpentina* (Fig. 3). The parietal of *M. temminckii* is generally more robust and is longer with respect to width than specimens of *C. serpentina* of comparable sizes. This was the only fossil element of this species collected from the site. Because this represents a significant range extension, assignment to this species was made only after exhaustive comparisons to the fossil and Recent collections at the Florida Museum of Natural History and the South Carolina State Museum negated all other possibilities.

Remarks: This is the largest freshwater turtle in North America and possibly the heaviest in the world (Ernst and Barbour 1989). The alligator snapping turtle often can be found in the deep waters of lakes, ponds, rivers and bayous that contain abundant aquatic vegetation and muddy bottoms. This turtle is highly aquatic and ranges westward from northern Florida into Texas along the Gulf Coast and thence northward up the Mississippi Valley into Illinois, Iowa and Kansas (Ernst and Barbour 1989).

This is the first fossil or Recent evidence of *Macrolemys* from South Carolina and the Atlantic Coastal Plain.

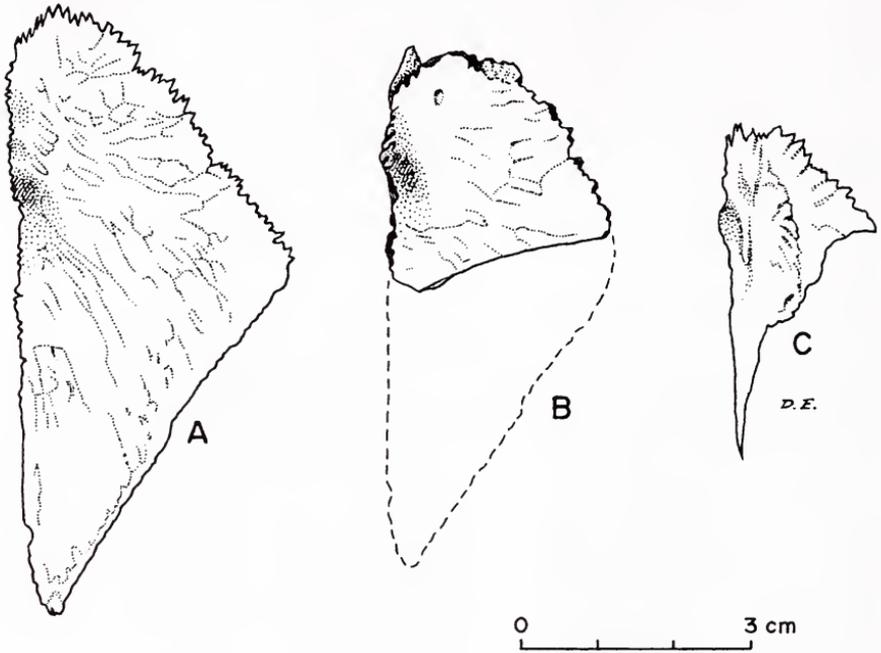
Emydidae

Emydinae

*Chrysemys picta* - Painted turtle (Schneider, 1783)

Material: An individual specimen consisting of a complete carapace (missing the 3rd right marginal) and plastron (.110); 7 cervical vertebrae (.110.1-.110.7); 1 ulna (.110.16); 1 radius (.110.17); 4 phalanges (.110.18-.110.21); 1 ungual (.110.22); 2 partial scapulo-acromial processes (.110.11-.110.12); 2 coracoids

Fig. 3 Right parietals of *Macroclemys temminckii* and *Chelydra serpentina*. A) Recent *M. temminckii*. B) Ardis fossil. C) Recent *C. serpentina*.



(.110.13-.110.14); 2 dorsal vertebrae (.110.9-.110.10); complete pelvic girdle (.110.15); 1 caudal vertebra (.110.8). An individual specimen consisting of a nearly complete carapace and plastron (.111). An individual specimen consisting of a complete carapace (missing left 8-9th peripherals and 6th neural) and plastron (.112); partial skull and mandible (.112.1); partial hyoid process (.112.2); 7 cervical vertebrae (.112.20-.112.26); 2 humeri (.112.5-.112.6); 2 ulnae (.112.7-.112.8); 2 radii (.112.9-.112.10); 2 scapulo-acromial processes (.112.15-.112.16); 2 coracoids (.112.17-.112.18); 2 femora (.112.3-.112.4); 2 tibiae (.112.11-.112.12); 2 fibulae (.112.13-.112.14); 7 metapodial elements (.112.42-.112.48); 31 phalanges (.112.49-.112.80); 13 unguals (.112.81-.112.91); 2 sacral ribs (.112.92-.112.93); partial pelvic girdle (.112.19); 3 dorsal vertebrae (.112.27-.112.29); 12 caudal vertebrae (.112.30-.112.41). An individual specimen consisting of a nearly complete plastron and attached 4-7th right peripherals (.113); skull (including inner ear ossicles) and mandible (.113.1); partial hyoid apparatus (.113.2); 4 cervical vertebrae (.113.9-.113.12); 2 humeri (.113.3-.113.4); 1 scapulo-acromial process (.113.7); 2 partial femora (.113.5-.113.6); 1 tibia (.113.8); 2 metapodial elements (.113.15-.113.16); 15 phalanges (.113.17-.113.31); 5 unguals (.113.32-.113.36); 2 caudal vertebrae (.113.13-.113.14). Specimen with partial carapace (.114); 3 cervical vertebrae (.114.3-.114.6); 1

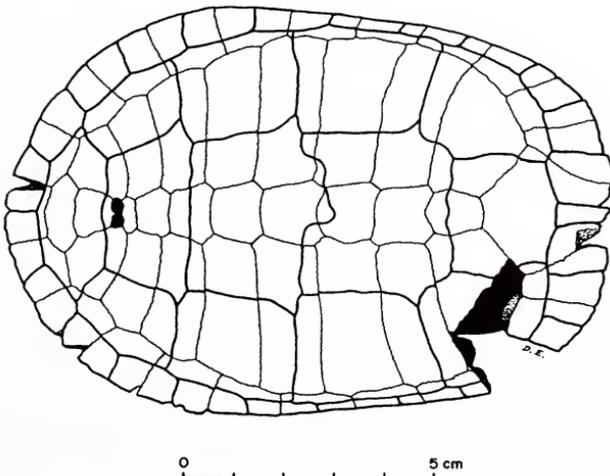
humerus (.114.1); 1 radius (.114.2); 1 phalange (.114.7). 2 mixed specimens both with partial fragmented carapaces and plastra (.115); 3 cervical vertebrae (.115.5-.115.6); 2 humeri (.115.1-.115.2); 2 scapulo-acromial processes (.115.3-.113.4); 2 coracoids (.115.8-.115.9); 2 tibiae (.115.10-.115.11); 1 ilium (.115.12); 1 phalange (.115.13). Four individual specimens with fragmented carapace and plastron (.116-.119). Two mixed specimens with badly fragmented carapaces and plastra (.120).

Isolated elements: 16 nuchals (.123-.132)(3 USNM)(3 UF); (SCSM 91.170.1) partial plastron; 10 right and 2 left epiplastra (.133-.144); 2 entoplastra (.169-.170); 10 left and 3 right hyoplastra (.145-.151)(3 USNM)(3 UF); 1 right hypoplastron and xiphiplastron (.122); 5 left and 7 right hypoplastra (.152-.157)(3 USNM)(3 UF); 6 left and 9 right xiphiplastra (.158-.168)(2 USNM)(2 UF); 8 right and 6 left 2nd costals (.227-.240); 3 right and 1 left 3rd costals (.241-.244); 6 right and 3 left 4th costals (.245-.253); 7 right and 8 left 5th costals (.254-.268); 4 right and 3 left 6th costal (.269-.275); 4 right and 1 left 7th costal (.276-.280); 56 peripherals (.171-.226); 1 mandible (.761); 2 right and 1 left mandibular rami (.758-.760); 10 humeri (.289-.298); 8 femora (.281-.288).

Characters used for identification: Identification of complete shells was based on nuchal characters (Bentley and Knight 1993), and the alignment of the vertebral and pleural sulci (Ernst and Barbour 1989) (Fig. 4).

Hyoplastron - The humeral sulcus does not cross dorsally over the plastral scute overlap area, as in *Clemmys*. *Terrapene* and *Emydoidea* have hinged plastra. Elements of comparable size can be separated from *Deirochelys reticularia* as the dorsal scute overlap area in *C. picta* is wider and more sharply curved

Fig. 4 Fossil carapace of *Chrysemys picta* (.110) from the Ardis local fauna.



distally, and the articulating surface of the epiplastron and hyoplastron between the entoplastron and the outside edge is wider in *C. picta*. *Trachemys* and *Pseudemys* are larger and more robust than *C. picta* as adults. Young specimens of *Trachemys* and *Pseudemys* can be separated by a less pronounced or inflated scute overlap area and signs of incomplete ossification.

**Hypoplastron** - The inguinal sulcus runs diagonally to the peripherals and into the inguinal notch in *Chrysemys* but is parallel to the peripherals in *Clemmys*. This element can be distinguished from *Deirochelys* as it is less elongate with respect to width in *C. picta*, and the scute overlap area is wider. It can also be separated from *Terrapene carolina* and *Emydoidea* by the lack of a hinge. Adult *Trachemys* and *Pseudemys* differ in being larger and more robust than adults of *C. picta*. Young specimens of *Trachemys*, comparable in size to adult *C. picta* and completely ossified, can be separated from *C. picta* by a larger bridge with respect to the hypoplastron proper and a greatly reduced or absent epidermal attachment scar.

**Entoplastron** - The humero-pectoral sulcus does not cross the entoplastron as in eastern species of *Clemmys* and in *Terrapene carolina*. It can be tentatively separated from *Pseudemys*, *Trachemys*, and *Emydoidea* by overall size, as specimens of the preceding genera tend to exhibit incomplete ossification when of comparable size to adult *C. picta*. However, size alone is not a reliable character for this element. We were unable to separate this element from that of *Deirochelys*, so entoplastra are only tentatively assigned to *C. picta*.

**Epiplastron** - This element differs from other species (except *Trachemys*) in that the anterior edge exhibits a degree of serration. This element often is serrated in specimens of *Trachemys*, but the size of these specimens allows easy separation from *C. picta*. Young specimens of *Trachemys* generally lack this serration and have a poorly developed scute overlap area in comparison to *C. picta* of comparable size.

**Xiphiplastron** - This element can be separated from *Clemmys*, *Terrapene*, and *Emydoidea* by the scute overlap area, which in those genera is more pronounced than in *C. picta*. Further, *Clemmys muhlenbergii* has a posterior edge tapered to a point, while in *Clemmys insculpta* the element is longer with respect to width, with a pronounced notch where the anal sulcus wraps over the edge, a condition minimal or lacking in *C. picta*. In *C. picta* the scute overlap of this element is wider and more pronounced on the posterior edge than on any examined specimens of *Deirochelys*. This element in *Trachemys* is generally more robust in adult specimens than in *C. picta*, and in young specimens of comparable sizes the scute overlap area is much less pronounced than that of *C. picta*.

**2nd Costal** - This element differs from *C. guttata* in being approximately 30% wider with respect to length, and the junction between the 2nd vertebral sulcus and the 1st and 2nd pleural sulcus is located generally more distally than in *C. guttata*. This element differs from *C. muhlenbergii* by having a

greater curvature, and the above mentioned junction point forms a distinct "T" shape in *C. muhlenbergii* and dips into a general "U" or "V" shape in *C. picta*. The 2nd costal of *C. picta* differs from *C. insculpta* by being completely smooth and lacking any "tortoise-like" bulges, by being more distally flared, and by having greater curvature of the element. It can be separated from *Trachemys* and *Pseudemys* by a lack of sculpting and smaller size, and from *Deirochelys* by lack of sculpting, a more proximal rib attachment (Jackson 1978), and the proximal tapering of the element.

3rd Costal - Differs from *Clemmys*, *Terrapene*, *Trachemys*, *Pseudemys*, *Emydoidea*, and *Deirochelys* in that it lacks the vertebral sulcus between the 2nd and 3rd vertebral scutes. Additionally, in *Deirochelys* the rib attachment is significantly more distal than in *C. picta*. This 3rd element can be separated from the 5th costal in *C. picta* in that it lacks the posteriorly directed curvature of the 5th costal.

4th Costal - Can be separated from all other emydid turtles in that it exhibits alignment of the sulci between the 2nd and 3rd vertebral and pleural scutes. This sulcal alignment occurs only in the subspecies *C. picta picta* (Conant and Collins 1991).

5th Costal - Can be separated from *Clemmys*, *Trachemys*, *Deirochelys*, *Pseudemys*, *Emydoidea*, and *Terrapene* by characters given for the 3rd costal.

6th Costal - Differs from *Clemmys*, *Trachemys*, *Deirochelys*, *Pseudemys*, *Emydoidea*, and *Terrapene* in that it lacks the sulcus of the 3rd and 4th vertebral scutes.

Peripherals, femora, humeri, and mandibular rami - These elements are tentatively assigned to this species as they compare most favorably to Recent and fossil material of *C. picta*.

Remarks: The painted turtle has a wide distribution, occurring from southern Canada south into Mexico and across the entire continental United States (Ernst and Barbour 1989). Lakes, ponds, and streams are typical habitats of the painted turtle. Slow to non-moving, shallow aquatic environments with soft bottoms are favored.

The completeness of many of the painted turtles recovered from the Ardis site are strong indicators of an obrution deposit. *Chrysemys picta* occurs in the Piedmont and mountains of South Carolina today but does not inhabit the Ardis site or any other part of the Coastal Plain. This is the first fossil record from South Carolina.

*Clemmys guttata* - Spotted turtle (Schneider, 1792)

Material: An individual specimen consisting of a nearly complete shell (SCSM 93.90.1) missing only the right hypoplastron and xiphiplastron, figured in Bent-

ley and Knight (1993), and the following associated cranial and postcranial elements; articulated skull fragment (prefrontal, frontal, postorbital, parietal, and supraoccipital), right maxilla, both quadrates, both opisthotics, basisphenoid, and articulated lower jaw, 1st cervical vertebra, 2 humeri, 1 ulna, 2 coracoids, 1 ischium, partial pubis and ilium, 1 sacral rib, 1 fibula, 3 phalanges, and vertebrae fragments. An individual specimen consisting of a partial carapace and plastron missing only the left hypoplastron and xiphiplastron (.299). Isolated skull fragment (parietal, supraoccipital, both maxillae, basisphenoid, 1 quadrate, 1 postorbital, 1 partial squamosal) (.299.1). A single sub-adult individual with partial plastron and 2 peripherals (.121.1-.121.2).

Isolated elements: 17 nuchals (SCSM 93.90.2-8)(5 USNM)(5 UF); 3 right and 2 left 2nd costals (.334-.338); 6 right and 5 left 3rd costals (.339-.349); 6 left and 6 right 4th costals (.350-.361); 3 right and 2 left 5th costals (.362-.366); 7 right and 4 left 6th costals (.367-.377); 1 left 7th costal (.378); 34 peripherals (.300-.333); 5 right and 3 left epiplastra (.379-.386); 3 entoplastra (.417-.419); 5 right and 13 left hyoplastra (.387-.399,.432)(2 USNM)(2 UF); 3 left hypoplastra (.400-.402); 6 right and 10 left xiphiplastra (.403-.416)(1 USNM)(1 UF); 1 mandible (.757); 3 humeri (.426-.428); 6 femora (.420-.425).

Characters used for identification: Identification of the two most complete specimens is discussed by Bentley and Knight (1993).

Nuchals - See Bentley and Knight (1993), for characters used to distinguish this from other possible identifications.

Epiplastron - Differs from *C. picta* in that the scute overlap area is more robust in *C. guttata*, and the anterior edge is not serrated as is common with *C. picta*. It can be separated from *C. muhlenbergii* because the bulbous area where the gular sulcus wraps onto the scute overlap is usually considerably wider medially to laterally in specimens of *C. guttata*, whereas the scute overlap portion that is posterior to the bulbous area is narrower in *C. muhlenbergii* than *C. guttata*. The length of the scute overlap posterior to the gular sulcus is longer than that of *C. picta*. Also, the epidermal attachment scar in *C. muhlenbergii* is deeply incised and tends to undercut the scute overlap area. The epiplastron of *C. guttata* is rarely incised to this extent. The epiplastra of *C. insculpta* differ from *C. guttata* in that the bulbous area where the gular sulcus crosses the dorsal surface is only slightly or not at all bulbous in specimens of similar size. The epiplastron of *Deirochelys*, *Trachemys* and *Pseudemys* that fall within the size range of *C. guttata* have less pronounced scute overlap area compared to that of *C. guttata*. *E. blandingii* specimens of comparable size show sub-adult traits (incomplete ossification) and have a less pronounced scute overlap area. *Terrapene* epiplastra differ in that the area posterior to the scute overlap is concave, forming a depression posteromedially to the gular sulcus, generally absent in *C. guttata*.

Hypoplastron - Differs from *Terrapene* and *Emydoidea* in that *C. guttata* lacks the hinge components. *C. muhlenbergii* differs slightly from *C. guttata* in that the scute overlap is narrower in *C. muhlenbergii*. Specimens of *Trachemys* and *Pseudemys* that fall within the size range of *C. guttata* have scute overlaps that are greatly reduced in comparison to *C. guttata* and the elements exhibit incomplete ossification. *Deirochelys* and *Chrysemys picta* can be separated from *Clemmys guttata* because the distance between the entoplastron and hypoplastron is ca. 40% greater in adults of the former two genera. Also, in *C. picta*, the humeral sulcus does not cross dorsally over the scute overlap area. *C. insculpta* exhibits incomplete ossification when elements fall within the size range of *C. guttata*.

Hypoplastron - This element can be separated from other genera of emydid turtles by the lack of hinge components (separating it from *Terrapene* and *Emydoidea*), or by its posterior width being greater than its length (separates it from *Trachemys* and *Pseudemys*). Holman (1977) gives characters used to separate this element from *C. muhlenbergii* and *C. insculpta*.

Xiphiplastron - Separation of this element from *C. picta* is listed under that species. It can be separated from *C. muhlenbergii* and *C. insculpta* in that the posterior edge is generally squared off rather than tapering to a point, as in the other two species. However, some specimens of *C. guttata* do exhibit a pointed condition. These still can be separated from *C. muhlenbergii* because the area where the abdominal muscle attaches to the xiphiplastron is more pronounced. *C. insculpta* can also be separated from *C. guttata* because, in the area where the anal sulcus crosses onto the scute overlap area, the xiphiplastron is deeply notched, being greatly reduced or lacking in *C. guttata*.

Entoplastron - In *C. guttata* the humero-pectoral sulcus crosses the entoplastron within the anterior half of that element. In *C. muhlenbergii* the humero-pectoral sulcus may cross the entoplastron at its posterior extremity, but typically it does not cross the entoplastron at all (Bentley and Knight 1993). These fossil entoplastra are tentatively assigned to *C. guttata*, and not *C. insculpta*, because this element is generally more robust in *C. insculpta* and the humero-pectoral sulcus crosses the entoplastron more posteriorly in *C. insculpta* than in *C. guttata*.

Costal - Characters used to differentiate costal elements from *C. picta* are described in that section. Costals of *Clemmys guttata* differ from *C. muhlenbergii* in having substantially more curvature. The dorsal surface of costals in *C. guttata* is smooth, lacking any exterior bulges or sculpturing common to adult *C. muhlenbergii*, *C. insculpta*, *Deirochelys*, *Trachemys*, and *Pseudemys*. The costals of *Emydoidea*, *Trachemys*, and *Pseudemys* exhibit immature traits when they are within the size range of *C. guttata*. *Terrapene* has deeply incised sulci, and its elements tend to be more acutely angled proximally and exhibit "bulbous" sculpturing.

Peripherals, femora, humeri, and mandible - These elements are tentatively referred to this species because they compare most closely to Recent and fossil *C. guttata*.

Remarks: The spotted turtle ranges from northern Illinois into Ohio and Ontario, east to Maine and New York, and south along the Atlantic Coastal Plain into northern Florida (Conant and Collins 1991). *Clemmys guttata* occurs most commonly in bogs or marshy pastures, but it also can be found in woodland streams. It favors habitats with soft substrates. *C. guttata* is frequently found away from water, but even so it is the least terrestrial of the three eastern species of *Clemmys* (Ernst and Barbour 1989). The fossil spotted turtle remains from the Ardis local fauna represent the oldest known material of this species (Bentley and Knight 1993), and the first fossil record for the eastern United States. Holman (1990) reports a right epiplastron from a 6,000-year-old fauna near Lansing, Michigan. Interestingly, Ernst and Barbour (1989) noted a relationship between this turtle and the burrows of muskrats, which the turtles apparently use for estivation and hibernation sites. Fossil muskrats were the most common mammals found at the Ardis site (Bentley et al. 1994) and are believed to have used the solution cavities as burrow sites. This may help to explain the abundance of this turtle at the Ardis site.

*Clemmys muhlenbergii* - Bog turtle (Schoepff, 1801)

Material: An individual consisting of a partial carapace (nuchal, 1st and 2nd left costals and peripherals, 2 peripherals, numerous shell fragments) and plastron (both epiplastra, and partial hyoplastron) (.429).

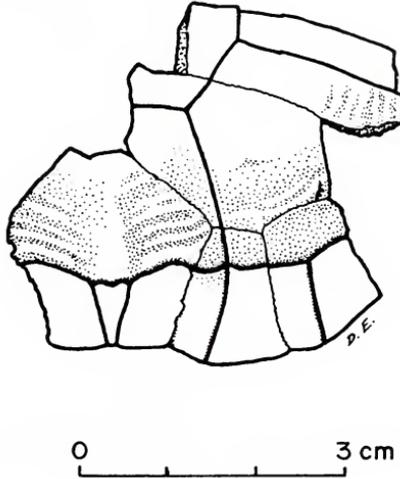
Isolated elements: 2 nuchals (.430-.431) ; 2 right epiplastra (.433-.434).

Characters used for identification: *C. muhlenbergii* fossils were distinguished from other emydid turtles based on characters listed in previous sections, along with additional nuchal and sulci characters given by Bentley and Knight (1993) (Fig.5).

Remarks: The soft bottoms and slow moving waters of swamps, bogs and marshes are typical aquatic habitats of the bog turtle (Ernst and Barbour 1989), but this turtle can also be found on land. *Clemmys muhlenbergii* has a patchy distribution in the Northeast, and ranges as far south as northern Georgia and extreme northwestern South Carolina. This disjunct spatial pattern has been interpreted as suggesting a larger former range (Smith 1957). The fossil evidence from the Ardis site suggests that the species' range extended at least 250 km farther southward during the late Pleistocene.

This is the second report of fossil material of *C. muhlenbergii* (Holman 1977) and represents the first fossil record from the eastern United States south of Allegany County, Maryland. This is the first sympatric occurrence of *C. muhlenbergii* and *C. guttata* in the fossil record.

Fig. 5 Partial fossil carapace of *Clemmys muhlenbergii* (.429). from the Ardis local fauna.



*Terrapene carolina major*- Gulf Coast Box turtle (Agassiz, 1857)

Material: An individual male specimen consisting of a partial carapace (SCSM 91.165.1) lacking its anterior edge (Fig. 6), complete plastron (SCSM 91.165.2), partial skull (SCSM 91.165.19), 8 cervical vertebrae (SCSM 91.165.10-.17), 1 humerus (SCSM 91.165.5), both scapulo-acromial processes (SCSM 91.165.6-.7), both coracoids (SCSM 91.165.8-.9), complete pelvic girdle (SCSM 91.165.3), 1 femur (SCSM 91.165.4), 1 sacral rib (SCSM 91.165.18). An individual female specimen consisting of a complete carapace (SCSM 91.163.1) and plastron (SCSM 91.163.2), 2 cervical vertebrae (SCSM 91.163.10-11), both scapulo-acromial processes (SCSM 91.163.4-.5), both coracoids (SCSM 91.163.8-9), both femora (SCSM 91.163.6-7), and complete pelvic girdle (SCSM 91.163.3). An individual female specimen consisting of a complete carapace and plastron (SCSM 91.164.1-2), 2 cervical vertebrae (SCSM 91.164.9-10), 1 humerus (SCSM 91.164.8), 1 scapulo-acromial process (SCSM 91.164.4), both coracoids (SCSM 91.164.5-6), 1 femur (SCSM 91.164.7), complete pelvic girdle (SCSM 91.164.3), and 1 caudal vertebra (SCSM 91.164. 11). An individual male specimen with complete carapace (SCSM 91.166.1) and posterior half of plastron from hinge (SCSM 91.166.2). An individual female spec-

imen consisting of a partial carapace and one half of posterior plastron from the bridge (SCSM 91.168.1). An individual female specimen consisting of a complete carapace and plastron (.435-.435.1). A individual partial carapace (SCSM 91.167.1).

Isolated elements: 8 nuchals (.459-.466); 2 right 1st costals (.471-.472); 1 fused left 7th and 8th costal (.473); 5 costals (.474-.478); 3 left 5th peripherals (.479-.481); 2 fused peripherals (1 USNM) (1 UF); 32 peripherals (.510-.541)(2 USNM)(2 UF); 2 complete, 10 partial anterior plastral lobes (.467-.469)(6 USNM)(3 UF); 1 right epiplastron (.470); 2 entoplastra (.508-.509); 2 complete, 9 partial posterior plastral lobes (.507)(5 USNM)(5 UF); 32 large shell fragments (.510-.541); 1 partial skull (.436); 1 right maxilla (.437); 3 postorbitals (.438-.440); 4 mandibles (.441-.444); 3 cervical vertebrae (.456-.458); 4 humeri (.445-.448); 4 femora (.449-.451); 4 ilia (.452-.455).

Characters used for identification: The more complete specimens are easily separated from other emydid turtles based on their hinged plastra and overall morphology. *Emydoidea* differs from the box turtle by its smooth, unkeeled carapace and tends to be anteriorly constricted (Holman 1985).

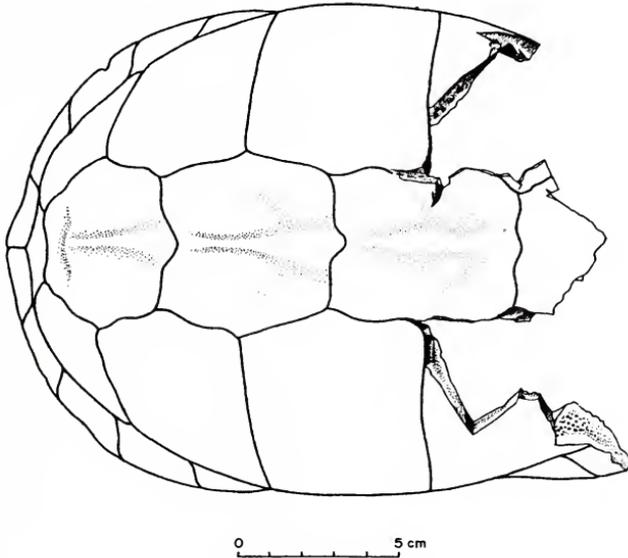
Plastron - The hinged plastral elements prevent confusion with any other emydid of North America except *E. blandingii*. The anterior end of this attachment area between the carapace and plastron differs from *E. blandingii*, as the carapace and plastron of *Terrapene* have a heavily sutured interlocking protrusion and pocket respectively. In *Emydoidea* this area lacks the sutured "ball and socket" mechanism and instead has a pronounced lateral flare generally located on the 5th marginal. The large size and robust nature of the fossil elements suggest an affinity to this subspecies.

Peripherals - These elements are distinguished by an upwardly curved anterior edge, forming, in some specimens, a "gutter-like" effect.

Humeri, femora, and ilia - Humeri and femora were separated from other emydid turtles based on comparison to Recent specimens and characters provided by Holman (1967, 1975). Iliia of *T. carolina* have a distinctive "boomerang-shape" and are straighter in other species (Holman 1977). Additionally, these fossil elements were identical to those retrieved from within the shells of the more complete fossil *T. c. major* collected from the Ardis site.

Remarks: This is the largest of the North American box turtles and today ranges from the coast of eastern Texas eastward along the Gulf coast into the Florida panhandle (Carr 1952). The Gulf Coast box turtle is commonly found in marshes, palmetto-pine forests, and upland hammocks. It enters water with a frequency similar to *T. c. carolina* (Carr 1952, Conant and Collins 1991).

Fig. 6 Partial fossil carapace of *Terrapene carolina major* (SCSM 91.165.1) which contained the skull (SCSM 91.165.19) shown in figure 6d.



Large fossil box turtle remains have generally been referred to as *T. c. putnami* or *T. c. putnami x major* (Milstead 1969). *T. c. putnami* differs from *T. c. major* only in size, attaining lengths upwards of 300 mm (Auffenberg 1967, Milstead 1969). The largest Recent specimen of *T. c. major* on record has a carapace length of 216 mm (Conant and Collins 1991). Auffenberg (1967) reported a large box turtle (233 mm), with skull, from Haile 8A, stating that it was very similar to *T. c. major*. Blaney (1971) placed *T. c. putnami* in synonymy with *T. c. major*, based on the shared characters of the two subspecies, and stated that size alone was not a justifiable reason to recognize a subspecies. The fossil box turtles from the Ardis site exhibit all the characters Milstead (1969) used to distinguish *T. c. putnami*. Furthermore, the five specimens had carapace lengths of 190.0 mm to 260.0 mm. Shell and axial elements of fossil box turtles from the Ardis site could not be consistently distinguished from Recent specimens of *T. c. major* except by size. Milstead (1969) stated that populations of *T. c. carolina* in Massachusetts and Michigan, on the northwestern edge of the subspecies range, appear to have strong morphological affinities to *T. c. major* having average carapace lengths of 140 mm and 139 mm respectively. Milstead suggested that this relationship may be due to a pre-Wisconsin influence of *T. c. putnami* or the influence of *T. c. triunguis*. An isolated, fused posterior plastral lobe (82.26 mm) collected from the Ardis site was estimated to belong to a specimen with a carapace length of about 140-145 mm. This plastral lobe might indicate the presence

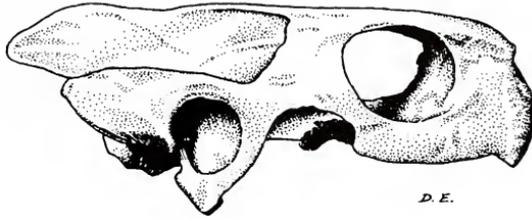
of box turtles at or near the size of the northwestern populations discussed by Milstead (1969). Additionally, several significantly smaller isolated peripherals were collected from the Ardis site, but these peripherals are largely unfused and may represent juveniles. The association of the smaller fused plastral lobe with significantly larger specimens suggests that during the height of the Wisconsin glaciation there may have been intergradation between local and northerly displaced populations of *T. c. carolina*, and populations of *T. c. major*, *T. c. triunguis*, and *T. c. bauri* radiating from the south. The Ardis population, being predominantly large box turtles, suggests that *T. c. major* traits (very large size, elongated shells, and upward curvature of peripherals) were more predominant during this time period.

The Ardis site produced two partial fossil skulls; SCSM 91.165.19 associated with a carapace of 245-250 mm. in length, and (.436), an isolated partial skull comparable in size to SCSM 91.165.19 (Fig. 6 and Fig. 7). We failed to distinguish any consistent differences between our skulls and Recent specimens except for size and an exaggerated upward curvature of the supraoccipital crest in specimen SCSM 91.165.19. This extreme curvature is considered an anomaly due to its complete absence in other fossil specimens; however, it is noted in Recent specimens but is less developed. The supraoccipital is thought to be one of the most variable cranial elements for box turtle systematics (W. Auffenberg, University of Florida, personal communication).

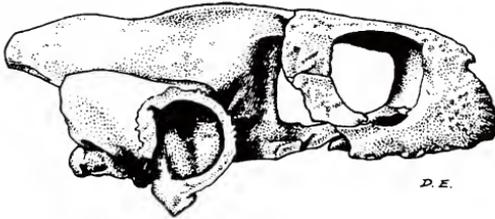
The parietals of most Recent specimens examined of *Terrapene carolina* had parietals that were inflated anteriorly, with a reduction in the tabled, dorsal surface of this element. Although extremely preliminary, we suggest a correlation between size and the degree of parietal inflation in *T. c. major*. Anterior inflation of the parietals is greatly reduced to absent among the largest specimens. In other subspecies of *T. carolina*, the inflation of the parietals remains fairly constant. The two skulls from the Ardis site do not exhibit anterior inflation of the parietals. The morphological similarities between the fossil box turtles of the Ardis site and the Recent and fossil specimens examined from museum collections (Fig. 7) suggests that the greatest affinity of the Ardis specimens is to *T. c. major*. They support the synonymy of *T. c. putnami* with *T. c. major* (Blaney 1971). Affinities noted by Milstead (1969) between northwestern populations and *T. c. major* may be a result of the proposed intergradation between box turtles during the height of the Wisconsin glaciation. The synonymy of *T. c. major* with *T. c. putnami* also suggests that *T. c. major* may have been capable of obtaining a considerably larger size than that observed in living specimens.

Although we believe a systematic revision of the genus *Terrapene* is needed, it exceeds the bounds of this faunal review. One of the goals of this discussion, however, is to emphasize the need for such a revision, based both on "standard" characters and on osteological characters of all fossil and extant forms.

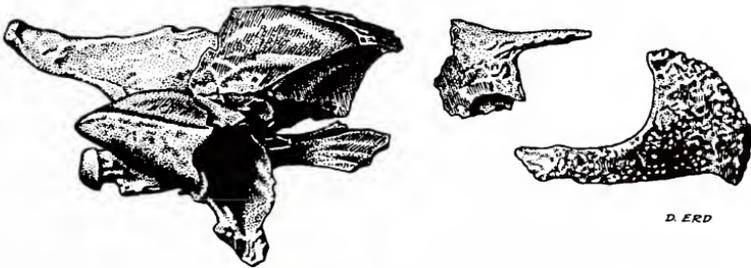
Fig. 7 *Terrapene carolina major* skulls. A) Recent (UF 18963). B) Haile 8A (UF 3148). C) Ardis fossil (SCSM 91.165.19). D) Ardis fossil (.436).



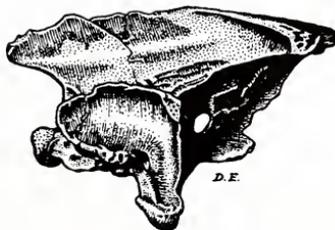
0 3 cm

**A**

0 3 cm

**B**

0 3 cm

**C**

0 3 cm

**D**

*Deirochelys reticularia* - Chicken Turtle (Agassiz, 1857)

Material: 2 peripherals (.542-.543).

Characters used for identification: Identification is based upon the distinctive "spike-like" pattern of the dorsal sculpturing on these elements (Jackson 1964, Holman 1978).

Remarks: This turtle today has a continuous range from Texas and Oklahoma through the Gulf states and along the southern half of the Atlantic Coastal Plain states into North Carolina, with isolated populations in southeastern Virginia (Conant and Collins 1991). Still-water habitats, such as ponds, swamps, marshes, and temporary pools, are commonly occupied by chicken turtles, which reportedly do not favor moving water (Ernst and Barbour 1989).

This is the first fossil record of *Deirochelys* from South Carolina. The species most extensive fossil record and probable origin is in Florida (Jackson 1978).

*Emydoidea blandingii* - Blanding's Turtle (Holbrook, 1838)

Material: An individual specimen consisting of a complete carapace, anterior plastral lobe (.544), left lower jaw (.544.1), partial hyoid (.544.2), 1 partial humerus (.544.4), 1 partial scapulo-acromial process (.544.3), 1 femur (.544.5), 3 partial dorsal vertebrae (.544.8-.544.10), 1 ilium (.544.6), 1 pubo-pectineal process (.544.7), 1 sacral rib (.544.11). An individual specimen consisting of a complete carapace, 1 phalange, 2 partial vertebrae (UF). An individual specimen consisting of a nearly complete carapace, anterior plastral lobe, 4 partial dorsal vertebrae, 3 caudal vertebrae (USNM). An individual specimen consisting of a complete carapace, posterior plastral lobe (.545), 5 cervical vertebrae (.545.1-.545.5), 2 humeri (.545.21-.545.22), 1 ulna (.545.31), 2 scapulo-acromial processes (.545.27-.545.28), 2 coracoids (.545.25-.545.26), 1 dorsal vertebra (.545.6), 2 femora (.545.23-.545.24), 1 fibula (.545.29), 1 tibia (.545.30), 1 complete pelvic girdle (.545.20), 5 phalanges (.545.32-.545.35), 1 unguis (.545.36), 2 sacral ribs (.545.37-.545.38), 13 caudal vertebrae (.545.7-.545.19). An individual specimen consisting of a complete carapace and plastron, partial skull (2 maxillae, 1 quadrate, basioccipital-condyle, basisphenoid, frontal-postorbital-parietal skull fragment) (.546), partial hyoid apparatus (.546.2), 6 cervical vertebrae (.546.3-.546.8), 1 humerus (.546.20); 2 ulnae (.546.25-.546.26), 1 radius (.546.27), 2 scapulo-acromial processes (.546.28-.546.29), 2 coracoids (.546.30-.546.31), 1 femur (.546.21), 1 tibia (.546.22), 2 fibulae (.546.23-.546.24), complete pelvic girdle (.546.19), 10 phalanges (.546.32-.546.41), 1 unguis (.546.42), 2 sacral ribs (.546.43), 10 caudal vertebrae (.546.9-.546.18). An individual specimen consisting of a complete carapace (.547). An individual specimen with the

anterior one half of the carapace (.548). An individual specimen with the anterior two-thirds of the carapace (.549). An individual juvenile specimen consisting of a partial carapace (nuchal, 1-2,4,8 neurals, pygal, 2-5, 7-11 left peripherals, 1-4 right peripherals, 3-8 right costals, 3rd left costal) and anterior lobe of plastron missing left epiplastron (.550), left xiphiplastron (.550.1), 1 dorsal vertebra (.550.2).

Isolated elements: 1 nuchal (.588); associated nuchal and 1st left and right costal with 1st left peripheral (USNM), 4 associated costals and single peripheral (.566); 1 left and 1 right 1st costal (.567-.568); 1 left 3rd costal (with rodent gnaw marks) (.569); 10 costals (.556-.565); 6 neurals (.570-.575); 3 right 1st peripherals (.576-.578); 1 left 5th peripheral (sub-adult) (.580); 1 left 6th peripheral (.579); 1 partial plastron (.607); 2 anterior plastral lobes (2 UF), 1 partial anterior plastral lobe (USNM), 2 pairs of associated epiplastra (.589-.590); 4 left and 2 right epiplastra (3 USNM)(3 UF), 7 entoplastra (.581-.587); 4 left and 6 right hyoplastra (.601-.602)(4 USNM)(4 UF); 4 posterior plastral lobes (.591)(1 USNM)(2 UF); 1 associated right hypoplastron and xiphiplastron (.592); 7 right and 8 left hypoplastra (.593-.600)(3 USNM)(4 UF); 3 right and 3 left xiphiplastra (.603-.606)(1 USNM)(1 UF); 2 partial skulls (.551-.552); 1 left postorbital (.553); 2 left auditory bullae and quadrate (.554-.555); 5 cervical vertebrae (.614-.618); 3 humeri (.608-.610); 3 femora (.611-.613); 1 partial pelvic girdle (.619).

Characters used for identification: It is possible to distinguish the more complete specimens of *Emydoidea blandingii* from *Deirochelys reticularia* on the basis of the hinged plastral elements and the lack of carapacial sculpturing in the former (Jackson 1978). Characters that distinguish this species from *Terrapene carolina* are given under that account. Isolated specimens can be distinguished from other emydid turtles based on characters mentioned in other sections of our paper and the following:

Epiplastron - *Emydoidea* epiplastron can be contrasted to *Terrapene* epiplastron in several ways. This element in *Emydoidea* differs from *Terrapene* by the presence of a depression located on the dorsal surface and medially to the anterior scute overlap area, which is less pronounced in *Emydoidea*. When compared to specimens of *Terrapene* of comparable size, this element is less robust and somewhat dorso-ventrally compressed. However, there is some difficulty in distinguishing large specimens of *T. carolina major* from *E. blandingii*. This element differs from *Trachemys* in that it is more elongated and thinner in *E. blandingii*.

Xiphiplastron - This element is most easily confused with *Clemmys*. Preston and McCoy (1971), suggested that the xiphiplastron of *Clemmys* is wider with respect to its length. Preston (1979) discusses additional characters used to identify this element in *Emydoidea*.

Neurals - These thin, very broad, smooth elements are distinctive among emydid turtles.

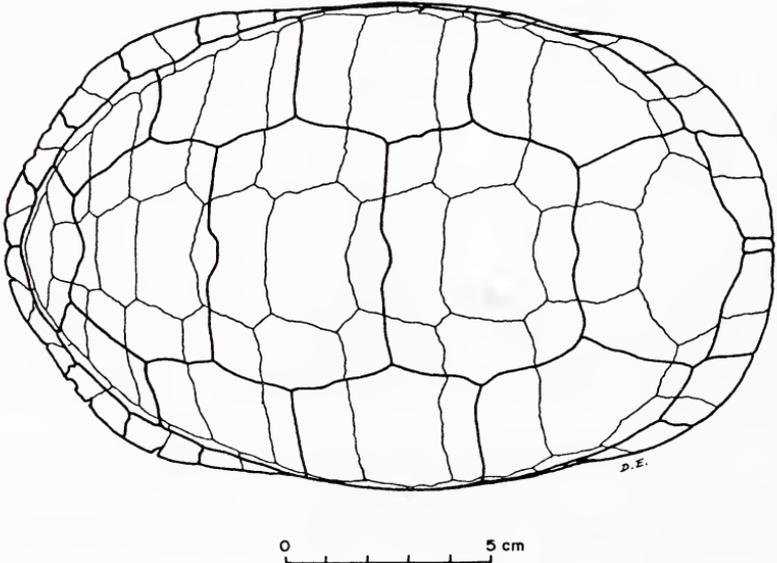
Axial and appendicular skeleton - Although cranial material of this species is distinctive, the generalized nature of the postcranial material makes the assignment to *E. blandingii* tentative.

Remarks: The recent distribution of *E. blandingii* is limited to southern Ontario and the Great Lakes region, with scattered populations occurring westward into northeastern Nebraska and south into northeastern Missouri, and eastward into New York and Massachusetts on the Atlantic coast (Conant and Collins 1991). The nearest fossil records of *Emydoidea blandingii* to the Ardis site are from Catalpa Creek, Mississippi (Jackson and Kaye 1975), and at New Trout Cave, West Virginia (Holman and Grady 1987). Both records are late Pleistocene.

The well preserved fossil material from the Ardis site (Fig. 8) is the first report of this species on the Atlantic Coastal Plain and is a range extension of about 1,200 km from its present continuous distribution and nearly 525 km south of the nearest reported fossil locality at New Trout Cave.

Habitats frequented by *E. blandingii* are generally in shallow, lentic waters with soft substrate, such as ponds, streams, marshes and sloughs (Ernst and Barbour 1989).

Fig. 8 Fossil *Emydoidea blandingii* carapace (.547).



*Trachemys scripta* - Slider Turtle (Schoepf, 1792)

Material: SCSM 91.169.1 a nearly complete carapace and plastron, partial right lower jaw, 1 scapulo-acromial process, 1 coracoid, 1 partial vertebra, partial pelvic girdle, 1 fibula. An individual specimen consisting of a partial carapace and plastron (.620).

Isolated elements; 3 nuchals (.621-.623); 23 partial costals (.624-.640)(3 USNM)(3 UF); 15 peripherals (.641-.655); 1 suprapygals (.656); 10 neurals (.657-.666).

Characters used for identification: This turtle is distinguished from other turtles by characters given by Holman (1985). Additionally, it has a diagnostic carapacial ornamentation.

Remarks: The slider has a nearly continuous distribution from Illinois southward into Texas and New Mexico and thence eastward across northern Florida north along the Atlantic coast into Virginia, with populations in Mexico and Maryland (Conant and Collins 1991). *Trachemys scripta* can be found in most freshwater habitats, but seems to prefer slow to non-moving water with a soft substrate (Ernst and Barbour 1989).

Today *Trachemys scripta* is common around the Ardis site and we have observed more than 10 within 100 m of the excavation site.

*Pseudemys* sp.-Cooters (Gray, 1855)

Material: 1 right 1st peripheral (.667); associated 9-10th right peripherals (.668); 2 peripherals (.669-.670).

Characters used for identification: These compare most favorably to species in this genus based on the thin, elongated sloping nature of the elements. We were unable to identify any diagnostic characters on these elements that could be used make a species placement. The only genus with which these may be easily confused is *Trachemys*. The fossil elements lack the sculpturing found in *Trachemys* and are significantly thinner and more elongated. The fossil peripherals also have a straight distal margin which contrasts with the notched margin in *Trachemys*.

Remarks: *Pseudemys* is a common genus of the Southeast, found in various aquatic systems (Conant and Collins 1991). The two species found in South Carolina today are *P. floridana* and *P. concinna*.

#### Testudinidae

*Hesperotestudo crassiscutata* -Giant Tortoise (Williams, 1950)

Material: 9 carapacial and plastral fragments (.671-.677)(1 USNM)(1 UF); 1 right xiphiplastron (.678); 1 vertebra (.685); 1 ungual (.686); 6 osteoderms (.679-.684).

Characters used for identification: The fragmented shell elements were assigned to this species rather than *H. incisa* on the basis of their extremely large size and robustness (40.0 mm thick). The large osteoderms, phalange, and vertebra could not be distinguished from *H. crassiscutata* in the Florida Museum of Natural History.

Remarks: Bramble (1971), Preston (1979), and Meylan (1995) place all North American non-*Gopherus* tortoises into the genus *Hesperotestudo*, and that practice is followed here. Dobie and Jackson (1979), provided the first report of (*Geochelone*) *H. crassiscutata* in South Carolina from the late Pleistocene of Edisto Island.

#### Trionychidae

*Apalone* sp.- Softshell turtle (Rafinesque, 1832)

Material: 1 partial nuchal (.47); 1 costal distal end (.48); 1 partial neural (.49).

Characters used for identification: These fossils are easily assigned to this genus, based on the relatively thin shell elements with characteristic pitting of the dorsal surfaces, general morphology, and the geographical distribution of Trionychidae. However, based on these elements, we were unable to identify a species with any certainty.

Remarks: Two species of the genus *Apalone* now occur in South Carolina, *A. ferox* and *A. spinifera*. Both species inhabit various aquatic environments with muddy or sandy bottoms in deep or shallow water (Ernst and Barbour 1989). *Apalone ferox* occurs throughout Florida and in the southern portions of Alabama, Georgia, and South Carolina. *A. spinifera* is restricted in Florida to rivers in the extreme northeastern and northwestern portions, and ranges no farther north along the Atlantic coast than North Carolina. It ranges westward into Colorado and north into Minnesota, with isolated populations in Montana, California, and

Mexico (Conant and Collins 1991). Only *A. spinifera* inhabits the area of the Ardis site today. Dobie and Jackson (1979) reported "*Trionyx* sp." from Edisto Island, South Carolina. Meylan (1987) has shown the correct name for North American softshells to be *Apalone*.

#### DISCUSSION AND PALEOECOLOGY

The turtle assemblage of the Ardis local fauna provides important new data for the late Pleistocene of the southeastern United States. In particular, it documents a shift in the spatial patterns of several turtle species during the late Pleistocene. The turtle fauna is unique in its geographical and temporal setting, and it contains the first sympatric fossil occurrences of several taxa, e.g., *Clemmys muhlenbergii*, *C. guttata*, *Emydoidea blandingii*, *Macroclemys temminckii*.

All of the fossil turtles collected from the site, except *Hesperotestudo crassiscutata* and *Terrapene carolina major*, are primarily aquatic and are commonly found in, or require, still or slow moving water with a soft substrate and aquatic vegetation (Ernst and Barbour 1989). Additional evidence of a nearby body of water included the presence of *Alligator mississippiensis* and elements of the fish fauna which are currently under study. This agrees with the habitat suggested by Bentley et al. (1994) based on the Ardis mammal fauna that indicates an ecotone between a mixed forest of conifers, hardwoods and meadows, and a permanent body of water such as a river or stream which may have given way to a bog or marsh. Portions of the mammalian fauna and avian material from the Ardis site further suggest the presence of a nearby large body of water such as a lake or pond. This association is based on the life histories and habitat requirements of many of the extant species represented in the Ardis fauna.

The Ardis turtle fauna consists of thirteen extant and one extinct species, with five taxa considered extralimital. Three of the five have northern affinities: *Emydoidea blandingii*, *Clemmys muhlenbergii*, and *Chrysemys picta*. *Terrapene carolina major* has a strong southern affinity. *Macroclemys* has a primarily Gulf coast distribution but extends as far north up the Mississippi Valley as Iowa (Pritchard 1989). Although *Hesperotestudo* was widespread in North America by the Miocene, Hibbard (1960) suggested that the presence of *Hesperotestudo crassiscutata* in a fauna indicated a mild climate with frost-free winters. The sympatric occurrence of species that are apparently ecologically incompatible today constitutes a "disharmonious fauna" (*sensu* Lundelius et al. 1983), which has been interpreted by many authors (Hibbard 1960, Holman 1980, Lindelius et al. 1983) as indicating a more equable climate (reduced seasonal temperature gradients) than that experienced in the region today. The Ardis local fauna reflects such a disharmonious biota, which clearly has no modern analogue. The turtle fauna corroborates conclusions made on the basis of the Ardis mammal fauna (Bentley et al. 1994), which also suggests that a more

equable climate than today prevailed near or during the maximum advance of the Laurentide ice sheet in the southeastern United States.

Based on the distribution of terrestrial vertebrates, Smith (1957) stated that the northeastern biota of North America was displaced southward during the Wisconsinan glacial maximum. Smith also suggested that during a "Climatic Optimum," southern counterparts dispersed northward. During the height of the Wisconsinan glaciation, *E. blandingii* would have been extirpated from its present-day northerly distribution (Mickelson et al. 1983, Conant and Collins 1991). The southern boundary of the Laurentide ice sheet, while abutted against the Appalachian Plateau (Mickelson et al. 1983), could potentially have forced the range of *E. blandingii* to be split, with one population occurring along the Mississippi Valley and another along the Atlantic Coastal Plain. This may have produced geographically isolated eastern and western populations of *Emydoidea blandingii* during the late Pleistocene.

In addition to *Emydoidea blandingii*, *Spermophilus tridecemlineatus* (thirteen-lined ground squirrel) was also collected from the Ardis site (Bentley et al. 1994). Based on Recent and fossil distributions (Kurten and Anderson 1980), the present northeastern distribution of the thirteen-lined ground squirrel also may have been displaced southward along the Atlantic Coastal Plain by the advancing Laurentide ice sheet.

As with the Gulf Coast Corridor, depressed sea levels during the Pleistocene glacial stage exposed much or all of the Atlantic continental shelf (Bloom 1983), thereby widening the Atlantic Coastal Plain. This may have facilitated the dispersal of glacially-displaced species southward along the coast. The newly emergent land area provided expanded habitats for species to utilize (Blaney 1971), and a more equable climate may have allowed for the range extension of both northern and southern species into these new areas. Northern populations of *T. c. carolina* in Massachusetts and Michigan that show affinity to *T. c. major*, discussed by Milstead (1969), may be relicts left over from a Pleistocene interval of extensive intergradation between the northerly displaced subspecies and radiating southern subspecies.

Bleakney (1958) suggested that the Recent population of *E. blandingii* in Nova Scotia survived glaciation in an "Atlantic Coastal Plain refuge" and then dispersed northward up the coast into Canada and Maine. Preston and McCoy (1971), suggested that "colonization of the Atlantic Coastal Plain from the Great Lakes region, along a 'steppe corridor' (Schmidt 1938) through the Mohawk Valley" was a more plausible hypothesis. Preston and McCoy (1971) also stated that the study of specimens from the eastern limits may provide an answer to the possibility of a "minor Atlantic Coast refuge for *Emydoidea* during ice advances." The presence of numerous *E. blandingii* at the Ardis site, as well as fossil material from New Trout Cave in West Virginia (Holman and Grady 1987), suggest that the Recent extreme northeastern populations may be products of a

re-invasion of the northeast by a substantial Atlantic Coastal Plain stock that had spread at least 900 km southward during the glacial advance of the late Pleistocene. Evidence from the Ardis local fauna indicates significant shifts longitudinally in the spatial distribution of *E. blandingii* along the Atlantic Coastal Plain during the late Pleistocene.

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## APPENDIX I

## Taxa and Minimum Number of Individuals Present

| Taxa                                | Minimum number of individuals |
|-------------------------------------|-------------------------------|
| <i>Kinosternon subrubrum</i> *      | 5                             |
| <i>Sternotherus odoratus</i> *      | 4                             |
| <i>Chelydra serpentina</i>          | 3                             |
| <i>Macrolemys temminckii</i> *      | 1                             |
| <i>Clemmys guttata</i>              | 19                            |
| <i>Clemmys muhlenbergii</i> *       | 3                             |
| <i>Chrysemys picta</i> *            | 25                            |
| <i>Deirochelys reticularia</i> *    | 1                             |
| <i>Trachemys scripta</i>            | 4                             |
| <i>Pseudemys</i> sp.                | 1                             |
| <i>Terrapene carolina major</i>     | 12                            |
| <i>Emydoidea blandingii</i> *       | 16                            |
| <i>Hesperotestudo crassiscutata</i> | 1                             |
| <i>Apalone</i> sp.                  | 1                             |

Number of turtle species = 14

Number of individuals = 96

\* = first fossil report from South Carolina

Observations of Freshwater Jellyfish, *Craspedacusta sowerbyi*  
Lankester (Trachylina: Petasidae), in a West Virginia Reservoir

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**ABSTRACT.** — A swarm of medusae of the freshwater jellyfish *Craspedacusta sowerbyi* was observed in a cove of a West Virginia reservoir in August and September, 1995. Medusae were abundant ( $>1000/m^3$ ) but extremely localized. Distribution of medusae in the cove did not appear to be linked to water chemistry. Size of medusae ranged from 6-21 mm in diameter and increased significantly with distance from the center of abundance, suggesting that the localized distribution of medusae resulted from dispersion rather than from environmentally-induced aggregation. Measurements of mean diameter of medusae on separate dates indicated a growth rate of about 0.2 mm/d, and a medusa life cycle of approximately 102 days.

The freshwater jellyfish *Craspedacusta sowerbyi* Lankester 1880 is an exotic species first observed (as medusae) in the United States in 1908 (Kramp 1950, Pennak 1989). Native to the Yang-tse River system in China (Kramp 1950), *C. sowerbyi* has been reported from many localities worldwide between 45° north and 45° south latitude (Acker and Muscat 1976, Pennak 1989). True freshwater jellyfishes are few, limited to about a dozen species worldwide (Hutchinson 1967, Pennak 1989).

*Craspedacusta sowerbyi* has been reported from 31 states and the District of Columbia; it has not been reported from northern New England, the Northern Rocky Mountains, or the Northern Great Plains (DeVries 1992). In West Virginia there are records of *C. sowerbyi* from Barbour, Fayette, Mercer, Monogalia, Wayne, and Wood counties (Reese 1940, Lytle 1962, Koryak and Stafford 1981, and D. Tarter, Marshall University, personal communication).

*Craspedacusta sowerbyi* has two life stages, a free-swimming medusa (10-20 mm diameter), and a sessile hydroid polyp (1 mm long, Acker and Muscat 1976). Lytle (1959) reviewed the developmental biology of the species. Medusae of *C. sowerbyi* appear sporadically in lentic and even less frequently in lotic ecosystems in the United States (Acker and Muscat 1976, Beckett and Turanchik 1980, DeVries 1992). Usually a swarm of medusae appears in sum-

mer where it has never before been observed or where it has not been observed for many years (Slobodkin and Bossert 1991). Lentic systems in which the medusae have been observed include reservoirs, natural lakes, ponds, quarries, ornamental pools, and aquaria.

Specific environmental factors associated with the formation of medusae from polyps via asexual reproduction (budding) are poorly understood. Factors suggested include increasing water temperature (McClary 1959) increased alkalinity (Koryak and Clancy 1981, McCullough et al. 1981), increasing dissolved CO<sub>2</sub> (Acker and Muscat 1976), decreasing stream flow (Brussock et al. 1985), changing reservoir levels (Deacon and Haskell 1967) and increasing supply of zooplankton (Lytle 1959), on which the medusae prey.

Dispersal of *C. sowerbyi* among water bodies probably occurs via polyps attached to aquatic plants or waterfowl, or in tanks used to transport fish (Byers 1945, Bushnell and Porter 1967, Howmiller and Ludwig 1970). The polyps can survive in moving water (Hutchinson 1967), so once the polyps enter a river system, the medusae may eventually appear in downstream reservoirs (e.g., Yeager 1987).

Because the medusae occur unpredictably and the polyps are microscopic and easily overlooked, the complete geographic distribution and ecology of *C. sowerbyi* are not well known. Field studies have been mostly descriptive (e.g., Garman 1916, Deevy and Brooks 1943, Dexter et al. 1949, Chadwick and Houston 1953, Bushnell and Porter 1967, Koryak and Clancy 1981, McCullough et al. 1981, Dodds and Hall 1984). Deacon and Haskell (1967) examined diel activity patterns of medusae at Lake Mead, Nevada. Dodson and Cooper (1983) examined trophic relationships of the medusae in the laboratory. Acker and Muscat (1976) and DeVries (1992) reviewed the literature on the ecology of *C. sowerbyi*.

The purpose of this paper is to describe a swarm of *C. sowerbyi* medusae I observed at Stonewall Jackson Lake, Lewis County, West Virginia, in August and September 1995. My initial observations of the medusae at Stonewall Jackson Lake suggested that the size distribution of medusae varied with distance from the main concentration of medusae (swarm). I hypothesized that the distribution of medusae resulted from dispersion from the apparent population center at the swarm, and I predicted that medusae collected away from the main swarm location would be larger than medusae within the swarm because more distant medusae would have had more time to grow. The null hypothesis that medusae collected from all locations have the same size class distribution implies that the dense concentration of medusae at the swarm location results primarily from aggregation due to water chemistry, temperature, food, current, wind, or some other factor rather than from dispersion. I collected and measured specimens to test this hypothesis. I also compared the mean size of

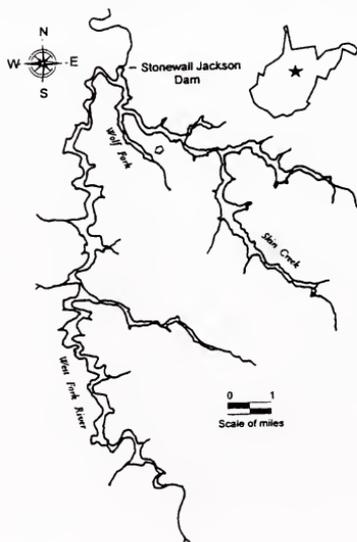
specimens collected on separate dates to calculate an approximate growth rate for the medusae.

### METHODS

I observed the medusae at Wolf Fork (80°28'W, 38°59'N), a cove formed by a flooded tributary to Skin Creek which forms the east arm of Stonewall Jackson Lake (Fig. 1). Wolf Fork is about 1.5-km long and 30-150-m wide and has abundant flooded timber. The cove is well sheltered from winds and is a no-wake boating zone. A culvert connects Wolf Fork and the stream draining the upper watershed. Stonewall Jackson Lake is a 1,070-ha Army Corps of Engineers reservoir filled in 1986. The main West Fork River arm of the reservoir is a tributary of the Tygart River in the Ohio River drainage.

During my initial visit to Wolf Fork (16 August 1995) I estimated the density (number  $m^{-3}$ ) of medusae using two methods. Where the medusae were abundant I used a 20-L plastic bucket. From a small boat I slipped the bucket into the water and withdrew it with minimal turbulence. I poured the bucket contents through a fine sieve and transferred the medusae to a tray for enumeration. Where the medusa were scarce, I estimated the density visually. Both methods are biased toward the upper 0.5 m of water surface because I could not see or sample medusa at greater depths. On the first visit to Wolf Fork I collected water samples and recorded water temperature and dissolved oxygen at several locations in the cove. Water samples were analyzed at the U.S. Forest Service Timber and Watershed Laboratory, Parsons, West Virginia.

Fig. 1 Map of Stonewall Jackson Lake showing the swarm location at Wolf Fork. Inset map shows location of the reservoir in West Virginia.



On subsequent visits to Wolf Fork (16 August and 12 September 1995) I collected medusae with an aquarium dip net from a small boat. I measured bell diameter of live specimens under a dissecting microscope by placing a ruler under a clear plastic petri plate containing a few medusae and a small amount of water. I judged measurement error to be  $\pm 1.0$  mm.

## RESULTS

On 16 August 1995, I observed a dense swarm of medusae near the head of Wolf Fork. Medusae decreased greatly in abundance with distance from the swarm. Density of medusae in three bucket samples was 1.2, 1.9, and 4.8 medusa/L. This is approximately equivalent to 1,000-5,000 medusae/m<sup>3</sup> in the upper 0.5 m of the water column within an area of about 25 m<sup>2</sup>. At 100-200 m from the swarm (toward the main channel of the reservoir) there were 10-50 medusae/m<sup>3</sup>; at 300-400 m medusae were scarce ( $<1$  medusa/m<sup>3</sup>). I did not observe medusae in lower Wolf Fork, the main channel, or in other coves of Skin Creek, although I did not make an exhaustive search. My conversations with anglers, reservoir managers, and local fish biologists suggest that this is the first record of *C. sowerbyi* at Stonewall Jackson Lake. The origin of *C. sowerbyi* in the drainage is unknown.

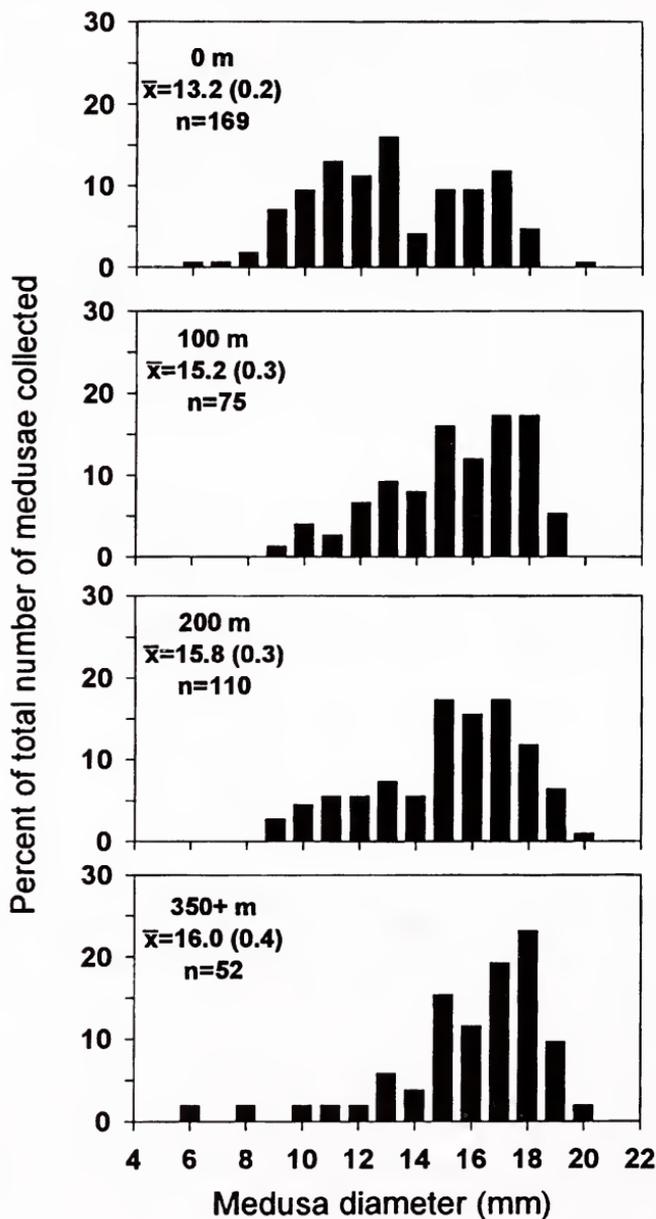
Table 1. Selected water quality measurements for Wolf Fork, 16 August 1995. Site distances are from the swarm toward the main channel. All values for samples collected at the water surface. DO=dissolved oxygen.

| Site (m) | Temp C | DO (mg/L) | pH  | Conductivity $\mu$ S/cm | Alkalinity mg/L (CaCO <sub>3</sub> ) | SO <sub>4</sub> (mg/L) | Ca (mg/L) | Medusa abundance (#/m <sup>3</sup> ) |
|----------|--------|-----------|-----|-------------------------|--------------------------------------|------------------------|-----------|--------------------------------------|
| -100     | 30.0   | 7.7       | 7.0 | 98.3                    | 19.1                                 | 21.9                   | 12.1      | <1                                   |
| 0        | 30.0   | 8.1       | 7.0 | 100.5                   | 18.2                                 | 21.6                   | 12.8      | 1000-5000                            |
| 100      | 30.5   | 8.3       | 7.1 | 99.8                    | 17.8                                 | 22.0                   | 12.5      | 10-50                                |
| 200      | 30.5   | 8.3       | 7.2 | 99.6                    | 17.5                                 | 23.7                   | 12.6      | <1                                   |
| 300      | 30.5   | 8.3       | 7.2 | 98.1                    | 17.2                                 | 22.6                   | 12.7      | <1                                   |

Water chemistry did not differ appreciably among sites within Wolf Fork (Table 1). Dissolved oxygen decreased with depth to 5 mg/L at 2.1 m and 1.8 mg/L at 2.7 m. Depth of the channel in Wolf Fork was 2.5-3.5 m. Flow from the Wolf Fork watershed (the stream) into Wolf Fork (the cove) could not be detected at the culvert.

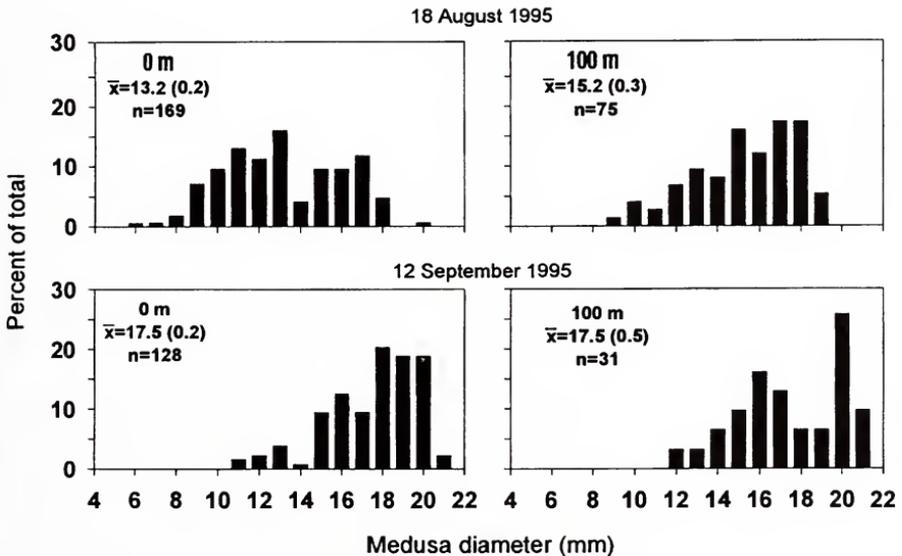
On 18 August 1995, medusae collected ranged in size from 6 to 20 mm (Fig. 2). Mean (SE) size and size class distribution of medusae collected from the swarm location were different from medusae collected at three other stations in Wolf Fork. Swarm medusae were 13.3 (0.2) mm in diameter; medusae from outside the swarm were 15.2 (0.3) to 16 (0.4) mm in diameter depending on col

Fig. 2 Size distribution of *C. sowerbyi* medusae collected 0, 100, 200, and 350+ m from a dense concentration (swarm) of medusae at Wolf Fork, Stonewall Jackson Lake, West Virginia on 18 August 1995. Figure legends give distance from the main swarm location, mean (SE) medusa diameter and sample size.



lection site, a significant difference (Kruskal-Wallis ANOVA on Ranks;  $H = 75.1$ ,  $P < 0.01$ ). Among sites outside the swarm location, there was also a trend of increasing size with distance from the swarm; mean medusa diameter was largest 350 m from the swarm, the location at which medusae were first observed when entering Wolf Fork from the reservoir. Within the swarm there was a bimodal size distribution of medusae concentrated in 9 - 13 mm and 15 - 18 mm size classes, with more medusae in the smaller size classes. Away from the swarm most medusae were in the larger size classes, but a semblance of the bimodal pattern was apparent (Fig. 2).

Fig. 3 Size distribution of *C. sowerbyi* medusae collected 0 and 100 m from a dense concentration (swarm) of medusa at Wolf Fork, Stonewall Jackson Lake, West Virginia on 18 August and 12 September 1995. Otherwise as for Fig. 2.



On September 12, I observed fewer medusae than on previous visits to Wolf Fork. Water temperature was 25 C, and reservoir level had dropped about 1 m since the previous visit. The sky was overcast and light rain was falling, whereas the sun shone on previous visits. Medusae were most abundant near the 18 August swarm site; at 100 m they were scarce, and were not observed elsewhere. Mean diameter of medusae was the same at both locations (Fig. 3), although more medusae from the 100 m site were in the largest size classes (20-21 mm). Between August 18 and September 12, mean diameter of medusae at the swarm location increased slightly more than 4 mm (Fig. 3). This is equiva-

lent to an average growth rate of about 0.2 mm/d. Assuming the medusa stage originates at about 0.5 mm and attains a maximum size of about 21 mm (Pennak 1989), this rate of growth indicates a life cycle for the medusa of about 102 days. The apparently slower growth of medusae away from the main swarm (Fig. 3) may be attributed to disproportionate mortality of the full-growth medusae.

## DISCUSSION

I observed great variation in abundance of medusae over a scale of a few meters that is not readily explained by available water chemistry data. My finding of larger individuals away from the main concentration of medusae is circumstantial evidence that spatial variation in abundance of the medusae results from dispersion from a highly localized swarm location.

If the polyps are lotic (Hutchinson 1967), then the distribution of the medusae in Wolf Fork results from events and conditions since delivery of immature medusae from upstream earlier in summer. During most of the year, flow from the stream would induce some current at the head of Wolf Fork, and the location and localization of the swarm at Wolf Fork may have resulted from flow-related concentration (e.g., in an eddy) of polyps or small medusae originally exported from the stream.

Several authors have also found a highly localized distribution of medusae. Dodson and Cooper (1983) found medusae only in one small sheltered cove of a Wisconsin Lake. Deacon and Haskell (1967) reported medusae from sheltered coves at Lake Mead, Nevada, and not from the open waters of the reservoir. Garman's (1916) description of the location of a dense swarm in a narrow flooded tributary of an impounded reach of the Kentucky River is similar to Wolf Fork and to other published accounts (e.g., Lytle 1962).

Few authors have explicitly commented on factors accounting for spatial variation in medusae abundance within a reservoir or lake. Acker and Muscat (1976) noticed an apparent effect of light on the distribution of medusae which they attributed to a direct light effect or to an indirect effect of light on food concentration. Other factors such as wind (Deevy and Brooks 1943), and ebullition (Koryak and Stafford 1981) have been proposed. I noticed no apparent light effect at Wolf Fork, and the cove is well protected from wind and boat-wake disturbance; these factors are unsatisfactory for explaining the large local variation in abundance of medusae at Wolf Fork. My observations suggest instead that the distribution of medusae may result from the pattern of dispersion from a location that is determined by the habitat requirements of the polyps in the reservoir or in tributary streams.

My observation of a bi-modal size distribution of medusae (Fig. 2) suggest the possibility of more than one period of medusa formation at Wolf Creek, perhaps associated with variation in water temperature, water chemistry, or streamflow during early summer. McClary (1959) reported medusa budding

only within a narrow temperature range, 26 C to 33 C. However, I found very few small (<8 mm) medusae in August while sampling within this temperature range (Fig. 2) suggesting that formation of medusae was not ongoing and most likely occurred during two periods in early summer.

#### ACKNOWLEDGMENTS

Cliff Brown of the West Virginia Division of Natural Resources provided access to Wolf Fork. Emmett Fox conducted water quality analysis. Neal Auvil brought the jellyfish to my attention. Linda Plaughter assisted with the figures.

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# Distribution and Status of Selected Fishes in North Carolina, With a New State Record

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**ABSTRACT** - We made status surveys of 22 state-listed fishes in the French Broad River, Nolichucky River, and Dan River systems from 1991-1995 from 105 collections at 99 sites made by us, augmented by data from 146 collections made by others, personal communications, and the literature. We believe state-listed endangered *Polyodon spathula* and *Percina sciera* have been extirpated from the state whereas *Exoglossum maxillingua*, *Thoburnia hamiltoni*, *Noturus flavus*, *N. gilberti*, and *Percina burtoni* are either secure or rare. All six threatened species surveyed were collected. Of these, *Lampetra appendix*, *Cyprinella monacha*, *Cottus carolinae*, and *Aplodinotus grunniens* probably warrant being elevated to state-endangered status, whereas *Luxilus chrysocephalus* and *Percina caprodes* appear to be secure. Nine species of special concern were surveyed. *Noturus eleutherus* and *Etheostoma simoterum* are presumed to be extirpated from the state and *Acipenser fulvescens*, *Hiodon tergisus*, and *Carpionides carpio*, if not extirpated, probably do not now have reproducing populations in North Carolina. *Etheostoma vulneratum* is restricted to the Little Tennessee River system and *Percina squamata* occurs in low numbers in the French Broad, Hiawassee, Little Tennessee, and Nolichucky river systems. Both warrant consideration for elevation to threatened status.

*Scartomyzon ariommus* and *Etheostoma podostemone* have apparent healthy populations in the Dan River system. The first record of *Ichthyomyzon bdellium* from North Carolina is presented.

The North Carolina Wildlife Resources Commission lists 9 species of fishes in this state as endangered, 11 as threatened, and 30 as of special concern (Article 25, Chapter 113 of General Statutes of the State of North Carolina, 1987, amended 1991). Since 1988 we have surveyed some of these species, and to date have reported on the distribution and status of the sandhills chub, *Semotilus lumbee*, and the pinewoods darter, *Etheostoma mariae* (Rohde and Arndt 1991), and of the sharphead darter, *E. acuticeps* (Rohde and Arndt 1994). In this paper we add new, and summarize existing, data on the distribution and status of 22 of the 25 state-listed fishes that occur in the North Carolina portions of the French Broad and Nolichucky river systems (Tennessee River drainage) and in the Dan River system (Roanoke River drainage). The former are located in the Blue Ridge Physiographic Province and the Dan River headwaters are located in Appalachian Mountain remnants in north central North Carolina in the Piedmont Physiographic Province. We also provide records on a species of fish new to North Carolina.

Three endangered, five threatened, and nine of special concern fish species (34% of the state total) occur in the French Broad River system; two endangered, two threatened, and one species of special concern (10% of the total) occur in the Nolichucky River system; and three endangered and two of special concern fishes (10% of the total) occur in the Dan River system (Table 1).

#### SURVEY AREAS

The French Broad River originates in North Carolina and runs some 166 river kilometers (rkm) to where it enters Tennessee and drains approximately 4,163 km<sup>2</sup> of North Carolina (Fig. 1). River elevation over this reach (Fig. 2) drops from 640 m to 378 m; river gradient from its headwaters to Asheville is 2.6 m/km and from Asheville to the Tennessee border is 5.2 m/km (Richardson et al. 1963). Redmon Dam near Marshall in Madison County, North Carolina, prevents upstream movement of fishes, and six species that might be expected to occur farther upstream are known only from below the dam (Menhinick 1986).

The Nolichucky River and its three major tributaries (Fig. 2), the Cane, North Toe, and South Toe rivers, drain an area of about 1,666 km<sup>2</sup> (Crowell 1965). The Nolichucky River enters Tennessee at an elevation of 539 m (Crowell 1965), and joins the French Broad River at Douglas Reservoir in Jefferson County, Tennessee (Fig. 1).

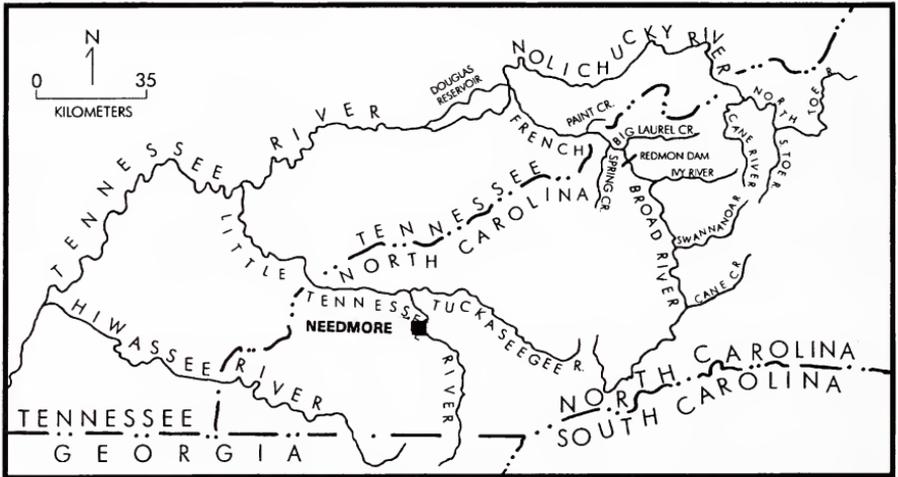
Table 1. List (1991) of endangered, threatened, and special concern fishes found in the mountainous portions of North Carolina (from Article 25, Chapter 113 of General Statutes of the State of North Carolina, 1991).

| Scientific Name                | Common Name         | River System     | Occurrence |
|--------------------------------|---------------------|------------------|------------|
| ENDANGERED                     |                     |                  |            |
| <i>Polyodon spathula</i>       | Paddlefish          | French Broad     |            |
| <i>Exoglossum maxillingua</i>  | Cutlips minnow      | Dan              |            |
| <i>Scartomyzon hamiltoni</i>   | Rustyside sucker    | Dan              |            |
| <i>Noturus flavus</i>          | Stonecat            | Nolichucky       |            |
| <i>Noturus gilberti</i>        | Orangefin madtom    | Dan              |            |
| <i>Percina burtoni</i>         | Blotchside logperch | French Broad     |            |
|                                |                     | Nolichucky       |            |
| <i>Percina sciera</i>          | Dusky darter        | French Broad     |            |
| THREATENED                     |                     |                  |            |
| <i>Lampetra appendix</i>       | Amer. brook lamprey | French Broad     |            |
| <i>Cyprinella monacha</i>      | Spotfin chub        | French Broad     |            |
|                                |                     | Little Tennessee |            |
| <i>Hybopsis rubrifrons</i>     | Rosyface chub       | Savannah         |            |
| <i>Luxilus chrysocephalus</i>  | Striped shiner      | Nolichucky       |            |
| <i>Etheostoma acuticeps</i>    | Sharphead darter    | Nolichucky       |            |
| <i>Percina caprodes</i>        | Logperch            | French Broad     |            |
|                                |                     | New              |            |
| <i>Aplodinotus grunniens</i>   | Freshwater drum     | French Broad     |            |
| <i>Cottus carolinae</i>        | Banded sculpin      | French Broad     |            |
| SPECIAL CONCERN                |                     |                  |            |
| <i>Acipenser fulvescens</i>    | Lake sturgeon       | French Broad     |            |
| <i>Hiodon tergisus</i>         | Mooneye             | French Broad     |            |
| <i>Clinostomus funduloides</i> | Rosyside dace       | Little Tennessee |            |
| <i>Notropis lutipinnis</i>     | Yellowfin shiner    | Little Tennessee |            |
|                                |                     | Savannah         |            |
| <i>Phenacobius teretulus</i>   | Kanawha minnow      | New              |            |
| <i>Carpionodes carpio</i>      | River carpsucker    | French Broad     |            |
| <i>Scartomyzon ariommus</i>    | Bigeye jumprock     | Dan              |            |
| <i>Noturus eleutherus</i>      | Mountain madtom     | French Broad     |            |
| <i>Etheostoma inscriptum</i>   | Turquoise darter    | Savannah         |            |
| <i>Etheostoma jessiae</i>      | Blueside darter     | French Broad     |            |
| <i>Etheostoma podostemone</i>  | Riverweed darter    | Dan              |            |
| <i>Etheostoma simoterum</i>    | Snubnose darter     | French Broad     |            |

Table 1. Continued.

|                              |                  |  |
|------------------------------|------------------|--|
| <i>Etheostoma vulneratum</i> | Wounded darter   | French Broad<br>Little Tennessee                           |
| <i>Percina macrocephala</i>  | Longhead darter  | French Broad   |
| <i>Percina oxyrhyncha</i>    | Sharpnose darter | New  |
| <i>Percina squamata</i>      | Olive darter     | French Broad<br>Hiwassee<br>Little Tennessee<br>Nolichucky |

Fig. 1. Upper Tennessee River drainage, North Carolina and Tennessee.



The Dan River is the major southern tributary to the Roanoke River. It originates on the Blue Ridge uplands in south central Virginia and, after a course of 59 rkm, enters North Carolina in northwest Stokes County; it crosses the state line five more times before joining the Roanoke River at Kerr Reservoir in Halifax County, Virginia (Fig. 3). The 140 rkm North Carolina portion drains approximately 4,410 km<sup>2</sup> of the state. River elevation drops from 366 m at the point where it first enters North Carolina to 140 m where it first exits North Carolina in northeast Rockingham County (from U.S. Geological Survey 7.5 minute series topographic maps).

Fig. 2. French Broad and Nolichucky river systems, North Carolina.

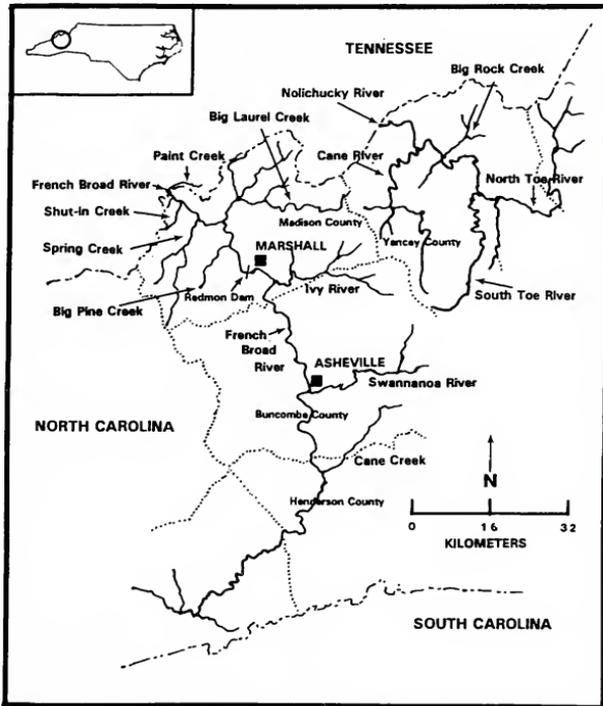
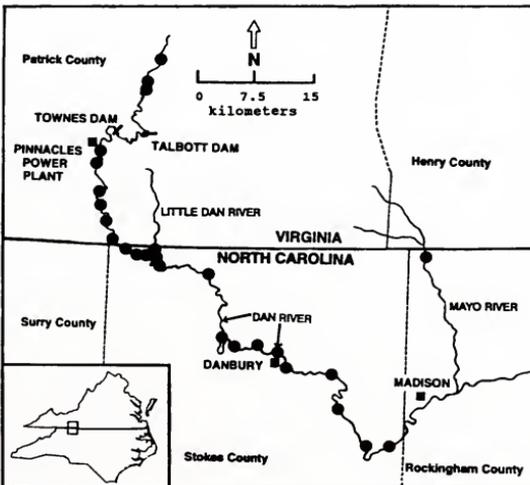
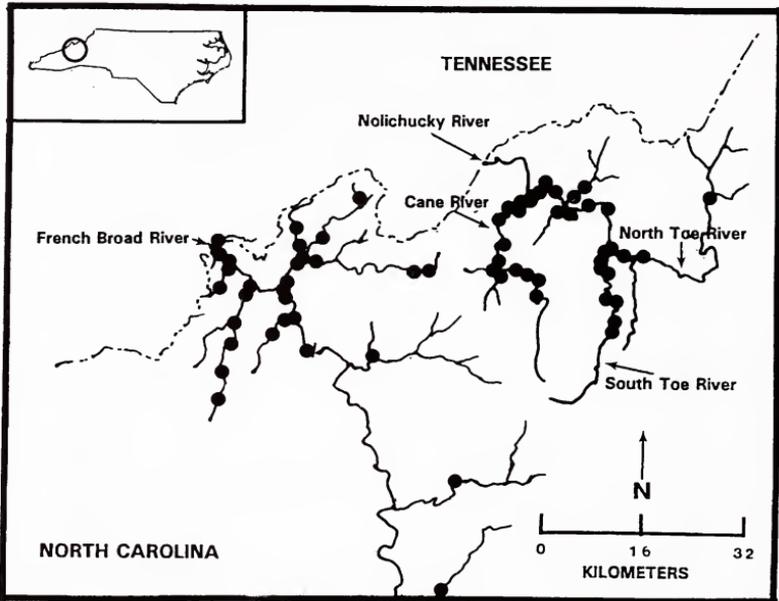


Fig. 3. Dan River system with sites (dots) we sampled from July 1992 to May 1995. Some dots overlap.



All three rivers are generally bordered by forest, although some land is pasture. River substrate ranges from bedrock to boulders to cobble to silt.

Fig. 4. French Broad and Nolichucky river systems with sites (dots) we sampled from July 1991 to April 1995. Some dots overlap.



#### METHODS AND MATERIALS

We sampled 99 sites in 105 collections: 32 sites in the lower reach of the French Broad River and some of its tributaries from May 1994 to May 1995, and at 2 sites in the middle reach of the river in September 1993 (Fig. 4); 39 sites in the Nolichucky River system between July 1991 and November 1994 (Fig. 4); and 15 sites in the Dan River and in 2 of its tributaries 25 times from July 1992 to May 1995 (Fig. 3). We sampled most sites only once, although four sites each in the French Broad and Nolichucky rivers were each sampled twice. We also sampled 11 sites in the Virginia portion of the upper Dan River from November 1993 to October 1994 (Fig. 3). All site locations and dates are available from the senior author. In addition, we include data from 146 collections made by others, other personal communications, and from the literature.

We sampled primarily with a backpack electroshocker and seine, using the technique described by Jenkins and Burkhead (1975). Each site was electrofished for 45-190 minutes, i.e., until we believed that sampling had been com-

prehensive. However, in the French Broad and in the Nolichucky rivers, we sampled 12 sites in 1991 and 2 in 1994 only by seine (3.05 m x 1.2 m, 0.64 cm mesh), and we sampled 2 sites in the former river in 1994 only by a 25 m, 14 cm stretched mesh monofilament gill net and a 50 m, 5.1 cm stretched mesh monofilament gill net. The nets were deployed overnight and fished on consecutive days for a total of six net days. In the Dan River in 1992 and in 1994, we sampled two sites in each year only by seine (size as above). At five sites in the North and South Toe rivers, in addition to sampling with electroshocker and seine, we also surveyed fishes underwater by snorkeling. In all sampling efforts, the known preferred habitat for each species was sampled most intensively.

In addition to the fishes taken, data on stream depth, width, and substrate type; current; air and water temperatures; pH; and dissolved oxygen concentration were often recorded at a site, and we include these data when available. Fishes were preserved in 10% formalin upon capture for subsequent examination. Fish measurements when available are given; TL is total length and SL is standard length. We deposited preserved specimens in the North Carolina State Museum of Natural Sciences in Raleigh. Scientific and common names of fishes used herein follow Mayden et al. (1992), except for *Cyprinella monacha* which follows Jenkins and Burkhead (1994).

We include figures that show all of our known fish capture localities in North Carolina. In our species accounts we occasionally include records of fishes taken in portions of adjacent states in an effort to make the accounts more accurate and complete.

Positive results are gratifying, but, as usual, negative results are not necessarily conclusive. When fish populations in rivers and large creeks decrease strongly, it becomes virtually impossible to differentiate between occurrence at a low level and extirpation (Etnier 1994).

## RESULTS AND DISCUSSION

### TENNESSEE RIVER DRAINAGE

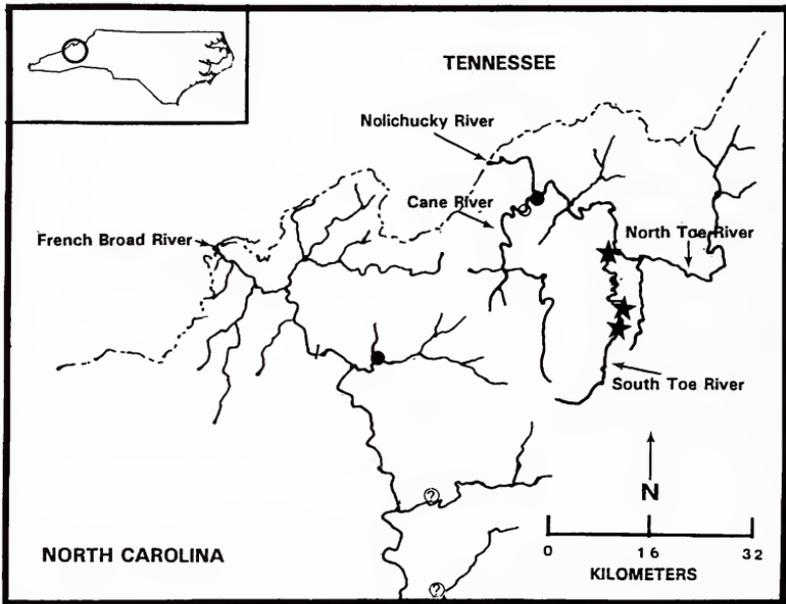
#### ENDANGERED SPECIES

##### Paddlefish, *Polyodon spathula* (Walbaum)

The paddlefish once occurred throughout the Mississippi River and its larger tributaries, but its distribution has decreased coincidental with river channelization, damming, and overfishing (Burr 1980). Cope (1870) maintained that it migrated up the French Broad River as far as Asheville in Buncombe County, North Carolina. Fishermen in this state reported that it had been caught in the lower reaches of the French Broad River as recently as 1983, but none of these reports has been substantiated by specimens (E. Menhinick, personal communication, 1994). We sampled with large-mesh gill nets in the French Broad River downriver of Hot Springs and in the river at the mouth of Big Laurel Creek, both Madison County, North Carolina, on 14 and 15 May and 15 and 16 August, 1994,

respectively. Swift currents limited our efficiency. We caught no paddlefish. Local fishermen in Madison County whom we questioned in 1994 told us that they had never seen a paddlefish from North Carolina nor heard of one caught there. We presume that the paddlefish has been extirpated from North Carolina.

Fig. 5. Distribution of the stonecat, *Noturus flavus*, (circle) and the blotchside logperch, *Percina burtoni*, (star) in the French Broad and Nolichucky river systems, North Carolina. An open circle overlaps two historical sites where the stonecat was not taken in this survey. Specific historical sites for the blotchside logperch in Cane Creek and the Swannanoa River are not known and are plotted as circles with a question mark.



#### Stonecat, *Noturus flavus* Rafinesque

The stonecat is distributed through portions of the Mississippi River basin, the Great Lakes, the Ohio River basin, and the St. Lawrence, Mohawk, and Hudson River systems (Rohde 1980). In North Carolina it is documented from only three sites in the Cane River, where it was collected on 18 June (one specimen) and 26 June (six), 1984, and 15 September 1985 (two) (Menhinick 1986). Despite our efforts to collect it at all three sites, we took two adults (photographed and released) only at the downstream-most site on 4 September 1993 (Fig. 5).

We record it here for the first time from the Ivy River, a tributary to the French Broad River, from upstream of Marshall in Madison County, North Carolina, where we took three adults (90-99 mm SL) on 14 August 1994 (Fig. 5). One adult (86 mm TL) and one specimen (released, not measured) were collected in the Little Tennessee River at Needmore in Swain County, North Carolina, by Tennessee Valley Authority (TVA) personnel on 20 June 1994 (E. Scott, personal communication, 1994) (Fig. 1). This site had been sampled five times by TVA biologists during the period 1988-1993 and once by us in 1993. The discovery of the species there in 1994 was unexpected. Preferred habitat was gravel riffles. Current at the Ivy River site was 0.31 m/sec, water temperature 20.6 C, pH 8.0, and dissolved oxygen concentration 8.0 ppm. Its status of endangered in North Carolina is warranted.

#### Blotchside logperch, *Percina burtoni* Fowler

The blotchside logperch occurs in disjunct populations in the Tennessee River drainage from westcentral Tennessee to southwestern Virginia (Page and Burr 1991); where it occurs it is localized and rare (Etnier 1994). In North Carolina it was taken at one site in Cane Creek (Henderson County) in 1902, at one site in the Swannanoa River (Buncombe County) in 1934, and at two sites in the South Toe River (Yancey County) in 1975 and 1977 (Menhinick 1986) (Fig. 5). We collected two adults (120 mm SL, one released) at a new locality in the South Toe River near its confluence with the North Toe River in September 1993. Since we noted that this fish can readily avoid electroshockers and seines, we observed 2 to 6 adults in each of 4 visits by snorkeling at the two upstream historic sites in the South Toe River in July and September 1993 and August 1995 (Fig. 5). Preferred habitat was in pools below riffles. Menhinick (1986) presumed *P. burtoni* to have been extirpated from the Swannanoa River and from Cane Creek since he did not obtain it there in 14 collections nor did the North Carolina Division of Environmental Management in 5 collections (V. Schneider, personal communication, 1994). We did not collect it in either stream in two collections made there in 1993, and we concur with Menhinick (1986). Its continued presence in North Carolina is tenuous.

#### Dusky darter, *Percina sciera* (Swain)

The dusky darter occurs from the Wabash River drainage in Indiana south and west to the Guadalupe River drainage in Texas and east to the Tombigbee-Black Warrior river system in Alabama (Page 1980). In North Carolina it is known only from Spring Creek, Madison County, where U.S. Forest Service personnel collected one specimen in 1966 and one in 1969 (Auburn University Collection 3442), although the specific sites are now not known (M. Seehorn, personal communication, 1994). We made 13 collections at 7 sites with suitable habitat in Spring Creek over a distance of 27.3 rkm in 1994 and 1995. We did not collect it. Apparently never widespread or common in North Carolina, we

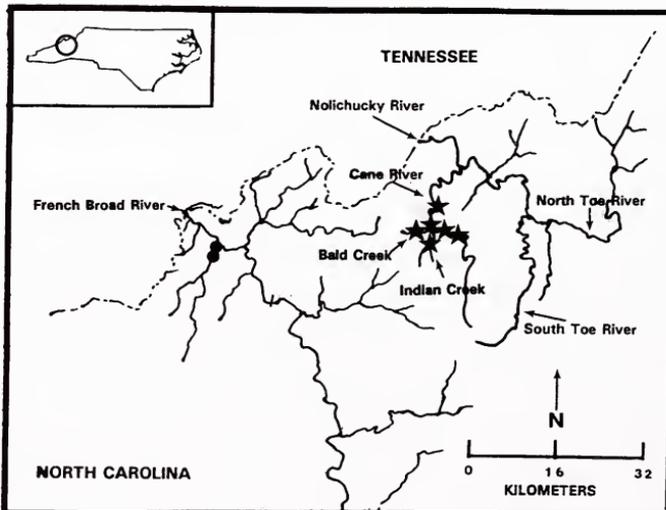
consider the dusky darter to have been extirpated from this state by unknown causes. It appears to be a relatively tolerant species in other portions of its range.

### THREATENED SPECIES

#### American brook lamprey, *Lampetra appendix* (DeKay)

The American brook lamprey is widely distributed in the St. Lawrence and Mississippi river basins from New York to northern Arkansas, and on Atlantic Slope drainages from southern Quebec south to the Roanoke River drainage in Virginia (Page and Burr 1991). In North Carolina it was known from only one site in the downstream reach of Spring Creek, Madison County, at a point where a railroad trestle crosses this creek, where 26 individuals were taken in 1980 and 1 in 1983 (Menhinick 1986). We took one adult some 200 m downstream of the above site (and about 50 m upstream of the confluence of Spring Creek with the French Broad River, Madison County) on 22 April 1995 (Fig. 6), and two adults on the same day, also in Spring Creek at a point about 0.9 rkm above this confluence. They were males and measured 144, 147, and 157 mm TL. All were taken in gravel riffles where the current was 0.45 m/sec. We collected one ammocoetes of 152 mm TL in a sandy-bottomed pool about 50 m downstream of the last-mentioned Spring Creek site on 14 August 1994. The pH here was 6.9, and the dissolved oxygen concentration was 8.4 ppm. This species appears to be restricted to this creek in North Carolina. Its status of threatened in North Carolina appears to be conservative.

Fig. 6. Distribution of the American brook lamprey, *Lampetra appendix*, (circle) and the striped shiner, *Luxilus chrysocephalus*, (star) in the French Broad and Nolichucky river systems, North Carolina. Some symbols overlap sites.



Spotfin chub, *Cyprinella monacha* (Cope)

The spotfin chub is endemic to the Tennessee River drainage in disjunct populations from southwestern Virginia to northwestern Alabama and in the Buffalo River in central Tennessee (Jenkins and Burkhead 1984, Etnier and Starnes 1994). It has apparently been extirpated from Alabama and Georgia (Etnier and Starnes 1994). In North Carolina it is restricted to a 16.8 rkm section of the Little Tennessee River in Macon and Swain counties (Alderman 1987). We collected and released 27 spotfin chub in this river at Needmore in Swain County (Fig. 1) on 25 September 1993. Three previous North Carolina records, two from the French Broad River system (1888) and one from the Tuckasegee River (1940), apparently represent now extirpated populations (Menhinick 1986). We did not take it in 36 collections in the French Broad River system, and we concur with Menhinick (1986) that it has been extirpated from this drainage. Its status of threatened in North Carolina appears to be conservative.

Striped shiner, *Luxilus chrysocephalus* Rafinesque

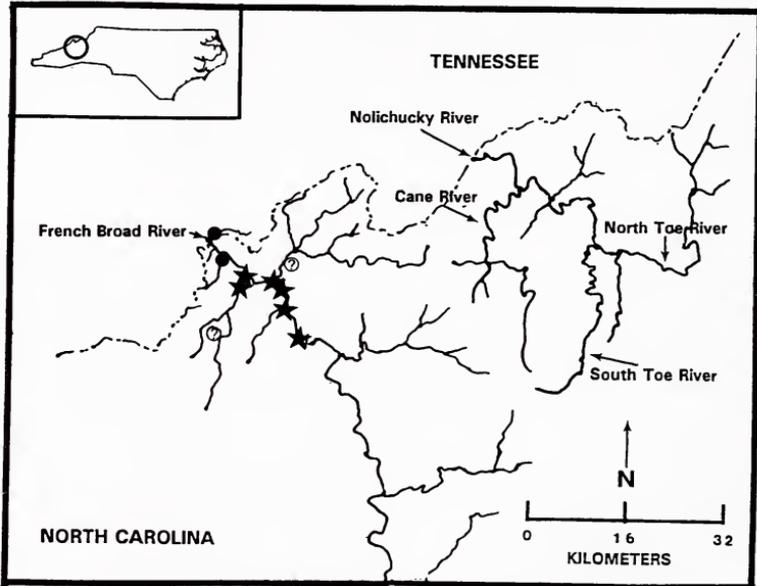
The striped shiner is common in the southern Great Lakes basin from western New York and southeastern Wisconsin south through much of the Mississippi River basin almost to the Gulf of Mexico (Page and Burr 1991). A disjunct population was discovered in the Cane River, Yancey County, North Carolina in 1980 by E. Menhinick, and soon thereafter it was known from five sites in the Cane River system (Menhinick 1986). We found it in four sites in 14.5 rkm of the middle reach of the Cane River and in two tributaries, Bald and Indian creeks (Fig. 6), in 1994. Numbers taken per our collections ranged from 2-23. Specimens ranged from 29-107 mm TL. Tennessee Valley Authority biologists took 61 individuals in one collection in the Cane River in 1992 (E. Scott, personal communication, 1994) (Fig. 6). Preferred habitat was pools and runs. Current ranged from 0.39-0.57 m/sec, pH 7.0-7.5, and dissolved oxygen concentration 6.8-8.4 ppm. Its status of threatened in North Carolina is warranted.

Banded sculpin, *Cottus carolinae* (Gill)

The banded sculpin inhabits mountainous areas of the Mississippi River basin from West Virginia west to Kansas and from the Ozark Mountains southeast to southern Alabama (Page and Burr 1991). In North Carolina it was reported only from Big Laurel and Spring creeks, Madison County (Robins 1954). Menhinick (1986) later reported it as restricted to the main stream of the French Broad River in North Carolina near the Tennessee line and absent from the two creeks. E. Menhinick (personal communication, 1994) took two adults and eight juveniles with rotenone in the downstream-most 100 m of Shut-in Creek, Madison County, North Carolina in July 1994 (Fig. 7). We did not collect it at two upstream-sites in this creek in 1994. However, we did take 58 specimens in two collections made on 14 May and 19 July 1994 throughout the lower 300 m of

Paint Creek, Greene County, Tennessee. This creek enters the French Broad River some 120 m downstream of the North Carolina/Tennessee line (Fig. 7). Its status as threatened appears to be conservative.

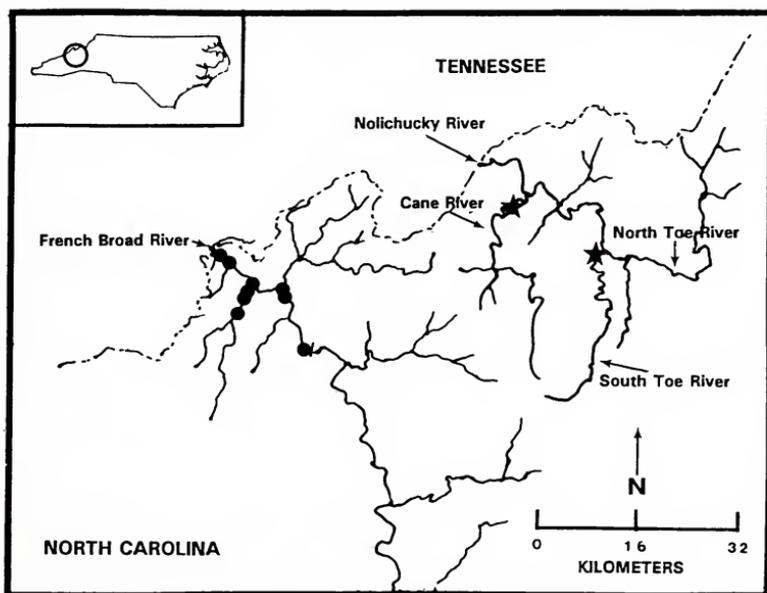
Fig. 7. Distribution of the banded sculpin, *Cottus carolinae*, (circle) and the freshwater drum, *Aplodinotus grunniens*, (star) in the French Broad River system, North Carolina. A circle with a question mark indicates an undefined historical site of the banded sculpin. Some symbols overlap sites.



#### Logperch, *Percina caprodes* (Rafinesque)

The logperch occurs from central Canada and the upper Mississippi River and adjacent drainages south to the Gulf of Mexico, and on Atlantic Slope drainages from the Hudson River south to portions of the Chesapeake Bay drainage (Rohde et al. 1994). In North Carolina it is known from four sites in the French Broad River between Redmon Dam and the Tennessee state line (Harned 1979) (Fig. 8), four specimens were collected below Redmon Dam in 1986 and 1987 (Birchfield et al. 1987) (Fig. 8), and from one site in the New River, Allegheny County (Menhinick 1986). We collected eight adults (88-132 mm SL) at four sites in the downstream reaches of the French Broad River and at two sites in the downstream portion of Spring Creek, Madison County on 13 May; 19, 22 July; and 5 November 1994 (Fig. 8). One specimen was taken in

Fig. 8. Distribution of the logperch, *Percina caprodes*, (circle) and the olive darter, *Percina squamata*, (star) in the French Broad and Nolichucky river systems, North Carolina. Some symbols overlap sites.



Spring Creek 7.1 rkm upstream from its mouth in July 1994 (S. Bryan, personal communication, 1994) (Fig. 8). Preferred habitat in the river was runs with large boulders. Current at our Spring Creek site was 0.58 m/sec, pH 7.1-7.6, and dissolved oxygen concentration 7.1-10.5 ppm. Its status of threatened is warranted.

#### Freshwater drum, *Aplodinotus grunniens* Rafinesque

The freshwater drum occurs throughout the Mississippi River basin from southern Canada and the Great Lakes to western Texas and western Florida (Rohde et al. 1994). Prior to this survey, it was known in North Carolina from six sites in the lower reaches of the French Broad River downstream of Redmon Dam, Madison County (Harned 1979) (Fig. 7). We collected one large specimen (305 mm TL) in a pool in Spring Creek, at a point 1 rkm upstream of its confluence with the French Broad River, on 22 July 1994, and E. Menhinick (personal communication, 1994) took one specimen in the same month in Spring Creek at this confluence (Fig. 7). Its status of threatened is warranted due to the lack of juveniles in collections.

## SPECIES OF SPECIAL CONCERN

Lake sturgeon, *Acipenser fulvescens* Rafinesque

The lake sturgeon is usually found over shoals in lakes and large rivers in central Canada and Hudson Bay and St. Lawrence River drainages, and in much of the Mississippi River drainage south to northeastern Louisiana (Page and Burr 1991). Eight specimens, presumably of this species, were taken from the French Broad River near Hot Springs in Madison County, North Carolina in 1945 (Brimley 1946). An occasional lake sturgeon is still reported from Douglas Reservoir in Jefferson County, Tennessee, but these are unsubstantiated records (Etnier and Starnes 1994). We set 2 large-mesh gill nets of 25 and 50 m total length in the French Broad River downstream of Hot Springs in mid-May 1995 and in the river at the mouth of Big Laurel Creek in mid-August but failed to collect sturgeon. Swift current limited sampling location possibilities at the former site and reduced gear efficiency. Local North Carolina state fishery biologists have no reported sightings (J. Borawa, personal communication, 1994). Menhinick (1986) considers the lake sturgeon to have been extirpated from North Carolina, and we concur.

Mooneye, *Hiodon tergisus* Lesueur

The mooneye is found in central and southern Canada and in much of the Mississippi River basin from the Great Lakes south to the Gulf of Mexico (Page and Burr 1991). It historically occurred in the upper reaches of the French Broad River near Bowman's Bluff, Henderson County, North Carolina in 1902 (Smith 1907), but it is now known only from Redmon Dam to the Tennessee state line (Menhinick 1986) based on several mooneye obtained from fishermen in the French Broad River just above the confluence with Big Laurel Creek by Harned (1979). We did not take it in this river in our electroshocker or gill net collections. Its status of special concern in North Carolina appears to be conservative.

River carpsucker, *Carpionodes carpio* (Rafinesque)

The river carpsucker occurs throughout the Mississippi River basin from Montana to Pennsylvania and south to the Gulf of Mexico (Lee and Platania 1980). There is one North Carolina 1947 record from the French Broad River near Hot Springs in Madison County (Menhinick 1986). It was also captured in the same river in Tennessee 41 rkm downstream of the North Carolina state line in 1979 (Harned 1979), but we failed to collect it in this study. Its status of special concern appears to be conservative.

Mountain madtom, *Noturus eleutherus* Jordan

The mountain madtom occurs in disjunct populations from northwestern Pennsylvania south and west through the Ohio River basin to the Red and

Ouachita river drainages in Oklahoma and Arkansas (Page and Burr 1991). The only verified North Carolina specimens are from Spring Creek, Madison County and were collected in 1889 (Taylor 1969). It was also collected at two sites in the French Broad River just upstream of Douglas Reservoir, Cocke County, Tennessee (32 km downriver of North Carolina) during a 1979 TVA survey (Harned 1979). We did not collect it at any of the 34 sites we surveyed in the lower reaches of the French Broad River system. We concur with Menhinick (1986) that it has been extirpated from North Carolina.

Snubnose darter, *Etheostoma simotermum* (Cope)

The snubnose darter is abundant in the Tennessee River drainage from southwestern Virginia to northern Alabama (Rohde et al. 1994). The only putative extant specimen from North Carolina was reported by Cope (1870) and is now in the United States National Museum, but it is unclear from Cope's records whether its provenance is North Carolina or Tennessee (Menhinick 1986). Menhinick (1986) reported two unverified records from Laurel and Spring creeks, Madison County, North Carolina. We collected no snubnose darter, nor did Menhinick (1986). M. Hopey, who made 13 collections for a general survey of the streams in this area for the Western North Carolina Alliance in 1992, did not collect it (M. Kelly, personal communication, 1994). We consider the past or present occurrence of this darter in North Carolina to be highly doubtful.

Wounded darter, *Etheostoma vulneratum* (Cope)

The wounded darter is restricted to the upper Tennessee River drainage from Virginia to Georgia (Rohde et al. 1994). It is abundant in the Little Tennessee River in North Carolina (F. Rohde, personal observations). Although the type locality is Spring Creek, Madison County, North Carolina (Cope 1870), none has been reported from the French Broad River system in North Carolina since then, including our survey. Harned (1979) collected one specimen in the French Broad River in Tennessee at a point approximately 23 km downstream of the North Carolina state line. We conclude that it has been extirpated from the French Broad River system in North Carolina. Its status of special concern in North Carolina appears conservative.

Olive darter, *Percina squamata* (Gilbert and Swain)

The olive darter is confined to the Rockcastle and Big South Fork rivers in the Cumberland River drainage in Kentucky and Tennessee and to the upper Tennessee River drainage (Rohde et al. 1994). There are five records from the lower reaches of the French Broad River system (three in the main river and two in Spring Creek) in North Carolina, and four records from the Nolichucky River system (three in Cane River and two in North Toe River); it also occurs in the Little Tennessee and upper Hiwassee rivers in the state (Menhinick 1991). We

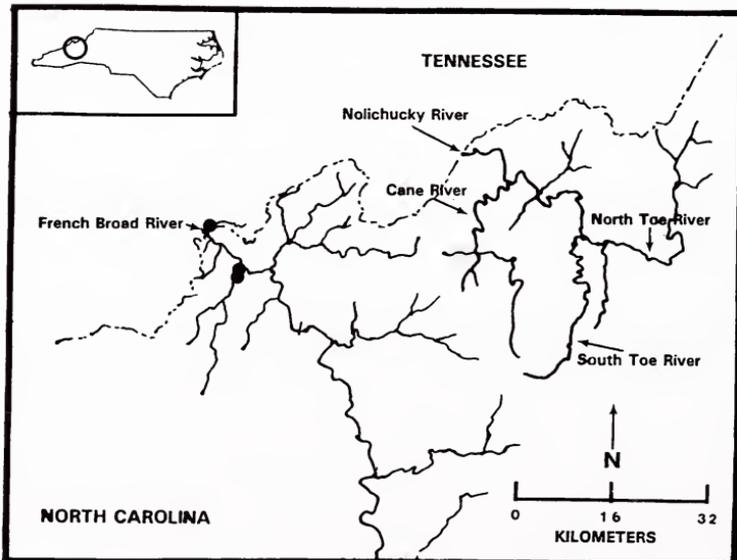
did not collect it in the French Broad River system, but we collected one juvenile (38 mm SL) in the Cane River on 19 July 1993, and three adults (104 mm SL, two released) in the South Toe River on 5 September 1993 (Fig. 8). Preferred habitat is around large boulders in fast riffles. Its status of special concern in North Carolina appears to be conservative.

### NEW STATE RECORD

#### Ohio lamprey *Ichthyomyzon bdellium* (Jordan)

The Ohio lamprey occurs in disjunct populations in the Ohio River basin, where it is uncommon (Rohde and Lanteigne-Courchene 1980). Because of its presence in nearby Tennessee, Menhinick et al. (1974) listed its occurrence in North Carolina as probable. However, there were no records from North Carolina until we took one male and three females from the mouth of Spring Creek, Madison County, on 14 May 1994 (Fig. 9). Each was adult (220-260 mm TL), had a well-developed digestive tract, and each female was gravid. We took another three males (243-246 mm TL), one female (244 mm TL), and two juveniles (not ammocoetes, nor mature adults) (152, 153 mm TL) here on 22 April 1995, as well as two adult males (239, 248 mm TL) 1 rkm further upstream in this creek on the same day. We took three females (235-240 mm TL) in nearby Paint Creek, Greene County, Tennessee on 14 May 1995. All our specimens were taken over rocky riffles with a current from 0.45-0.78 m/sec.

Fig. 9. Distribution of the Ohio lamprey, *Ichthyomyzon bdellium*, in the French Broad River system, North Carolina.

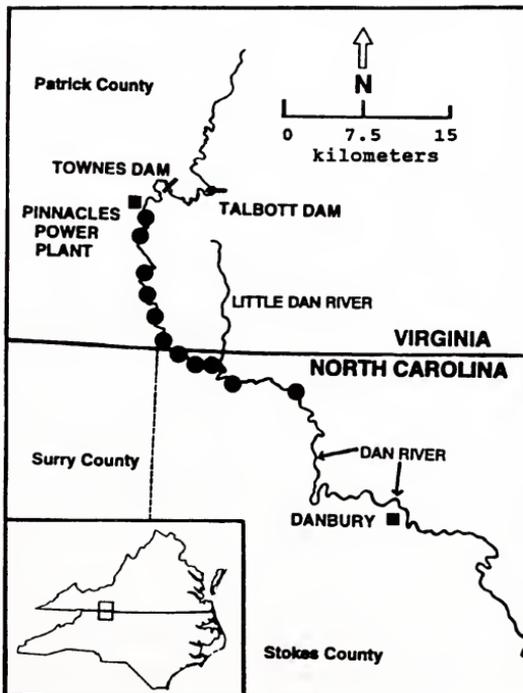


## DAN RIVER SYSTEM ENDANGERED

Cutlips minnow, *Exoglossum maxillingua* (Lesueur)

The cutlips minnow occurs on the Atlantic slope from the St. Lawrence River and eastern Lake Ontario drainages south to the upper Dan River in North Carolina (Gilbert and Lee 1980). Menhinick (1986) reported it from one site on the Dan River in Stokes County, North Carolina, within 1.6 rkm downstream of the Virginia state line. We found it in the North Carolina portion of this river at four sites from the Virginia line downstream to NC Route 704 and at six Virginia sites upstream to the Pinnacles Power Plant, over a total distance of 43 rkm (Fig. 10). Numbers (39) taken in our collections ranged from 1-6 (mean 3.9), and their length ranged from 69-133 mm SL; most specimens were adults. This species preferred fast-flowing runs or pools, near large rocks or boulders over sand and gravel. Current where it was collected was 0.54-0.75 m/sec; water temperature 7.7 C (November)-22 C (July); pH 6.8-7.6; and dissolved oxygen concentration 10.6-11.8 ppm (both November). The species appears to be secure in its limited distribution in North Carolina.

Fig. 10. Distribution of the cutlips minnow, *Exoglossum maxillingua*, in the Dan River system, North Carolina and Virginia.



Rustyside sucker, *Thoburnia hamiltoni* Raney and Lachner

The rustyside sucker is endemic to the upper Dan River system in North Carolina and Virginia (Jenkins and Burkhead 1994). In North Carolina it is known only from the 1.4 rkm downstream-most portion of the Little Dan River in Stokes County. Here Menhinick (1986) collected four specimens at a point some 400 m downriver of the Virginia line in 1985 (Fig. 11). We made three collections in the Little Dan River, from its confluence with the Dan River upstream to the North Carolina/Virginia line, and took one adult (144 mm SL) in a run with gravel and rubble substrate on 21 December 1992. In Virginia we took three adults (118-142 mm SL) in the Dan River at one site located 365 m, and at another site 914 m, downriver of the Pinnacles Power Plant on 28 November 1993 (Fig. 11). Both sites were deep and fast rock-strewn riffles, current velocity 0.62-0.75 m/sec, water temperature 8.3 C, pH 6.8, and dissolved oxygen concentration 10.0 ppm. The distribution of the rustyside sucker in North Carolina is extremely limited, and its continued existence there is precarious.

Fig. 11. Distribution of the rustyside sucker, *Thoburnia hamiltoni*, in the Dan River system, North Carolina and Virginia.

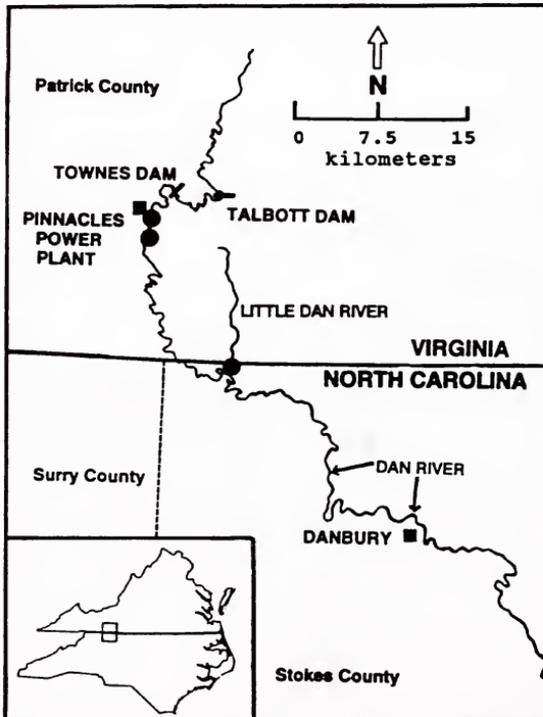
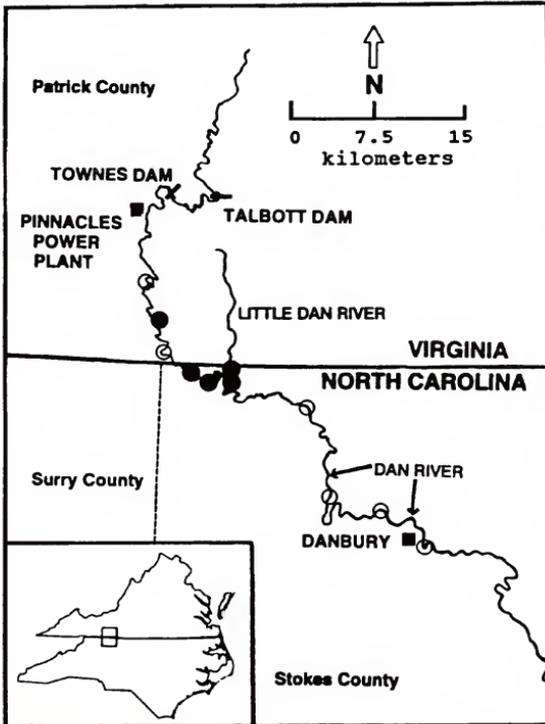


Fig. 12. Distribution of the orangefin madtom, *Noturus gilberti*, in the Dan River system. An open circle indicates an historical site where the species was not taken in this survey.



#### Orangefin madtom, *Noturus gilberti* Jordan and Evermann

The orangefin madtom is a Roanoke River drainage endemic (Jenkins and Burkhead 1994). Menhinick (1986) reported it from five North Carolina localities in the Dan River from the Virginia line downstream to Danbury, all discovered after 1968. Simonson and Neves (1986) found it at four Dan River sites in 45.2 rkm in North Carolina during a 1985 survey; including three of the Menhinick (1986) sites. We collected two adults (photographed and released) at 2 sites (of 16 sampled) in the Dan River in North Carolina 1.6 and 7.3 rkm below the Virginia line on 16 and 17 July 1992 (Fig. 12). Personnel from the North Carolina Wildlife Resources Commission took two individuals (93 and 96 mm TL) at an intermediate site on 5 October 1990 (A. Braswell, North Carolina State Museum of Natural Sciences, personal communication, 1992) (Fig. 12). We did not take it in three collections made at the downstream-most historical locality in the Dan River near Danbury in Stokes County, North Carolina, nor in five col-

lections made at three other historic localities upstream of this site in this river and state (Fig. 12). We took the first specimens known from the Little Dan River in North Carolina, at a point 1.1 rkm upstream of the confluence with the Dan River: one adult (released) on 21 December 1992, and one subadult (68 mm SL) on 21 August 1993 (Fig. 12). We also took three adults and one subadult (44-75 mm SL) at one locality in the Dan River in Virginia on 10 June 1994 (Fig. 12). Simonson and Neves (1986) took it at four Dan River sites in 12.4 rkm in Virginia. All fishes were taken in riffles with a gravel/rubble substrate; pH was 7.6-8.0.

Our capture of the two specimens in the Little Dan River was surprising, especially since Jenkins and Burkhead (1994) presumed that it had disappeared from this river. Since we did not take it at the four historical downstream-most sites in the Dan River in North Carolina (Fig. 12), we suspect that it may now be absent there. Its status of endangered in North Carolina is warranted.

#### SPECIAL CONCERN

Bigeye jumprock, *Scartomyzon ariommus* (Robins and Raney)

The bigeye jumprock is endemic to the upper and middle portions of the Roanoke River drainage in North Carolina and Virginia (Jenkins and Burkhead 1994). We found it at eight sites in a 41 rkm section of the Dan River, Stokes and Rockingham counties, North Carolina, between July 1992 and May 1995 and in the Mayo River, a tributary of the Dan River, 1.1 rkm below the Virginia state line on 22 August 1993 (Fig. 13). We collected 32 adults (106-170 mm SL, mean 154.1 mm) and 3 juveniles (52-91 mm SL, mean 75.3 mm); collections ranged from 1-7. Adults were taken in deep runs and heads of pools, usually near large boulders and rock outcrops, and juveniles in a shallow gravel riffle (one specimen) and in a sandy-bottomed pool (two); pH at capture sites was 7.4-7.8. Duke Power Company personnel (unpublished data) took two individuals by electroshocker at the Dan River Steam Station in Eden in Rockingham County, North Carolina, in August 1990 (Fig. 13). Within its limited distribution in North Carolina, this difficult-to-collect species is apparently secure.

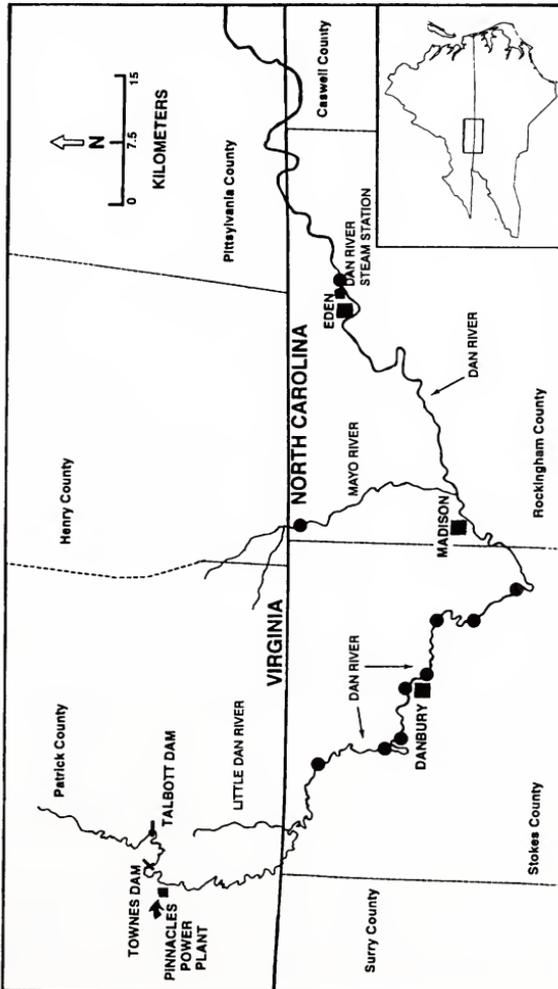
Riverweed darter, *Etheostoma podostemone* Jordan and Jenkins

The riverweed darter is endemic to the upper Roanoke River drainage in North Carolina and Virginia (Jenkins and Burkhead 1994). It is widely distributed in the Dan River and its tributaries (Menhinick 1991). We found it in a 124 rkm section of the main Dan River in North Carolina between July 1992 and May 1995, as well as in the Little Dan River, Mayo River, and Virginia portion of the upper Dan River (Fig. 14). We collected 434 specimens from 21-61 mm SL, ranging 2-62 (mean 21.7) per collection. It was common in shallow riffles with a gravel/cobble substrate; pH was 7.4-8.1. Within its limited distribution in North Carolina, the species is apparently secure.

SUMMARY AND CONCLUSIONS

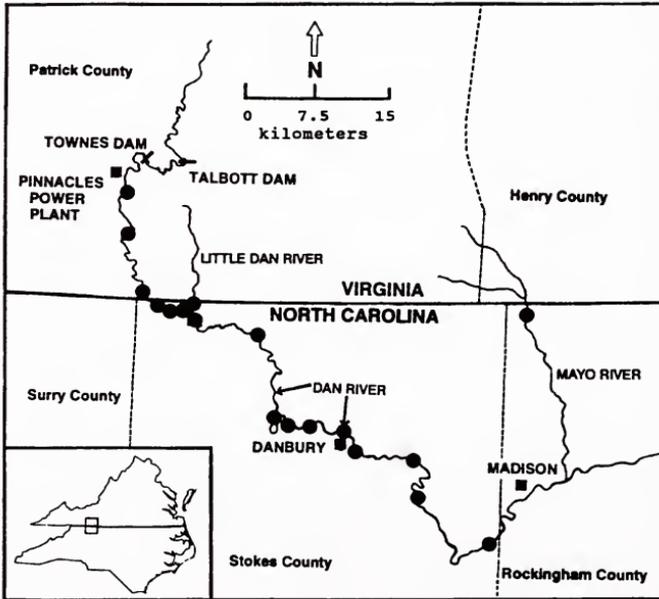
We conducted surveys for 22 North Carolina fishes currently considered to be endangered, threatened, and of special concern and known from the French Broad River (14 species), Nolichucky River (5 species), and Dan River system (5 species). We made 105 collections over the period July 1991-May 1995 inclusive, and augmented these collections with data from the literature and from personal communications.

Fig. 13. Distribution of the bigeye jumprock, *Scartomyzon ariommus*, in the Dan River system, North Carolina.



We did not collect two of the seven species considered to be endangered, the paddlefish and dusky darter, and believe that they have been extirpated from the state. The cutlips minnow in North Carolina is restricted to the Dan River, where we found it in 21 rkm rather than the 1.6 rkm in which it was previously known; this population at present appears to be secure. The rustyside sucker in North Carolina is confined to the downstream reaches of the Little Dan River, where it is extremely rare. We discovered that the North Carolina distribution of the stonecat is significantly larger than the small portion of the Cane River from which it was previously known, and to also include the Ivy River and the Little Tennessee River. Nevertheless, its status of endangered is warranted. The orangefin madtom in North Carolina is restricted to the Dan and to the Little Dan rivers; its distribution there appears to have decreased. The blotchside logperch in North Carolina has been extirpated from historical sites in the French Broad River system, and it is today restricted to 24 rkm of the South Toe River; its continued existence there appears to be tenuous.

Fig. 14. Distribution of the riverweed darter, *Etheostoma podostemone*, in the Dan River system, North Carolina and Virginia.



Records of all six North Carolina species considered threatened were collected in our survey. The American brook lamprey in North Carolina is known only from the downstream portion of Spring Creek; consequently, we

believe that its status in North Carolina should be increased to endangered. The spotfin chub has apparently been extirpated from at least Alabama and Georgia, as well as from the French Broad River system and the Tuckaseegee River in North Carolina, and it remains only in the Little Tennessee River; its status in North Carolina should probably be elevated to endangered. A viable population of the striped shiner is present in the Cane River. Its status of threatened in North Carolina is appropriate. Although we did not collect the banded sculpin, E. Menhinick took 10 specimens in North Carolina in a creek tributary to the lower French Broad River in 1994. Its status more accurately may be described as endangered. The logperch was found at several sites in the French Broad River and in Spring Creek. Its North Carolina status of threatened is warranted. Two freshwater drum were taken in Spring Creek. We doubt that a viable population of this species occurs in North Carolina, and it appears to be endangered.

Of the nine listed species of special concern that we surveyed, the big-eye jumprock and riverweed darter have apparently healthy populations in the limited Dan River system area in which they occur in North Carolina. The wounded darter in North Carolina apparently has been extirpated from the French Broad River system, although it is still abundant in the Little Tennessee River. Its status in North Carolina is more accurately described as threatened. The olive darter apparently still occurs in very low numbers in the French Broad River system, as well as in the Cane, North Toe, and South Toe, but its current status appears too conservative. We believe that the mountain madtom and the snubnose darter have been extirpated from North Carolina. We did not collect the lake sturgeon, mooneye, or the river carpsucker, nor could we obtain any recent records. The occasional specimens of these larger species, if they still occur, would be exceedingly difficult to catch. If they have not yet been extirpated from North Carolina, they almost certainly do not today have reproducing populations there.

We report the first North Carolina specimens of the Ohio lamprey, from Spring Creek, Madison County.

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# Status of the River Frog, *Rana heckscheri* (Anura: Ranidae), in North Carolina

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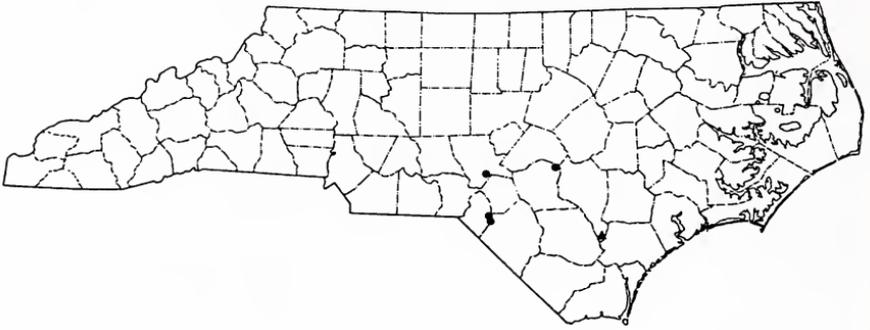
Raleigh, North Carolina 27626-0555

ABSTRACT--The river frog (*Rana heckscheri*), a large ranid occurring in aquatic and riparian habitats in the southeastern United States, reaches the northern edge of its range in southeastern North Carolina, where it has been recorded historically from a few scattered localities in the Lumber and Cape Fear river systems. Currently listed by the state as a species of Special Concern, *R. heckscheri* was last documented from North Carolina in 1975. A survey was undertaken to determine the frog's status in the state. Considerable field work has failed to yield any current evidence of its existence in North Carolina, and it appears likely that the species no longer occurs there. Reasons for its apparent disappearance are unknown.

The river frog (*Rana heckscheri*) is a large ranid occurring in association with blackwater river habitats from southern Mississippi to southeastern North Carolina (Sanders 1984, Conant and Collins 1991). The species is known in North Carolina from only a few scattered localities in the Lumber and Cape Fear river systems (Fig. 1). Little has been published on *R. heckscheri* in North Carolina. Its occurrence in the state was first suggested by Brimley (1944), who listed it among the state's fauna with some doubt on the basis of a single specimen of a frog found dead at a heron rookery at Battery Island in Brunswick County on 13 June 1938. His tentative identification was apparently based solely on the frog's dark ventral coloration, and his brother, H. H. Brimley (1938), remarked that "it was a noticeably black specimen, with very definite markings showing on the inside of the thighs, so we brought it back . . . to identify . . . but it turned out to be nothing more than a common bull frog!" DePoe and Funderburg (1959) and Simmons and Hardy (1959) discounted that specimen as being *R. heckscheri*, probably rightfully so, as the specimen apparently was not retained and cannot be verified.

DePoe and Funderburg (1959) reported a specimen of *R. heckscheri* from Greenfield Lake in New Hanover County, collected 10 May 1948, but that specimen (Cornell University 5496) was later identified as *R. catesbeiana* (Sanders 1984).

Fig. 1. Historical distribution of *Rana heckscheri* in North Carolina. Dots represent localities documented by specimens in curated collections. The triangle represents an approximate locality supported by a specimen.



The first legitimate records of the river frog in North Carolina were reported by DePoe and Funderburg (1959) and Simmons and Hardy (1959). The apparent earliest specimen was collected as a tadpole by a University of North Carolina student in March, 1957, at an imprecise locality on the Black River in Sampson County, and kept in an aquarium at the University until it transformed (DePoe and Funderburg 1959). It was later donated to the North Carolina State Museum (NCSM 14610) by W. L. Engels. Simmons and Hardy (1959:37) reported collecting a series of *R. heckscheri* tadpoles on 21 March and additional specimens on 12 April 1958 (a date of 12 March was also reported later in the same paper, but appears to be an erroneous reference to 21 March) from "a gravel pit pond" near Maxton in Robeson County, "located at the intersection of State Highway 71 and the Lumbar [sic.] River." They further reported that "a local farmer, obviously familiar with the distinctive tadpoles, has been aware of their occurrence [sic.] in the Maxton ponds for at least fifteen years." It is not known what became of the specimens Simmons and Hardy collected. No repository was listed in the paper, and it is possible that the specimens were not saved. A photograph of one of the tadpoles was included; it appears to be the only published photograph of a river frog tadpole from North Carolina. A currently existing small, shallow pond near the west bank of the Lumber River just southwest of the NC 71 bridge is probably the site referred to, but no *R. heckscheri* have been found there in recent years. The locality for four specimens in the U.S. National Museum (USNM 144367-144370), collected by Hardy 30 May-1 June 1960, was given as only "Robeson-Scotland Co. line, Air Base," and may or may not

refer to the same site. The air base (now Laurinburg-Maxton Airport) actually lies in Scotland County ca. 2 air miles WNW of the NC 71 bridge.

On 7 August 1958, C. E. DePoe collected a single juvenile *R. heckscheri* (NCSM 7004) at Rhodes Pond, a large cypress lake located 1.5 air miles NE of Godwin in Cumberland County (DePoe and Funderburg 1959). A specimen in the American Museum of Natural History (AMNH 22433) is reported as having been collected at Southern Pines in Moore County, with no further data.

DePoe and Funderburg (1959) reported several additional specimens found among frogs brought to Carolina Biological Supply Company by commercial collectors, believed to have been collected "either in the Cape Fear or Pee Dee river drainages in southern North Carolina." Only one of these has been confirmed as *R. heckscheri*, a specimen (NCSM 7005) collected ca. mid June 1958 from an undetermined locality.

The remaining records from the state have come from a series of borrow pit ponds along the Lumber River near the SR 1433 bridge at the Scotland-Robeson County line, 5 air miles S of Wagram; and from along the Lumber River between that site and the NC 71 bridge. Voucher specimens from that locality in the collections of the North Carolina State Museum of Natural Sciences are as follows:

7 Feb. 1965: Series of 17 larvae seined from borrow pit pond by W. M. Palmer and J. R. Paul (NCSM 3741).

16 April 1967: Five of six adults taken from borrow pit pond by J. R. Bailey et al. (NCSM 32080-32084, formerly DU A6819). Bailey (personal field notes) noted "no significant difference in habit or habitat . . . from bullfrogs taken there at same time."

23 May 1968: Series of nine adults collected by floating the Lumber River from 8-12 pm "from first half to 2/3 of distance" between the SR 1433 and NC 71 bridges by J. R. Bailey et al. (NCSM 9790 and 32085-32092, formerly DU A9349). Bailey (personal notes) noted that 40 bullfrogs were also taken along the same stretch, but that only bullfrogs were taken upstream from the SR 1433 bridge.

6 Feb. 1971: Series of larvae seined from borrow pit pond by W. M. Palmer and D. L. Stephan [NCSM 10058 (5 larvae) and NCSM 26534 (10 larvae)].

21 Oct. 1973: Series of 30 larvae collected from borrow pit pond by A. L. Braswell and D. L. Stephan (NCSM 12895).

12 July 1975: Adult female taken beside borrow pit pond by A. L. Braswell, D.L. Stephan, and J. H. Reynolds (NCSM 15659). This is the last known specimen from the state. Its photograph appears in Martof et al. (1980) and in a popular article by Dopyera (1995).

Little else has been published on *R. heckscheri* in North Carolina, and little is known about its natural history in the state. Neither eggs nor calling adults have been reported from the state. Martof et al. (1980) provided a brief descriptive account of the species in the Carolinas and the aforementioned photograph. Stephan (1985) and Beane (1993a) wrote popular articles, and Stephan (1989) provided a brief account of the frog's status in the state. In 1990 it was granted protection as a species of Special Concern under the North Carolina Endangered and Threatened Wildlife Law (G.S. 113-331 to 113-337). Beane (1993b) provided a more detailed summary of its status in the state.

Short accounts of *R. heckscheri* in other states and general information on the species may be found in Wright (1924, 1932), Allen (1938), Carr (1940), Wright and Wright (1949), Mount (1975), Sanders (1984), Behler and King (1985), Ashton and Ashton (1988), and Conant and Collins (1991). Recordings of the breeding call are provided by Bogert (1958), Anon. (1982), and Elliott (1992).

A survey was undertaken to determine the current distribution of the river frog in North Carolina (if indeed it still occurred in the state), to evaluate the status of any populations located, to learn more about the biology and habitat requirements of the species, to identify the level of protection it should be afforded, and to outline any conservation measures that might be justified.

## METHODS

Efforts were made to locate all museum specimens and literature records of the river frog in North Carolina. Field survey work was centered around the vicinity of these records, as well as other potential sites. Sites investigated included many areas along the Lumber, South, Black, Northeast Cape Fear, Cape Fear, Waccamaw, and Lockwood Folly rivers and their larger tributary streams and swamps.

Field work for this survey was conducted between spring 1987 and fall 1996, and is ongoing; however, most of the work was conducted between April 1992 and September 1993. During 1992-1993 over 1,500 man-hours were devoted to field work and travel for the project, and a comparable amount of time was devoted to office work. Over 10,600 miles of travel were logged in that time period. The area surveyed included portions of Robeson, Scotland, Columbus, Bladen, Sampson, Cumberland, Pender, Brunswick, Hoke, Duplin, New Hanover, Moore, Richmond, and Harnett counties, North Carolina; and Horry County, South Carolina. Beane (1993b) provided a map and list of specific localities visited during 1992-1993 along with dates and survey methods used at each site.

Survey techniques included navigating rivers and other bodies of water by canoe or johnboat during the day to search for suitable habitat, adult frogs, or schools of tadpoles; floating the same areas by night with flashlights and head-

lamps in search of adult frogs; walking or wading potential habitat at night with lights; visually scanning for the large and conspicuous tadpoles at bridge crossings or other sites with good visibility; seining and dipnetting for tadpoles; slowly driving and walking roads through suitable habitats--particularly bridge crossings--on rainy (and non-rainy) nights; and listening for calling adults at potential sites by day and night.

Posters depicting a drawing of the river frog's distinctive tadpole were widely distributed in the southeastern part of the state. Biologists and outdoor enthusiasts residing in, collecting in, or frequenting areas within the frog's range were encouraged to report any suspected sightings. Local residents were often questioned when encountered in the field, and many were shown a large preserved tadpole and photographs of adult frogs. Several articles featuring the river frog project appeared in regional newspapers, and the survey was advertised in several issues of the North Carolina Herpetological Society newsletter. Several public field trips to search for river frogs were organized through the North Carolina State Museum, and several public talks on the project were presented, using slides, photographs, call tapes, preserved specimens, field guides, and a live adult frog from Florida as educational tools. Participants in the field work were familiarized with river frog identification.

## RESULTS

This survey revealed no current evidence of river frogs anywhere in North Carolina. All 26 other anuran species known to share the potential range of the river frog (NCSM files, Conant and Collins 1991) were encountered in the state during the survey, most of them in relative abundance. The most productive methods for locating ranids were nocturnal searches with lights, conducted either by canoe or on foot, and driving roads on rainy nights. All other *Rana* (*R. catesbeiana*, *R. clamitans*, *R. utricularia*, *R. palustris*, *R. virgatipes*) with similar habits and utilizing habitats similar to those of the river frog were frequently encountered. River frogs were encountered with little difficulty in Franklin, Liberty, and Wakulla counties, Florida; Charlton, Clinch, and Ware counties, Georgia; and Hampton, Jasper, and Sumter counties, South Carolina during the time of the survey.

No reports of river frog encounters in North Carolina were received during the time of the survey. Only two plausible and previously undocumented reports of earlier sightings were received, and both may have occurred prior to the last documented sighting in 1975. J. H. Carter III, an environmental consultant and experienced field biologist with herpetological expertise, reported (personal communication) having seen what he believed to be an adult river frog in a large lake on the campus of St. Andrews Presbyterian College in Laurinburg, Scotland County. (Visits to this site during the day and again at night during a thunder shower in late June of 1993 yielded no evidence of the species.) David

Scott of Fair Bluff, an active conservationist and founding member of the Lumber River Basin Committee, also reported (personal communication) having taken what he believed to be an adult river frog while frog gigging on the Lumber River in the vicinity of Fair Bluff along the Columbus-Robeson County line. Neither individual could recall the date of the sightings, but both estimated them to have been in the early to mid-1970s. Unfortunately, neither of these sightings can be verified because of the similarities between adult river frogs and some bullfrogs.

Only three responses to the many "wanted" posters distributed were received, all of them false leads. Most local persons, when shown preserved tadpoles, had obviously never encountered them before.

### DISCUSSION

The results of this survey suggest that the river frog no longer occurs in North Carolina. However, such a conclusive statement is difficult to make with absolute confidence. The rather large amount of potential habitat present in the state, and the limited scope of the current work, make it possible to envision how populations of this frog could escape detection. Beane (1993b) remarked that if the species still occurred in the state, it probably deserved Endangered status, but recommended that it remain Special Concern since its occurrence had not been verified.

The status and range of the river frog in South Carolina are not well known. Until recently, the northernmost known populations from that state were from the vicinity of Poinsett State Park in Sumter County, in the Santee drainage (Sanders 1984), and the species still appears common at that site (personal observation). In 1996, *R. heckscheri* was first documented from the Pee Dee drainage in South Carolina by Michael E. Dorcas et al. from two sites on the "Woodbury Tract," a 20,000-acre parcel of land situated at the confluence of the Great Pee Dee and Little Pee Dee rivers, ca. 16 air miles SSE of Brittons Neck in Marion County. River frogs were heard calling from two sites on that tract on 6 April and 18 April 1996. Although no specimens were collected or seen, a recording was made of three individuals calling on 18 April. The tape was verified by J. Whitfield Gibbons and is on file at the Savannah River Ecology Laboratory (Michael E. Dorcas and Katie Distler, personal communication). The species has yet to be reported from the Waccamaw drainage in either North or South Carolina. It is possible that the lack of records from the northern Coastal Plain of South Carolina reflect a lack of collecting efforts in that region rather than a genuine absence, and more field work is needed in that area to determine whether any currently or previously existing North Carolina populations should be regarded as peripheral or disjunct.

Much attention has been devoted in recent years to the apparent global decline in many amphibian populations (Barinaga 1990; Blaustein and Wake 1990; Phillips 1990, 1995; Wyman 1990; Livermore 1992). No single cause explains all of these widespread and often alarming disappearances, and there is general agreement that a combination of factors is probably responsible. Although habitat loss has been associated with the decline of many species, this does not seem to be the case with the river frog in North Carolina; suitable habitat appears to be plentiful. The fact that oxbow lakes on blackwater rivers are rarer in North Carolina (Schafale and Weakley 1990) than in areas further south, might represent a limit of prime breeding habitat for river frogs. However, the species breeds in other habitats as well, and places where it has been taken historically in the state do not seem unique in any way that is readily observable.

Reasons for the apparent disappearance of the river frog from sites where it once occurred are unknown and must remain speculative. Factors limiting the distribution of the species are poorly known. The frog was apparently never common or widespread in North Carolina, and small, scattered populations of any species are usually more vulnerable to extinction than are large, widespread ones. Species at the edge of their range likewise tend to be susceptible. Some possible explanations for the apparent disappearance of *R. heckscheri* from North Carolina, all of them speculative, include a number of diverse factors:

- 1) Frog gigging or spearing still appears to be a popular sport in some parts of southeastern North Carolina, although many persons encountered during the survey spoke of its being more widely practiced (as well as more productive) in past years. The rather unwary adult river frogs (Carr 1940, Wright and Wright 1949, Mount 1975) probably make easier targets for frog hunters than any other *Rana* species. It is conceivable that intensive take by humans in an area could seriously impact or eventually eliminate populations, especially those that were relatively small.

- 2) Other ranids surely compete with river frogs, both as larvae and adults, and the niche of the bullfrog in particular seems to overlap that of the river frog rather broadly (Carr 1940, Wright and Wright 1949). Although the two have been taken sympatrically at numerous sites, the highly adaptable bullfrog is probably a better competitor in certain, if not most, situations, and it is possible that a change in environmental quality or in some particular selective pressure could offer bullfrogs an advantage leading to river frog extirpation.

- 3) A general overall decline in environmental quality could be responsible for the river frog's decline in North Carolina. It was beyond the scope of this survey to delineate the exact causes or effects of any environmental degradation that may have occurred over the past several decades. Although precise long-term data are difficult to obtain, it seems almost certain that some declines in water quality have occurred in the state's blackwater rivers. Most fishermen and other local residents encountered during the course of field work seemed of the opin-

ion that fishing and frogging had declined, and that various species of wildlife were not as frequently observed as in past years. While frogs were generally found to be common during this survey, there were occasions when far fewer were observed than expected. As an example, during four hours of night canoeing on a stretch of the Northeast Cape Fear River in Duplin County on 6 September 1992, a total of only three anurans were observed. Little is known about the sensitivity of the river frog to environmental changes.

Finally, Pechmann et al. (1991) pointed out the difficulties sometimes involved in distinguishing true amphibian declines from natural population fluctuations, and Hairston and Wiley (1993) emphasized the value of long-term studies in determining whether supposed amphibian declines were genuine. While the apparent absence of *R. heckscheri* in North Carolina could represent a natural fluctuation, the lack of a single record in more than 22 years suggests otherwise. Still, conclusive documentation of extinction can be difficult for any organism, and more field work is needed to determine the river frog's true status at the northern edge of its range. It is hoped that biologists working in southeastern North Carolina will make every effort to collect and report all possible evidence of *R. heckscheri* in the state.

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# Wood Ducks, *Aix sponsa* (Anseriformes: Anatidae), and Blackwater Impoundments in Southeastern North Carolina

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**ABSTRACT**--Three small (<2.0 ha) newly constructed, wooded impoundments located on first-order blackwater streams were examined for suitability as habitat for wood ducks (*Aix sponsa*). We evaluated brood and roosting cover as well as availability of mast and invertebrate foods. Wood ducks used the new impoundments for nesting, brood rearing, feeding, and roosting. Feeding was heaviest on impoundments with dense cover where water oak (*Quercus nigra*) acorns were abundant. Brood rearing was restricted to sites with dense low cover. Roosting activity was highest where live, dense, woody cover was available. All sites were used by wood ducks throughout much of the year. Management recommendations include drawdown prescriptions designed to ensure live, woody shrub cover and continued mast production. We conclude that construction and active management of small blackwater impoundments offer a means of improving habitat for wood ducks and other wetland wildlife in the Coastal Plain of North Carolina.

Bottomland wetlands and other sites suitable for wood ducks have declined across North America (Dugger and Fredrickson 1992). North Carolina has been no exception, with alteration of more than 50% of the state's palustrine wetlands (Cashin et al. 1992). Thus, the creation of new wetlands is potentially significant in ameliorating the problem of wetland drainage, and is potentially significant to wood ducks. Three blackwater creeks at Camp Lejeune were impounded by the Environmental Management Division in October 1990, creating small (<2.0 ha) wetlands to be managed primarily for wood ducks. Although much is known about wood ducks elsewhere (Bellrose and Holm 1994), the usefulness of creating small impoundments as wood duck habitat is questionable.

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We monitored environmental parameters, changes in vegetation, and the response of wood ducks within these blackwater impoundments during the two years following construction and initial inundation.

### STUDY SITES

The study was conducted on three small blackwater impoundments at Camp Lejeune Marine Base, Onslow County, North Carolina. The impoundments were located approximately 5 km east of Stone Bay (on the New River) and about 8 km northwest of the Atlantic Ocean.

Impoundment 1 (hereafter I-1) covered 1.2 ha with a mean depth of 1 m. Black gum (*Nyssa sylvatica*), red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), American holly (*Ilex opaca*), red bay (*Persia borbonia*), sweetbay (*Magnolia virginiana*), and willow (*Salix caroliniana*) formed a partial canopy over the inundation. Fetterbush (*Lyonia lucida*), wax myrtle (*Myrica cerifera*), and titi (*Cyrilla racemiflora*) furnished a thick undergrowth around and within I-1. Duckweeds (*Spirodela* spp., *Wolffia* spp., *Wolffiella* spp., and *Lemna* spp.) blanketed much of the water in spring and summer.

Impoundment 2 (I-2) covered 1.9 ha at a mean depth of 1.5 m. I-2 was heavily wooded by yellow poplar (*Liriodendron tulipifera*), sourwood (*Oxydendrum arboreum*), water oak (*Quercus nigra*), American holly, red bay, and sweetbay. Other woody vegetation included black gum, sweetgum, loblolly pine, fetterbush, wax myrtle, loblolly bay (*Gordonia lasianthus*), and white oak (*Quercus alba*). Duckweeds flourished during spring and summer.

Impoundment 3 (I-3) covered 0.36 ha with a mean depth of 1.5 m. Most of I-3 was open water, flanked by two wooded coves vegetated with water oak, loblolly pine, wax myrtle, American holly, sourwood, and red maple. Mats of bladderwort (*Utricularia biflora*) spread across the water, and organic matter supporting herbaceous plants such as yellow-eyed grasses (*Xyris* spp.) and club moss (*Lycopodium alopecuroides*) draped floating logs.

### METHODS

Dissolved oxygen, pH, and Secchi disk readings were recorded monthly from June 1991 - December 1992 at each impoundment. Vegetation was sampled with a series of 15 m<sup>2</sup> circular plots, each selected randomly within a grid at a ratio of one plot per 0.40 ha. of pond surface. Plots were sampled in August 1991 and again in June and August 1992. All trees within each plot were counted and measured for diameter at breast height (dbh). The number of above-water stems of shrubs and vines was counted, and percent cover of herbaceous vegetation was visually estimated to the nearest 10% in a 0.50-m<sup>2</sup> quadrat.

Mast was sampled biweekly from September through December 1992 in square baskets of 1-m<sup>2</sup> surface area. Ten baskets were placed randomly at each wetland, with the restriction that they were spaced evenly around each wetland.

Five baskets were placed over water at no more than 50 cm of depth, and another five were placed in the adjacent uplands within 15 m of the apparent high-water mark. Mast captured in each basket was identified and weighed in the field to the nearest 0.01 g. The data obtained at each wetland were log 10 transformed because of heterogeneity of variances and were tested by species and location (inside or outside the impoundment) using a one-way ANOVA in the General Linear Models (SAS 1989) procedure. Transformed means were compared using the Student-Newman-Keuls test at the  $\alpha = 0.05$  level.

Macroinvertebrates were sampled in each vegetation plot monthly during April, May, June, and July 1992, using a plankton tow net and a sweep net. Three water surface samples were obtained with a plankton tow. The water column was sampled with a sweep net by making semicircular sweeps on the left, center, and right side of the plot. An attempt was made to sweep across the entire plot, thus sampling a standardized area. A sweep net also was used to sample the benthos by scraping the substrate with the net across the left, center, and right side of the plot. Samples were preserved in 45% isopropyl alcohol and identified using Thorp and Covich (1991). Specimens were air dried overnight, then oven-dried at 55 C for eight hours, and their biomass was determined with a Mettler electronic balance. Data were log10 transformed because of heterogeneity of variances and tested for differences in total invertebrate biomass between wetlands with a one-way ANOVA in the General Linear Models (SAS 1989) procedure. Transformed means were contrasted using the Student-Newman-Keuls test at the  $\alpha = 0.05$  level.

Three cypress nest boxes designed for wood ducks were erected at each impoundment upon inundation in October 1990. Each nest box was erected on a steel post equipped with a predator-proof guard and supplied with wood shavings. Prior to the 1992 nesting season, sufficient numbers of nest boxes were added to provide one box per 100 m of shoreline at each of the three wetlands, thereby resulting in eight boxes at I-1, nine at I-2, and four at I-3. The boxes were inspected biweekly during May, June, and July and monthly August through April.

Flush counts were conducted biweekly on the impoundments between September and December 1992. All ducks flushed by an observer walking the perimeter of each wetland were recorded. Brood surveys were conducted each week during May, June, and July 1992 from blinds located at sites arbitrarily selected for their enhanced visibility of shrub-strewn habitat (Rumble and Flake 1982, Robb and Bookhout 1990). Broods were counted for two-hour periods beginning one-half hour before sunrise. Species, brood size, age-class (Gollop and Marshall 1954), and activities were recorded whenever broods were observed. Evening roost censuses were made biweekly between September and December 1992 from suitable vantage points adjacent to each wetland. Sampling effort and number of counts were identical at all impoundments. Flush and roost

count data were analyzed by Chi-square tests to detect differences among wetlands.

## RESULTS AND DISCUSSION

Dissolved oxygen was low at all three sites, averaging 2.0 - 2.1 ppm with a range of 0.4 - 6.6 ppm. Acidity was similar among impoundments, averaging 5.1 - 5.4 with a range from 4.1 - 6.1. Secchi disc readings also were similar with a range from 0.18 - 0.93 m.

Water control structures in I-1 and I-3 remained closed throughout the two years of this study, while I-2 was partly drained half-way through the second year. Density of living upland vegetation within each impoundment diminished with time after flooding, whereas the density of aquatic plants increased (Table 1). Most woody vegetation at I-1 remained vigorous during the first year of inundation, but after two years more than 55% had died. Duckweeds and bladderwort first appeared during the summer of 1991 and covered approximately 50 % of the water's surface by the following summer. Aquatic emergent vegetation, including cattail (*Typha latifolia*), common rush (*Juncus effusus*), arrowhead (*Sagittaria latifolia*), and swamp loosestrife (*Decodon verticillatus*), was pioneering along the perimeter of I-1 by the second summer of inundation (Table 1).

About 75% of woody vegetation at I-2 was dead by the end of the first growing season; 90% was dead a year later. Duckweeds and bladderwort quickly colonized I-2 and covered more than 40% of the surface one year after inundation (Table 1). Downed timber and dying, woody, emergent vegetation at I-2 provided conditions generally favored by wood ducks and their broods in the southern United States (see Cottrell et al. 1990). However, favorable conditions declined after two years of inundation, as woody cover died and disappeared rapidly creating a more open impoundment.

A lack of inundated woody vegetation at I-3 resulted in an open pond, except for one wooded cove and vegetation bordering the stream that fed the impoundment. Some perimeter vegetation was inundated when the water-control structure was closed. Plant mortality in I-3 thus occurred primarily in the wooded coves, which covered only 0.14 ha. Aquatic vegetation present at I-3 consisted primarily of bladderwort and duckweeds. Cattail was growing along the perimeter of I-3 by the end of the second growing season, and floating organic muck supported thick patches of swamp loosestrife. Swamp loosestrife, giant cane (*Arundinaria gigantea*), and fetterbush within and along the wooded coves offered cover for wood ducks as they foraged on water oak acorns.

Mast production varied greatly among impoundments. In the uplands adjacent to the impoundments, more mast was collected at I-1 (158.7 g, of which southern red oak acorns contributed 148.5 g) than I-2 (52.2 g) or I-3 (68.7 g). Mast collected in baskets within the impoundments probably better represents availability in terms of food for wood ducks. However, wood ducks were

Table 1. Changes in density<sup>a</sup> of live and dead vegetation in three blackwater impoundments at Camp Lejeune between August 1991 and August 1992.

| Wetland                   | Date        | Woody Emergent Vegetation       |       |      | Aquatic Vegetation |                    |            |
|---------------------------|-------------|---------------------------------|-------|------|--------------------|--------------------|------------|
|                           |             | Density (stems/m <sup>2</sup> ) | Alive | Dead | % Dead             | Alive <sup>b</sup> | % of Total |
| I-1(3 plots) <sup>c</sup> | August 1991 | 3.42                            | 0.36  |      | 10                 | 0                  | 0          |
|                           | June 1992   | 1.53                            | 2.05  |      | 57                 | 5.00               | 58         |
|                           | August 1992 | 1.22                            | 1.84  |      | 60                 | 8.00               | 72         |
| I-2(4 plots)              | August 1991 | 0.88                            | 2.78  |      | 76                 | .38                | 9          |
|                           | June 1992   | 0.64                            | 3.28  |      | 84                 | 2.08               | 35         |
|                           | August 1992 | 0.42                            | 3.45  |      | 89                 | 6.50               | 63         |
| I-3(2 plots)              | August 1991 | 3.77                            | 0.00  |      | 0                  | .92                | 20         |
|                           | June 1992   | 1.67                            | 1.30  |      | 44                 | 0.42               | 12         |
|                           | August 1992 | 1.32                            | 1.87  |      | 59                 | 3.50               | 52         |

<sup>a</sup> Densities of aquatic plants (e.g., duckweed) derived from estimates in 0.5 m<sup>2</sup> plots.

<sup>b</sup> Aquatic plants include floating plants and herbaceous emergents.

<sup>c</sup> Each plot = 15 m<sup>2</sup>.

observed feeding upon water oak acorns both at the water's edge and as far as 5 m above the shoreline of the wooded coves at I-3. Within the coves of I-3, water oaks yielded significantly ( $p < 0.05$ ) more acorns ( $>28.0$  g/m<sup>2</sup>) than at I-1 or I-2 and attracted large numbers of wood ducks on a regular basis.

Acorn yields adjacent to the impoundments were similar to those in Missouri, where the upper range of acorn production in an upland forest varied from 4.0 to 25.5 g/m<sup>2</sup> during a 2-year period (Dalke 1953). Elsewhere in Mis-

souri, pin oaks (*Quercus palustris*) within green-tree reservoirs produced an average of 14.2 g/m<sup>2</sup> (McQuilken and Musbach 1977).

Invertebrates are important waterfowl foods because of their protein and mineral contents, which are essential for egg production in hens and tissue growth of chicks (Krapu 1974, Swanson et al. 1974, Drobney and Fredrickson 1979, Drobney 1990). Invertebrate biomass within the impoundments ranged from 0.06 - 0.20 gm/m<sup>2</sup> (Table 2). Insects in the order Odonata (primarily Libellulidae) and Heteroptera (primarily Notonectidae) were the most abundant invertebrates. Most other groups were much less abundant (Table 2).

Table 2. Macroinvertebrate biomass<sup>a</sup> (in grams) in three blackwater impoundments at Camp Lejeune in April, May, June, and July 1992.

| Taxa <sup>b</sup>                | Pond            |       |                 |
|----------------------------------|-----------------|-------|-----------------|
|                                  | I-1             | I-2   | I-3             |
| Chelicerata                      |                 |       |                 |
| Araneae                          | 0.01            | 0.05  | 0.01            |
| Crustacea                        |                 |       |                 |
| Amphipoda                        | 0.02            |       |                 |
| Decapoda                         |                 | 2.22  | 1.34            |
| Insecta                          |                 |       |                 |
| Coleoptera                       | 0.27            | 0.33  | 0.07            |
| Diptera                          | tr <sup>c</sup> | 0.09  | tr <sup>c</sup> |
| Heteroptera                      | 4.91            | 1.34  | 0.36            |
| Megaloptera                      | 0.02            | 0.45  |                 |
| Odonata                          | 2.10            | 8.39  | 0.07            |
| Total for all plots              | 7.33            | 12.87 | 1.85            |
| Average/ plot                    | 2.44            | 3.22  | 0.93            |
| Number Plots (15m <sup>2</sup> ) | 3               | 4     | 2               |

<sup>a</sup> Includes adults, nymphs, pupae, and larvae.

<sup>b</sup> For further taxonomic breakdown, see Harper (1993).

<sup>c</sup> tr = trace.

While investigating invertebrate productivity within a blackwater river in south Georgia, Benke et al. (1984) recorded 20-50 times more standing stock biomass on snags than in sandy habitat and 5-10 times more than in muddy habitat. They also found increased species richness on snag habitats as compared to other benthic habitats and concluded that production on snags appeared to be limited by available substrate. Thus, blackwater impoundments with significant

amounts of flooded vegetation and downed timber (such as I-2 in our study) seem to provide habitat for a larger standing stock and increased production over riverine sites (e.g., non-impounded blackwater streams). High diversity and biomass of invertebrates make an important contribution to nesting and brooding wood ducks.

Wood ducks utilized the impoundments as nesting and brooding sites during both years of the study. One wood duck nest was located in 1991 (nine boxes were available). In 1992, two wood duck nests were among 15 bird nests found in 21 boxes available on the impoundments. Other birds using the nest boxes included eastern bluebirds (*Sialia sialis*), Carolina wrens (*Thryothorus ludovicianus*), great-crested flycatchers (*Myiarchus crinitus*), and prothonotary warblers (*Protonotaria citrea*).

Broods were sighted 34 times on I-1 during the survey period (May - June 1992). Because no eggs hatched in nest boxes at I-1, these broods either emigrated from other wetlands or hatched from nests in natural cavities nearby. The thick cover of fetterbush, titi, wax myrtle, honeysuckle (*Lonicera japonica*), and blackberry (*Rubus* spp.) around and within I-1, coupled with an abundance of invertebrates, made this impoundment an attractive brood rearing site. Molting adults also were observed within I-1 during brood surveys. Broods and adults were observed using floating logs in I-1 as loafing sites.

Brood habitat also was favorable at I-2, where broods were sighted on 35 occasions. The largest of these consisted of seven ducklings, but because this brood was observed before any clutches hatched in nest boxes located at I-2, the ducklings must have come from another site or a natural cavity in the local area. Movement of broods should not be unexpected in light of the mobility McGilvrey (1969) recorded for wood duck broods on impoundments elsewhere.

Thick cover at both I-1 and I-2 precluded precise censuses of broods; however, two broods were commonly observed concurrently on each impoundment, thus providing a conservative estimate of use. This compares favorably with the average of three broods per sampling date observed on impoundments of 0.71 to 2.70 ha in South Dakota, where visibility was much greater (see Rumble and Flake 1982). Similarly, Belanger and Couture (1988) recorded the greatest density of dabbling duck broods (2.0 broods/ha) on man-made ponds containing >30% cover and 0.35 g of invertebrate biomass per m<sup>2</sup>, similar to conditions at I-1 and I-2.

Broods were not observed at I-3 during the survey, and the 10 ducklings that hatched from a nest box there in 1991 left the impoundment shortly afterward. The relative lack of invertebrates and plant cover, along with the small size of I-3, likely contributed to the absence of broods (Sousa and Farmer 1983, Drobney and Fredrickson 1979, Haramis 1990). Continued use of these impoundments as brood cover will depend on the schedule of flooding and drawdown. Brooding, molting, and roosting wood ducks depend on thick cover.

Unless managed to maintain living woody cover, impoundments will, in time, become more open, much like beaver (*Castor canadensis*) ponds.

Significantly ( $p < 0.05$ ) fewer wood ducks were flushed from I-2 ( $n = 38$ ) than I-1 ( $n = 82$ ) and I-3 ( $n=71$ ). Numbers of wood ducks using the impoundments increased dramatically during autumn. Numbers recorded during flush counts were highest in November: I-1 ( $n = 50$ ), I-2 ( $n = 20$ ), and I-3 ( $n = 45$ ). Decreased density of vegetation within I-2 probably accounted for fewer ducks flushed. Mortality of woody vegetation was highest at I-2 in 1992. By fall 1992, almost 90% of the standing vegetation within I-2 was dead, whereas only about 60% had died in I-1 and within the coves of I-3 (Table 1). Apparently, the availability of acorns in the two wooded coves at I-3 attracted wood ducks to these specific sites, which were the only locations on I-3 where wood ducks were flushed (i.e., no ducks were flushed from open water).

Wood ducks used I-1 and I-2 regularly for roosting during autumn and winter. Roosting activity increased from a low average of seven wood ducks per night on I-1 and 10 wood ducks per night on I-2 in September to a seasonal high of 140 per night on I-1 in November. Dense, low, evergreen shrub cover within I-1 similar to conditions described by Parr et al. (1979), provided attractive roosting habitat. Differences in cover apparently influenced the degree to which each site served as a roosting area, because significantly ( $p < 0.05$ ) more wood ducks roosted under the live vegetation in I-1 as opposed to the dead vegetation in I-2. While only 10 wood ducks per day were flushed from I-2 in November, many more (average 65/night) sought roosting cover at night. Because very few acorns were available within I-1 or I-2, we believe wood ducks flushed during the day were loafing and not necessarily actively feeding. The wooded coves of I-3 were presumably too narrow for use as a secure roosting area. Wood ducks avoided roosting on I-3, which was mostly open water, thereby underscoring the value of impoundments with thick living emergent woody vegetation for loafing and for roosting.

#### MANAGEMENT CONSIDERATIONS AND CONCLUSIONS

The presence of myriad, first-order blackwater rivulets and streams in eastern North Carolina offers opportunities for creating many small impoundments suitable as habitat for wood ducks and many other species. Within a year of construction, small wooded impoundments were used readily by wood ducks for nesting, rearing broods, molting, roosting, and feeding. Depending upon physiographic features of each site (e.g., presence of live, low, woody cover; size of impoundment; topography; presence of preferred mast trees; etc.), use by wood ducks varied among the impoundments, yet certain biological needs were met at each.

Management goals for waterfowl on small impoundments are best achieved where water levels can be manipulated (Johnsgard 1956). Additional-

ly, water-level management enhances biodiversity in wetland environments (Fredrickson and Taylor 1982). Maximum benefits are achieved when water-level management follows a schedule of drawdowns and flooding designed to maintain suitable communities of food and cover plants (Fredrickson and Taylor 1982, Fredrickson and Batema (no date), Fredrickson 1991). When managing small impoundments for wood ducks, we recommend initiating a flooding and drawdown schedule that allows maintenance of living, emergent woody vegetation at a density of  $> 3 - 5$  stems/m<sup>2</sup> where possible. Drawdowns and flooding should be completed slowly (i.e., approximately 3 weeks), thereby maximizing food availability (e.g., invertebrates and mast) within the wood duck's foraging niche ( $< 20$  cm water depth) and allowing time for the establishment of moist-soil vegetation. Drawdowns should be timed so that they coincide with the spring migration of wood ducks. When managing for broods, drawdowns should not be completed until August, when most wood duck broods have fledged. Upon drawdown, areas inundated for brood utilization during the growing season should not be flooded again for 2 - 3 years to allow complete aeration of soil in order to perpetuate live woody cover. Reflooding in the fall should be timed so that at least 85% of the impoundment is inundated for the peak migration period of wood ducks (for our study, the first week of November. (See Harper 1993 for additional details.)

Water-level management enables managers to provide needed resources for wood ducks year-round. Obviously, this would be very difficult with only one wetland; however, with a complex of small, managed impoundments, the task is more feasible. With a schedule where an impoundment provides flooded cover only every 2 to 3 years, it is essential to have several impoundments that are diverse and can be inundated on a rotation, thus meeting the various needs of wood ducks each year. Three ponds, with one flooded each year and with the other two recovering, appear to represent a minimal management unit.

Although it is usually possible for landowners to construct small impoundments on small streams for wildlife enhancement, the regulatory office of the local United States Army Corps of Engineers should always be contacted prior to initiating work to determine the effect of regulations relative to section 404 of the Clean Water Act.

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# Relationship of Mass to Girth in Raccoons, *Procyon lotor* (Mammalia: Procyonidae), from West Tennessee

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**ABSTRACT**--Mass to girth ratio of 103 captured, adult (>14 months) raccoons (*Procyon lotor*) was analyzed to assess allometric relationships. Use of this ratio as a measure of physical condition was investigated with linear regression and a comparison of the ratio by year, season, sex, and age. There was no statistically significant difference among years ( $F = 0.17$ ;  $P = 0.8473$ ) or between seasons ( $F = 1.13$ ;  $P = 0.2916$ ). The ratio differed significantly among ages and was smallest for raccoons 14 to 38 months in age ( $F = 12.31$ ;  $P = 0.0001$ ). Males exhibited a significantly larger ratio than females ( $F = 25.03$ ;  $P = 0.0001$ ). There was no difference found within all groupings in parallelism or coincidence based on the regression equations. The regression equation for mass to girth for all individuals was  $\text{Mass} = 0.02916 * (\text{Girth}) - 5.5904$  ( $r^2 = 0.8044$ ;  $P = 0.0001$ ). Although the allometric relationship between the mass and girth of raccoons was significant, this relationship does not appear to be indicative of the physical condition of the animal.

Estimating fitness of individuals in a population requires direct count of the reproductive success of the females or some other measure of physical condition such as antler beam diameter of white-tailed deer (*Odocoileus virginianus*) (Halls 1984), or kidney fat index of white-tailed deer and raccoons (*Procyon lotor*) (Johnson 1970, Glenn and Clark 1990). When studying medium-sized nocturnal mammals, it is difficult to accurately determine the number of offspring produced per female in live animals because typical measures of physical condition (such as placental scar counts, body fat indices, kidney fat indices) involve sacrificing the individual (Johnson 1970, Sanderson and Nalbandov 1973, Glenn and Clark 1990). In long-term population and community ecology studies, sacrificing individuals is not a suitable method. Thus, a nondestructive method of quantitatively reporting physical condition is needed.

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The inherent relationship known for mass and length (Thompson 1961, Schmidt-Nielsen 1984), suggests that a relationship between mass and girth could be an estimable parameter to investigate as a measure of physical condition. The girth of an animal could increase disproportionately to overall mass if there is a great amount of fat in relation to the skeletal and muscular tissue. This would indicate an improvement in the relative condition of an individual. Conversely, a decrease in girth measurement would likely be noticed before a large decrease in mass due to the loss of fat around the thoracic region, the first fat to be lost during a shortage of food (Stuewer 1943). Bissonette and Csech (1938) found smaller litters were produced by malnourished female raccoons, suggesting a possible correlation of mass to girth with reproductive fitness in raccoons.

No indirect method of estimating physical condition that avoids sacrificing individuals has been described for the raccoon. The objectives of this study were to investigate the allometric relationship between mass and girth in raccoons and to evaluate the suitability of this relationship as an indirect method of quantifying physical condition in this species.

#### STUDY AREA AND METHODS

The study was conducted on the 252 ha Edward J. Meeman Biological Station (MBS) located ca. 20 km north of Memphis, Tennessee, 35°20'N latitude and 90°01'W longitude. Tree species are described as western mixed mesophytic forest (Braun 1950, Miller and Neiswender 1987). Five permanent ponds, one temporary pond and permanent and intermittent streams provided water sources to MBS. No trap site was located at a distance greater than 450 m from permanent water. Topography varies from gentle (<3%) to steep (>45%) slopes. Climatic conditions varied greatly throughout the three years of the study. Rainfall at MBS from April to September was 77.4 cm in 1991, 50.9 cm in 1992, and 48.9 cm in 1993, and from October to March was 71.2 cm in 1991, 52.7 cm in 1992, and 26.2 cm for October and November 1993. Mean temperature did not vary greatly from the 30-year mean temperature at MBS. Mean seasonal temperature was 16.5 C in spring, 26.6 C in summer, 17.3 C in autumn, and 6.0 C in winter. There was an extended period equal to 30 days of >32 C daytime temperature from July to August 1993 that did not occur during the previous two years. Detailed analyses of the habitat and climatic patterns at MBS can be found in Ladine (1995).

Beginning 3 February 1991 and running through 30 November 1993, a 5 X 10 trapping grid was established with folding Tomahawk live traps (Tomahawk Live Trap Co.; Tomahawk, Wisconsin) placed 150 m apart (grid size = 112 ha). Traps were open four nights per week from 3 February 1991 to 31 January 1992, after which they were open three nights per week. Traps were baited with canned cat food.

Captured raccoons were anesthetized with a 1:1 mixture of ketamine hydrochloride (Ketaset; Bristol Laboratories, Syracuse, New York) and acepromazine maleate (PromAce; Ayerst Laboratories, New York, New York), based on estimated body mass, then tagged in both ears with No. 3 Monel ear tags (National Band and Tag Co., Newport, Kentucky). Data collected from captured raccoons included mass, girth, and age. Raccoons were weighed at the site of capture to the nearest 0.1 kg with a spring loaded scale. Girth measurements were taken at the posterior end of the sternum immediately anterior to the xiphoid process with a flexible tape pulled taught against the raccoon. Age was determined by tooth wear (Grau et al. 1970). Age classes were: 0-14 months (Age I), 14-38 months (Age II), 38-56 months (Age III), 56-84 months (Age IV), and >84 months (Age V).

Only adult raccoons, age II and older, were included in the analysis to avoid confounding relationships due to different patterns in growth for younger animals (Johnson 1970). To maintain independence of observations, only the first capture of an individual was used in data analysis, except for analysis of individual variation. Date of capture was categorized into two seasons, summer (April through September) and winter (October through March). Data were analyzed by year, season, age, and sex.

All data were analyzed using Statistical Analysis Systems (SAS Institute 1989). Comparison of the mass to girth ratio was analyzed with General Linear Models (PROC GLM) using Tukey's multiple comparison procedure to test among classes. The relationship between mass and girth was analyzed using linear regression (PROC REG). Because of the possibility that the allometric relationship may differ among age classes, years, or between sexes and seasons, parallelism and coincidence of the regression equation of the allometric relationship between mass and girth were tested within each grouping. Parallelism tests for the equality of the slope of the equation for more than one population. Coincidence tests for the equality of the intercept of the y-axis of the equation. Dummy variables were created to test for parallelism and coincidence for the three years of the study, each season, the four adult ages, and sex.

To investigate the stability of the allometric relationship, the linearity of the mass to girth ratio was examined with PROC REG for individuals with >5 captures. This analysis was used to determine if the allometric relationship exhibited temporal variation among individuals.

## RESULTS

One hundred and five raccoons (61 males, 42 females) were measured. There was no difference among years ( $F = 0.17$ ;  $P = 0.8473$ ), or between seasons ( $F = 1.13$ ;  $P = 0.2916$ ). Differences in the mass to girth ratio were found among age classes ( $F = 12.31$ ;  $P < 0.0001$ ) and between sexes ( $F = 25.03$ ;  $P < 0.0001$ ). Age class II raccoons exhibited a smaller ratio than did the three older age class-

es (Table 1). The ratio was larger in males than females. There was no two-way interaction for SEX X AGE ( $F = 1.08$ ;  $P = 0.3622$ ), SEASON X AGE ( $F = 0.97$ ;  $P = 0.4118$ ) and SEASON X SEX ( $F = 3.36$ ;  $P = 0.0709$ ).

Table 1. Mass to girth ratio for year, season, sex, and age for captured raccoons (*Procyon lotor*). See text for explanation of age classes and definition of seasons.

| Grouping  | n  | Mean       |
|-----------|----|------------|
| Year      |    |            |
| 1991      | 40 | 1.27:1.00  |
| 1992      | 31 | 1.25:1.00  |
| 1993      | 32 | 1.24:1.00  |
| Season    |    |            |
| Summer    | 44 | 1.14:1.00  |
| Winter    | 59 | 1.16:1.00  |
| Sex       |    |            |
| Males     | 61 | 1.27:1.00* |
| Females   | 42 | 1.05:1.00* |
| Age class |    |            |
| II        | 37 | 1.01:1.00* |
| III       | 38 | 1.32:1.00  |
| IV        | 22 | 1.22:1.00  |
| V         | 6  | 1.23:1.00  |

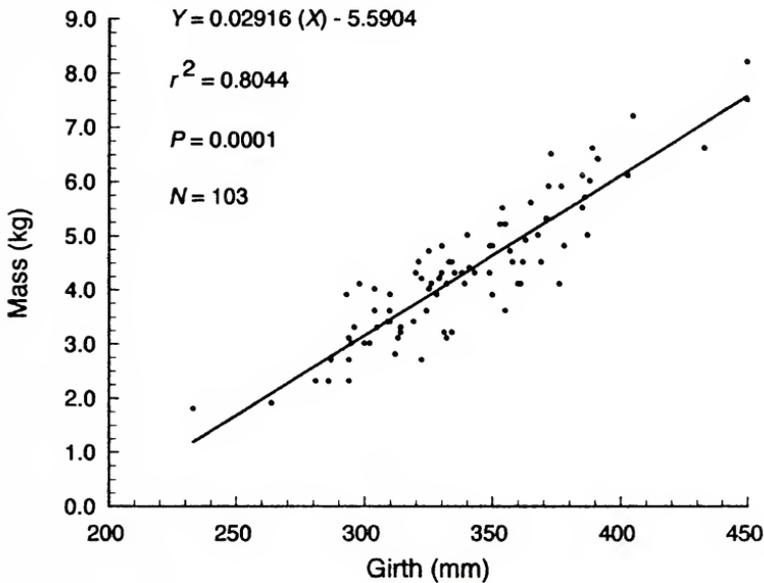
\* Means are different within grouping ( $P < 0.05$ ).

There was no difference between sexes in either parallelism ( $F = 0.00002$ ;  $P = 0.9964$ ) or coincidence ( $F = 0.0407$ ;  $P = 0.9601$ ). There was no difference among ages for either parallelism ( $F = 0.0105$ ;  $P = 0.9985$ ) or coincidence ( $F = 0.0277$ ;  $P = 0.9998$ ), between seasons for parallelism ( $F = 0.0365$ ;  $P = 0.8489$ ) or coincidence ( $F = 0.0407$ ;  $P = 0.9601$ ), and among years for parallelism ( $F = 0.0173$ ;  $P = 0.9829$ ) or coincidence ( $F = 0.0216$ ;  $P = 0.9957$ ).

Because there was no difference in parallelism or coincidence regardless of grouping, all data were analyzed in a single regression equation (Fig. 1). The regression equation, was significantly linear ( $\text{Mass} = 0.02916 * (\text{Girth}) - 5.5904$ ;  $r^2 = 0.8044$ ;  $P = 0.0001$ ) and indicates a strong positive relationship between mass and girth. The lack of difference for either parallelism or coincidence indicate that the equation is useful across all age and sex classes regardless of season or year.

Thirteen raccoons were captured 5 or more times for analysis of individual variation in the mass to girth ratio. The stability of the allometric relationship between girth and mass exhibited substantial variability in correlation and linearity (Table 2). Only three raccoons showed a linear correlation between girth and mass during their capture histories. One female (4160M) exhibited a significant linear correlation without a strong fit of the data to the line indicating little relationship between mass and girth for this individual.

Fig. 1. Linear relationship between mass and girth of raccoons captured in western Tennessee from February 1991 to November 1993.



## DISCUSSION

Several studies have shown a relationship between length and mass when length is converted to a volumetric measure (see Johnson 1970, Dunn and Chapman 1983, Vogel 1979, Schmidt-Nielsen 1984). The mass of an animal is believed to be approximated by volume, thus, the reason comparing mass to the cubed length of an animal. Because girth is a circumgeal measurement, a closer approximation to mass may be achieved. The relationship between mass and girth has been shown for phocid seals (Hofman 1975, Castellini and Kooyman 1990) and dromedary camels (*Camelus dromedarius*) (Schroter et al. 1992).

Due to the manner in which most subcutaneous fat is accumulated in raccoons (Stuewer 1943), girth should vary in relation to mass. Regression analysis indicated that this occurred. Additionally, the mass to girth ratio was

linearly constant regardless of year, season, and sex class, with slight differences among age classes. The lower ratio for age II raccoons might indicate that these individuals are not able to accumulate the fat reserves of older animals resulting from potential lower dominance status. The potential for dominance hierarchies in raccoons has been shown experimentally (Barash 1974).

Table 2. Correlation of mass and girth of 13 individual raccoons (*Procyon lotor*). See text for explanation of age class.

| Raccoon | Age Class | Sex | Number of Captures | Adjusted R <sup>2</sup> <sup>a</sup> | P      |
|---------|-----------|-----|--------------------|--------------------------------------|--------|
| 2760M   | V         | M   | 5                  | -0.1134                              | 0.4923 |
| 4022M   | III       | M   | 8                  | 0.7185                               | 0.0049 |
| 4145M   | II        | M   | 10                 | 0.9030                               | 0.0001 |
| 5208M   | II        | M   | 5                  | -0.2968                              | 0.7901 |
| 4080M   | II        | F   | 5                  | 0.1993                               | 0.3172 |
| 4083M   | III       | F   | 8                  | 0.3829                               | 0.0601 |
| 4090M   | II        | F   | 6                  | 0.8742                               | 0.0127 |
| 4100M   | II        | F   | 10                 | -0.0667                              | 0.5269 |
| 4117M   | IV        | F   | 6                  | -0.0259                              | 0.4130 |
| 4160M   | IV        | F   | 9                  | 0.5973                               | 0.0089 |
| 4186M   | II        | F   | 7                  | 0.2152                               | 0.1648 |
| 4188M   | II        | F   | 9                  | 0.2329                               | 0.1065 |
| 4190M   | II        | F   | 6                  | -0.0819                              | 0.4746 |

<sup>a</sup> Adjusted R<sup>2</sup> was used due to the small sample sizes for each individual.

Sanderson (1950) noted that the strain of pregnancy and lactation have a marked effect on the mass of female raccoons. Thus, adult females would be expected to have lower fat reserves than adult males due to the stress of rearing young. Furthermore, the observed difference between the males and females might be due to potential physiological differences between the sexes, a potential social dominance of the males (see Barash 1974), or a combination of the two.

The seasonal variation observed in individuals could be due to seasonal mass changes. Raccoons are known to exhibit seasonal fluctuations in mass (Stuewer 1943, Mech et al. 1968, Moore and Kennedy 1985). As indicated previously, the mass to girth ratio in raccoons is a linearly constant relationship. Consequently, one would expect to see girth fluctuate with mass.

The assumption for using a mass to girth ratio as a measure of physical condition was: the greater the amount of fat the better the physical condition of a raccoon. This assumption is based on the manner in which subcutaneous fat is accumulated in raccoons (see Stuewer 1943). Body fat and kidney fat indices have shown some correlation of the amount of fat to physical condition for the species (Johnson 1970, Dunn and Chapman 1983).

My findings indicate that the mass to girth ratio was not indicative of physical condition in raccoons for several reasons. No difference in slope or intercept existed between any groupings for the equation relating mass to girth. Although a difference existed among age classes and between sexes, this difference can be explained by reasons other than physical condition. Further evidence of the shortcoming of the mass to girth ratio as an indicator of physical condition was the lack of any consistent relationship between the two variables when the relationship was tested for each individual. All individuals appeared to be in good condition when captured, and differences in the ratio probably only reflect individual variation and might not be indicative of physical condition.

Thus, I concluded that the mass to girth ratio was not a good indicator of physical condition. Nevertheless, because of need for determining physical condition during long-term population and community ecology studies, there remains a necessity to determine physical condition through nonintrusive methods.

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# A Multiscale Approach to Capture Patterns and Habitat Correlations of *Peromyscus leucopus* (Rodentia, Muridae)

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**ABSTRACT**--Capture patterns (presence/absence) of *Peromyscus leucopus* were examined in relation to 12 selected habitat variables at three spatial scales. Trapping was conducted on a 14 X 14 trapping grid established at the Edward J. Meeman Biological Station in southwestern Tennessee. Density of the population was estimated at 18.5 mice per hectare. Twelve habitat variables were collected in three circular plots (1 m<sup>2</sup>, 5 m<sup>2</sup>, 10 m<sup>2</sup>) centered on 60 trap sites (30 trap sites where captures of *P. leucopus* occurred, 30 randomly selected sites where no captures occurred). There was a significant difference among spatial scales for six habitat variables. We observed no discernable patterns through principal components analysis for any scale. However, the centroid of the cluster of traps in principal component space shifted from negative to positive as scale increased. Sites where captures occurred and those where no captures occurred were not significantly different at the 1-m<sup>2</sup> scale for any habitat variables. Capture occasions differed significantly for stems 10-15-cm diameter and logs 10-15 cm at the 5-m<sup>2</sup> and 10-m<sup>2</sup> spatial scales, respectively. Our study emphasizes the need for including multiscale assessments of habitat use. Scales might best be selected by assessing the habitat of the study site and the behavior of the species being studied.

The concept of scale, while not a new concept in other disciplines, has only recently been investigated in ecology (Wiens 1989). Levin (1991) stated that because there is an absence of any correct scale at which to investigate a population, a multiscale approach should be taken. Thus, investigations of species relating habitat use to capture success could be affected by the selected scale. Studies relating habitat use to capture success have generally selected a single scale in which to measure the habitat. This scale of habitat assessment is usually based on amount of time spent for amount of data return. Thus, the scale

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selected for habitat assessment might not be representative for the species being investigated or may affect the results of the study (see Levin 1991, Schneider 1994).

The need for a multiscale approach has been demonstrated in several studies of species interactions. Depending on the scale selected, species of marine birds were or were not associated with their prey species (Woodby 1984, Schneider and Piat 1986). Least flycatchers (*Empidonax minimus*) and redstarts (*Setophaga ruticilla*) had a negative association at small scales and a positive association at larger scales (Sherry and Holmes 1988). Furthermore, behavior of an animal can be affected by the spatial scales at which prey are distributed (Boyd 1996).

Similarly, the association between habitat around a live trap and capture of a selected species lends itself to a multiscale approach. However, capture-recapture studies rarely, if ever, use multiple scales to assess correlations between captures and habitat use. Using capture success is warranted for studies investigating habitat correlations because densities within a habitat can be influenced by factors (e.g. intra- and interspecific interactions) that place subordinates into suboptimal habitats (van Horne 1983). Also, factors such as curiosity of a new object (e.g. a trap) in an area may influence captures (Lackey et al 1985). However, an animal must be present in a habitat for a capture to occur; thus, must use the habitat in some way.

The objective of our study was to investigate the association between captures of *Peromyscus leucopus* and selected habitat variables at three spatial scales centered on location of live traps. Although there is a large amount of literature on *P. leucopus* (see Lackey et al. 1985), to our knowledge, no study has been conducted relating spatial scale to the association between capture success of *P. leucopus* and selected habitat variables.

*Peromyscus leucopus* is an excellent organism to use in multiscale analyses of correlations between captures and habitat. The species is well studied throughout its range, and habitat affinities are well documented (see Lackey et al. 1985). Because *P. leucopus* is a small mammal, a multiscale study design can be done at small scales, and fine grained changes in habitat are more likely to be exhibited. Previous investigations of habitat affinities of *P. leucopus* (see Lackey et al. 1985) indicate loosely defined associations. However, these loosely defined associations may become more clearly defined with a different or more meaningful choice of scales.

#### STUDY AREA AND METHODS

The study was conducted at the 252-ha Edward J. Meeman Biological Station (hereafter referred to as the station) located ca. 20 km north of Memphis, Tennessee, (35°20' N, 90°01' W) on the third Chickasaw loess bluff. The station is surrounded on three sides by private lands and on the fourth by the Shelby Forest Wildlife Management Area.

Habitat has been described as a western mixed mesophytic forest (Braun 1950, Miller and Neiswender 1987). Dominant canopy plants are sweet gum (*Liquidambar styraciflua*), tulip poplar (*Liriodendron tulipifera*), elms (*Ulmus* spp.), oaks (*Quercus* spp.), and hickories (*Carya* spp.). There is an extensive network of grape (*Vitis* spp.) and poison ivy (*Toxicodendron radicans*) vines throughout the canopy. The understory is dominated by spicebush (*Lindera benzoin*). Dominate ground cover species are *Osmorhiza* sp., *Smilacina racemosa*, *Toxicodendron radicans*, *Urtica* sp., various woodland grass species, and seedlings of the dominant canopy and understory species. A detailed analysis of the habitat on the station can be found in Ladine (1995).

A 14 X 14 trapping grid was established using folding Sherman live traps (H. B. Sherman Traps, Inc.; Tallahassee, Florida) spaced ca. 10-m apart. Trapping was conducted from 28 January 1995 through 9 February 1995. Traps were baited with oatmeal, left open during the day, and checked at sunrise. Estimation of population size was made using the Schnabel method (Krebs 1989).

Location of the trapping grid was entirely within a mature stand of oak, sweet gum, and tulip poplar trees. The selected location has been shown to be homogenous on the macrohabitat scale (Ladine 1995). Placing the grid in this location avoided potential confoundment during statistical analyses posed by placing traps in differing macrohabitats.

Trap sites were classified according to the occurrence of captures of *P. leucopus*. Trap sites with at least one capture were classified as capture sites. Other sites were classified as no-capture sites. To strengthen the multivariate analyses and remove the possibility of nonorthogonal functions and components (Tabachnick and Fidell 1989), thirty randomly selected no-capture sites were designated for habitat association analyses.

Twelve selected habitat variables (Table 1) were measured at each capture site and at each no-capture sites. All selected habitat variables were measured at each of three spatial scales (1 m<sup>2</sup>, 5 m<sup>2</sup>, and 10 m<sup>2</sup>) in circular plots centered on each trap. These scales were selected following Noon (1981) who suggested that a more homogeneous habitat be sampled more finely than a heterogeneous habitat in order to detect the inherent heterogeneity. Thus, because of the apparent homogeneity of the habitat within the trapping grid (Ladine 1995), these selected scales were used.

All statistical analysis were conducted using Statistical Analysis Systems (SAS Institute 1989). Habitat variables for capture and no-capture sites were compared at each scale with a Kruskal-Wallis test of Chi-square approximation. Selected habitat variables between scales were compared with a Kruskal-Wallis test of Chi-square approximation to test for differences among selected scales. To control for group-wide Type I error, all multiple pairwise comparisons were made using a sequential Bonferroni adjustment (Rice 1989) with initial  $\alpha = .05$ .

Table 1. Description of selected habitat variables measured at 30 sites with captures of *Peromyscus leucopus* occurred and 31 sites with no captures of *P. leucopus* for a study in western Tennessee.

| Habitat variables | Description   |
|-------------------|---|
| COVER0            | Percent green vegetation at ground level                              |
| COVER1            | Percent green vegetation at 1 m height                                |
| COVER2            | Percent green vegetation at 2 m height                                |
| STEMS0-5          | Number of vertical woody stems with diameter <5 cm                    |
| STEMS5-10         | Number of vertical woody stems with diameter 5-10 cm                  |
| STEMS10-15        | Number of vertical woody stems with diameter 10-15 cm                 |
| STEMS>15          | Number of vertical woody stems with diameter >15 cm                   |
| LOGS0-5           | Number of horizontal woody stems on the ground with diameter of <5 cm |
| LOGS5-10m         | Number of horizontal woody stems on the ground with diameter 5-10 cm  |
| LOGS10-15         | Number of horizontal woody stems on the ground with diameter 10-15 cm |
| LOGS>15           | Number of logs at ground level with diameter >15 cm                   |
| LITTER            | Mean of seven leaf litter depths taken for each scale                 |

The existence of potential patterns at each scale was examined with principal components analysis. Discriminate function analysis was used to further examine the difference between sites with captures and sites where no captures occurred. Initial discriminating variables were selected with stepwise selection discriminate analysis and an initial entry level of significance of  $P = 0.15$ . Variables were removed or added to check the selection of variables from the stepwise selection procedure for improvement of the discriminating capabilities of the variables. No addition or subtraction improved the classification for any scale.

## RESULTS

Thirty-one *Peromyscus leucopus* were captured 55 times at 30 trap sites. Population size was estimated at 32 mice (range = 26 - 38) with a mean density of 18.5 mice per hectare. Other species, *Tamias striatus* ( $n = 1$ ), *Blarina carolinensis* ( $n = 2$ ), *Glaucomys volans*, ( $n = 7$ ) were captured at eight additional sites. No *P. leucopus* were captured at trap sites where captures of other species occurred.

Table 2. Selected habitat variables ( $\bar{x} \pm SD$ ) and Kruskal-Wallis test ( $X^2$  approximation and probability values) for the differences among three selected scales (1 m<sup>2</sup>, 5 m<sup>2</sup>, 10 m<sup>2</sup>). (See Table 1 for description of the habitat variables.)

| Habitat variable | Spatial scale             |                           |                            | $X^2$ | P      |
|------------------|---------------------------|---------------------------|----------------------------|-------|--------|
|                  | 1 m <sup>2</sup>          | 5 m <sup>2</sup>          | 10 m <sup>2</sup>          |       |        |
| COVER0           | 2.34 ± 4.20               | 2.62 ± 4.27               | 3.06 ± 4.57                | 2.06  | 0.3566 |
| COVER1           | 0.22 ± 1.02               | 0.60 ± 2.87               | 0.95 ± 3.81                | 1.75  | 0.4171 |
| COVER2           | 0.44 ± 2.63               | 0.81 ± 5.15               | 1.08 ± 5.91                | 0.56  | 0.7565 |
| STEMS0-5         | 4.24 ± 5.24 <sup>b1</sup> | 7.65 ± 8.71 <sup>a</sup>  | 4.03 ± 14.92 <sup>ab</sup> | 21.56 | 0.0001 |
| STEMS5-10        | 0.06 ± 0.24 <sup>b</sup>  | 0.13 ± 0.34               | 0.31 ± 0.59 <sup>b</sup>   | 8.59  | 0.0136 |
| STEMS10-15       | 0.08 ± 0.27               | 0.13 ± 0.34               | 0.22 ± 0.42                | 5.44  | 0.0657 |
| STEMS>15         | 0.04 ± 0.21               | 0.11 ± 0.32               | 0.22 ± 0.46                | 7.63  | 0.0220 |
| LOGS0-5          | 6.72 ± 7.68 <sup>a</sup>  | 1.42 ± 12.81 <sup>a</sup> | 18.34 ± 21.31 <sup>a</sup> | 21.44 | 0.0001 |
| LOGS5-10         | 0.24 ± 0.50 <sup>b</sup>  | 0.42 ± 0.71               | 0.70 ± 1.08 <sup>b</sup>   | 8.07  | 0.0176 |
| LOGS10-15        | 0.08 ± 0.37               | 0.08 ± 0.37               | 0.27 ± 0.68                | 8.03  | 0.0180 |
| LOGS>15          | 0.08 ± 0.27               | 0.11 ± 0.36               | 0.18 ± 0.42                | 2.27  | 0.3215 |
| LITTER           | 46.57 ± 12.78             | 49.19 ± 11.84             | 51.12 ± 13.01              | 4.36  | 0.1132 |

<sup>1</sup> Means followed by the same letter are not different ( $P > 0.017$ ) with a Bonferroni adjustment to the initial significance level ( $P = 0.05$ ).

Significant differences among the selected scales were found for STEMS<5, STEMS5-10, STEMS>15, LOGS<5, LOGS5-10, and LOGS10-15 (Table 2). Except for LOGS<5, the 1-m<sup>2</sup> and 5-m<sup>2</sup> scales did not differ significantly for selected variables. The 10-m<sup>2</sup> scale was significantly different from both the 1-m<sup>2</sup> and 5-m<sup>2</sup> scales for all variables exhibiting significant differences between the three scales.

No significant difference was observed between capture and no-capture sites for selected habitat variables at the 1-m<sup>2</sup> scale (Table 3). Except for STEMS10-15, no significant difference was found between capture and no-capture sites for selected habitat variables at the 5-m<sup>2</sup> scale (Table 4). At the 10-m<sup>2</sup> scale, a significant difference was found between capture and no-capture sites for LOGS10-15 (Table 5).

Sites with no captures tended to be centered in the cluster of sites on graphs of principal components for all scales. Outliers from sites where no captures occurred were only observed at the 1-m<sup>2</sup> spatial scale. Percent variation accounted for by the first three principal components for each scale was 42.0% at 1 m<sup>2</sup>, 39.5% at 5 m<sup>2</sup>, and 45.3% at 10 m<sup>2</sup>. Variables loading on each of the first three principal components varied for each scale. For the 1-m<sup>2</sup> scale, all

Table 3. Selected habitat variables ( $\bar{x} \pm SD$ ) and Kruskal-Wallis test ( $\chi^2$  approximation and probability values) for differences between sites where *Peromyscus leucopus* were captured and randomly selected sites where no captures occurred for the 1-m<sup>2</sup> scale. (See Table 1 for description of habitat variables. See text for explanation of capture and no-capture sites.)

| Habitat variable | Capture           | No-Capture        | $\chi^2$ | P      |
|------------------|-------------------|-------------------|----------|--------|
| COVER0           | 2.50 $\pm$ 4.84   | 2.29 $\pm$ 3.68   | 0.02     | 0.8841 |
| COVER1           | 0.13 $\pm$ 0.73   | 0.29 $\pm$ 1.19   | 0.36     | 0.5507 |
| COVER3           | 0.07 $\pm$ 0.37   | 0.74 $\pm$ 3.51   | 0.36     | 0.5507 |
| STEMS0-5         | 4.63 $\pm$ 5.33   | 4.59 $\pm$ 5.57   | 0.46     | 0.4995 |
| STEMS5-10        | 0.03 $\pm$ 0.18   | 0.09 $\pm$ 0.29   | 0.99     | 0.3210 |
| STEMS10-15       | 0.13 $\pm$ 0.35   | 0.03 $\pm$ 0.17   | 2.04     | 0.1536 |
| STEMS>15         | 0.03 $\pm$ 0.18   | 0.06 $\pm$ 0.24   | 0.31     | 0.5766 |
| LOGS0-5          | 8.13 $\pm$ 8.49   | 5.32 $\pm$ 6.51   | 2.06     | 0.1512 |
| LOGS5-10         | 0.17 $\pm$ 0.46   | 0.29 $\pm$ 0.52   | 2.04     | 0.1532 |
| LOGS10-15        | 0.13 $\pm$ 0.51   | 0.03 $\pm$ 0.17   | 0.43     | 0.5128 |
| LOGS>15          | 0.13 $\pm$ 0.35   | 0.03 $\pm$ 0.17   | 2.04     | 0.1536 |
| LITTER           | 49.22 $\pm$ 13.52 | 44.45 $\pm$ 11.28 | 2.10     | 0.1471 |

Table 4. Selected habitat variables ( $\bar{x} \pm \text{SD}$ ) and Kruskal-Wallis test ( $\chi^2$  approximation and probability values) for differences between sites where *Peromyscus leucopus* were captured and randomly selected sites where no captures occurred for the 5-m<sup>2</sup> scale. (See Table 1 for description of habitat variables. See text for explanation of capture and no-capture sites.)

| Habitat variable | Capture           | No capture        | $\chi^2$ | P      |
|------------------|-------------------|-------------------|----------|--------|
| COVER0           | 2.20 $\pm$ 4.63   | 2.85 $\pm$ 3.82   | 2.02     | 0.1558 |
| COVER1           | 0.17 $\pm$ 0.65   | 0.94 $\pm$ 3.79   | 0.22     | 0.6383 |
| COVER2           | 0.33 $\pm$ 1.09   | 1.18 $\pm$ 6.86   | 1.02     | 0.3132 |
| STEMS0-5         | 8.60 $\pm$ 9.35   | 8.09 $\pm$ 9.17   | 0.32     | 0.5716 |
| STEMS5-10        | 0.17 $\pm$ 0.38   | 0.09 $\pm$ 0.29   | 0.64     | 0.4227 |
| STEMS10-15       | 0.23 $\pm$ 0.43   | 0.06 $\pm$ 0.24   | 5.32     | 0.0211 |
| STEMS>15         | 0.07 $\pm$ 0.25   | 0.15 $\pm$ 0.36   | 1.32     | 0.2503 |
| LOGS0-5          | 12.47 $\pm$ 14.37 | 10.38 $\pm$ 11.18 | 0.02     | 0.8793 |
| LOGS5-10         | 0.27 $\pm$ 0.58   | 0.56 $\pm$ 1.39   | 3.26     | 0.0709 |
| LOGS10-15        | 0.13 $\pm$ 0.51   | 0.03 $\pm$ 0.17   | 0.43     | 0.5128 |
| LOGS>15          | 0.17 $\pm$ 0.46   | 0.06 $\pm$ 0.24   | 0.85     | 0.3565 |
| LITTER           | 48.80 $\pm$ 12.37 | 49.53 $\pm$ 11.34 | 0.06     | 0.8118 |

Table 5. Selected habitat variables ( $\bar{x} \pm \text{SD}$ ) and Kruskal-Wallis test ( $\chi^2$  approximation and probability values) for differences between sites where *Peromyscus leucopus* were captured and randomly selected sites where no captures occurred for the 10-m<sup>2</sup> scale. (See Table 1 for description of habitat variables. See text for explanation of capture and no-capture sites.)

| Habitat variable | Capture           | No capture        | $\chi^2$ | P      |
|------------------|-------------------|-------------------|----------|--------|
| COVER0           | 2.53 $\pm$ 4.14   | 3.47 $\pm$ 4.86   | 1.62     | 0.2033 |
| COVER1           | 0.47 $\pm$ 1.48   | 1.29 $\pm$ 4.93   | 0.13     | 0.7152 |
| COVER2           | 0.60 $\pm$ 2.06   | 1.41 $\pm$ 7.72   | 0.24     | 0.6275 |
| STEMS0-5         | 15.43 $\pm$ 15.34 | 15.15 $\pm$ 16.54 | 0.91     | 0.3395 |
| STEMS5-10        | 0.33 $\pm$ 0.61   | 0.26 $\pm$ 0.57   | 0.12     | 0.7298 |
| STEMS10-15       | 0.30 $\pm$ 0.47   | 0.18 $\pm$ 0.39   | 1.63     | 0.2015 |
| STEMS>15         | 0.17 $\pm$ 0.38   | 0.27 $\pm$ 0.51   | 0.83     | 0.3611 |
| LOGS0-5          | 20.63 $\pm$ 25.15 | 16.38 $\pm$ 17.18 | 0.02     | 0.8851 |
| LOGS5-10         | 0.67 $\pm$ 1.09   | 0.71 $\pm$ 1.06   | 0.28     | 0.5937 |
| LOGS10-15        | 0.50 $\pm$ 0.90   | 0.09 $\pm$ 0.29   | 5.97     | 0.0144 |
| LOGS >15 cm      | 0.23 $\pm$ 0.50   | 0.12 $\pm$ 0.33   | 0.62     | 0.4318 |
| LITTER           | 52.26 $\pm$ 13.04 | 50.65 $\pm$ 13.05 | 0.12     | 0.7292 |

percent cover measurements correlated positively along the first principal component. Vertical stems correlated along the second principal component with the two smaller stem categories correlating positively and the larger stem categories correlating negatively. Logs were correlated to the third principal component with all but LOGS>15 correlated positively. For the 5-m<sup>2</sup> scale, the first principal component was correlated positively to all cover measurements and STEMS0-5, and negatively to STEMS10-15. The second principal component was correlated positively to LOGS0-5 and LOGS5-10. The third principal component was correlated positively to STEMS5-10 and STEMS>15 and LITTER, and correlated negatively to LOGS10-15 and LOGS>15. For the 10-m<sup>2</sup> scale, the first principal component was correlated positively to STEMS10-15, LOGS0-5, and LITTER, and correlated negatively to COVER0 and COVER1. The second principal component was correlated positively to LOGS5-10, LOGS10-15, and LOGS>15. The third principal component was correlated positively to COVER1 and STEMS5-10, and correlated negatively to STEMS0-5, and STEMS>15.

Correct classification of sites with captures was poor for all scales: 1 m -- 46.7%; 5 m -- 56.7%; 10 m -- 40.0%. Classification of sites where no captures occurred was better at all three scales: 1 m -- 70.0%; 5 m -- 98.3%; 10 m -- 76.7%. Variables selected for discriminating between capture and no-capture sites were different for each scale. LITTER, and LOGS>15 were selected for the 1-m<sup>2</sup> scale. STEMS10-15, 2 m COVER, and LOGS>15 cm were selected at the 5-m<sup>2</sup> scale. LOGS10-15, 2 m COVER, STEMS0-5, and LITTER were selected at the 10-m<sup>2</sup> scale.

## DISCUSSION

Members of the genus *Peromyscus* exhibit habitat generality, at least on a local scale, and often occur across a broad range of habitats within a small geographic area (Kirkland 1976, Batzli 1977, Sullivan 1979, Van Horne 1981, Martell 1983, Adler et al. 1984). There are conflicting reports concerning relationship between density of *P. leucopus* and habitat type (Klein 1960, Stickel and Warbach 1960, Getz 1961, Bongiorno and Pearson 1964, Kaufman and Fleharty 1974). Density in our study was within the reported ranges for the species (see Lackey et al. 1985). Findings of our study at the 5-m<sup>2</sup> scale, in concurrence with Kaufman and Fleharty (1974), suggest a relationship between number of stems 10-15 cm and captures of *P. leucopus*. However, this relationship was not observed at the 10-m<sup>2</sup> scale. A relationship between logs 10-15 cm and captures of *P. leucopus* was observed at the 10-m<sup>2</sup> scale. These findings are similar to those of Getz (1961). Although relationships were observed between two of the selected habitat variables and captures of *P. leucopus*, lack of significant relationships between other variables for all scales appears to reflect the habitat generality of the species.

Lack of readily discernable patterns between captures and selected habitat variables could be a reflection of the variables we selected and lack of differences between spatial scales for some variables. There are at least three potential reasons for the lack of a readily discernable pattern between capture and no-capture sites. First, low statistical power might have resulted in the lack of differences observed in our study. However, because of the large amount of variation observed for all means and the finding of significant differences for the larger scales, the lack of differences is most likely not due to low statistical power. Second, captures of *P. leucopus* are often related to factors other than habitat. The species is known to respond to new objects placed within a familiar area (Lackey et al. 1985), and densities have been shown to correlate to food distribution (Getz 1961). Third, the spatial scales selected for study might have been of an incorrect size for ascertaining capture patterns. However, the lack of patterns in our study does not necessarily indicate scale is not important in associating captures of *P. leucopus* with habitat, only that a different scale may be warranted for future studies.

Our study shows at least two potential means by which selection of scale could influence results of a study warranting investigation of potential patterns at each scale. First, significant differences found for some variables suggest difference at the 10-m<sup>2</sup> scale, but not at smaller scales. Second, the differences in the loadings of variables on the principal components axes, differences in variables selected for use in discriminant analysis, and the decrease in outliers as scale increases suggest differences between all of the scales. These differences between scales may potentially have a large effect on the conclusions (see Schneider and Piat 1986, Woodby 1984). For example, our study had inconsequential findings at the 1-m<sup>2</sup> scale; but significant results at the larger scales.

Our data show that, even when using the small scales that we selected, differences in habitat affinities for capture can occur around the same trap site. Because our data were collected in a homogenous habitat over a short period of time, the differences observed in our study concerning correlations between habitat and capture can be attributed to the different scales. While a species may appear to be a habitat generalist with an affinity toward a variety of habitats (e.g. *P. leucopus*), studies incorporating a multiscale approach may indicate a narrower range of optimal habitat affinities. Thus, studies assessing habitat use should incorporate analyses at multiple scales. It appears this may be achieved by the incorporation of at least three scales of assessment allowing for comparison at different scales in the same habitat.

More study is needed in the selection of scale to be measured. Selection of scale is difficult to evaluate due to differences in habitat at each study site. However, we feel choice of scale should be selected based on at least the following factors. Of primary concern should be the habitat in which the study is conducted. More homogeneous habitats may require a larger number of scales

to detect observable differences. Additionally, the behavior of the species being studied must be addressed in selecting the size and number of scales to be assessed. For example, species with large ranges will require large scales to account for greater movement of individuals of these species.

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# Methods Used To Survey Shrews (Insectivora: Soricidae) And The Importance Of Forest-Floor Structure

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ABSTRACT--We examined shrew (Insectivora: Soricidae) capture rates using selective (best-site) transects, linear transects, and drift-fence arrays to better understand how pitfall trap arrangement might affect our perception of shrew assemblages in the southern Appalachian mountains. Also, we studied the use of microhabitat structure (coarse woody or rocky debris) by shrews to determine how microhabitat selection might affect capture probabilities. The distributions of shrew captures were similar at selective and linear transects, but different between either transect type and the drift-fence arrays ( $P < 0.05$ ). Differences in the effectiveness of trap arrangements were apparently related to microhabitat use. We found a gradient of selection for habitat structure among *Sorex fumeus*, *S. cinereus*, and *Blarina brevicauda*, although relationships were weak. Captures of *S. fumeus* were most closely associated with the abundance of and distance to woody or rocky debris, and those of *B. brevicauda* were independent of these microhabitat factors. Caution should be used when comparing the results of surveys using different pitfall trap arrangements.

Ecologists studying small mammals often attempt to accurately depict the structure of small mammal assemblages from trapping data. This effort is complicated by differences in size and microhabitat use among species, which can affect species- and trap type-specific probabilities of capture. Some types of sampling, notably mark-and-recapture (Otis et al. 1978), may be used to estimate capture probability and avoid this as a confounding factor. However, survey of shrew (Soricidae) assemblages using live-trapping methods is made problematic by high rates of trap mortality, and removal sampling is commonly employed using pitfall traps (Kirkland and Sheppard 1994). Therefore, particular care must be taken to minimize biases associated with sampling shrew communities.

Many studies have examined differences among types of traps used to sample shrews (e.g., Williams and Braun 1983). However, there is little information regarding biases introduced through the arrangement of traps. Despite recent efforts to promote standardized methods (Handley and Varn 1994, Kirkland and Sheppard 1994), many different pitfall-trap arrangements have been used to survey shrews (Kalko and Handley 1993). Because trap arrangements, like trap types, vary in their effectiveness at catching certain species (Bury and Corn 1987, Mitchell et al. 1993), the assessment of shrew community structure could be affected by trap arrangement.

Pitfall trapping designs often take advantage of patterns of microhabitat use, such as drifting behaviors often observed when small mammals encounter an obstruction (Brillhart and Kaufman 1991). Because these behaviors may vary among species, methods that rely on drifting could selectively under- or over-represent certain species in samples. Two methods that take advantage of drifting behavior are transects of traps placed along natural habitat structures, such as fallen logs or exposed rock (selective transects), and drift-fence arrays, which use artificial obstructions to direct small mammal movement.

To assess how perception of a shrew assemblage might vary with trapping design, we concurrently sampled shrews with selective transects, linear transects, and drift-fence arrays in the southern Appalachians. To gain insight into behaviors that might affect capture success with these trapping techniques, we also examined microhabitat (coarse woody or rocky debris) use by shrews.

## METHODS

### STUDY AREA

We conducted our study at the Coweeta Hydrologic Laboratory (35°03'N, 83°25'W), located in the Nantahala Mountain Range of Macon County, North Carolina (Swank and Crossley 1988). Elevation at our study plots ranged from 792 to 1,524 m above sea level. Study plots were restricted to plant communities typical of cove hardwood and northern hardwood forests (Wharton 1977). Cove hardwood forests were characterized by the dominance of yellow poplar (*Liriodendron tulipifera*), yellow buckeye (*Aesculus octandra*), black

cherry (*Prunus serotina*), and birch (*Betula* spp.) in the canopy, sparse woody vegetation below the canopy, and lush herbaceous vegetation. Northern hardwood forests were dominated by black oak (*Quercus velutina*), northern red oak (*Q. rubra*), yellow birch (*B. lutea*), and black cherry in the canopy. Rhododendron (*Rhododendron maximum*) and mountain laurel (*Kalmia latifolia*) were common shrubs, and the composition and density of herbaceous vegetation was variable.

### COMPARISON OF TRAPPING METHODS

At each of 12 plots we established one selective transect and one linear transect of pitfall traps in July 1994. Both transects consisted of 20 traps placed at 5-m intervals, were approximately parallel, and were separated by 50 m. Pitfalls in selective transects were placed along logs, rocks, and stumps where our previous experience had indicated that chances for shrew capture might be good. Traps in linear transects were placed without regard to microhabitat conditions. Pitfalls were tapered plastic cups (11-cm lip diameter and 14-cm depth) partially filled with preservative and set flush with the ground surface.

In August 1995, we constructed a series of five Y-shaped drift-fence arrays at each of four plots randomly chosen from among the 12 original plots. Each array consisted of three, 3-m "arms" of 36-cm-wide aluminum flashing radiating from the center of the array. Arms were set at 120° angles, and flashing was buried to 3 cm to prevent mammals from burrowing under the fences (Handley and Varn 1994, Kirkland and Sheppard 1994). Nine pitfall traps were set in association with each array, such that three were placed in the middle, and two at the ends of each of the three arms. The five arrays were set in a line approximately parallel to, and 50 m from, the previously established transects at these plots. Individual arrays were spaced 25 m apart, so that the length of the array series was equal to the length of the transects (100 m).

We operated the two types of transects at 12 plots from 9 to 23 July 1994 for a total of 3,360 trapnights (TN) per method. We operated all three methods at four plots from 4 to 11 August, and again from 18 November to 2 December 1995. Trapping effort was equal at the two types of transects (2,240 TN), but greater at the arrays (4,040 TN). Because pitfalls associated with an array are interdependent, it is not meaningful to compare sampling effort between transects and arrays. Thus, we used methods of analysis that were not influenced by differences in sampling effort. All specimens were identified to species and accessioned into the collections of the University of Georgia Museum of Natural History.

The distributions of capture frequencies using each survey method were compared using likelihood-ratio tests of independence (Agresti 1990). Rejection of the null hypothesis of independence indicated that the methods produced different distributions of capture frequencies, and thus different perceptions of

shrew assemblage structure. We also partitioned the data table involving all three methods into several independent, four-fold (2-by-2) tables (Lancaster 1949) to better determine patterns of dependence. For example, capture rates of *Sorex* spp. (both species combined) and *Blarina brevicauda* were compared between transects (both types combined) and arrays. For each four-fold table, we calculated the corresponding odds ratio and tested the hypothesis that the odds ratio was equal to unity (Agresti 1990).

### MICROHABITAT ANALYSES

In July 1994, we measured several microhabitat variables surrounding each of the 240 pitfall traps of the linear-transects. Because these traps were placed without regard to microhabitat conditions, surveys provided an unbiased sample of conditions at the forest floor and could be compared to capture frequencies of each species at those locations. Only traps associated with linear transects were considered in this analysis.

At each trap station, we established a circular plot with a 2.5-m radius. Within each plot we measured the diameter and length of all coarse woody debris greater than 4 cm in diameter. We also measured the greatest length and width of all rocky debris, and the diameter at the forest floor of all stumps within each plot. These measurements yielded an index to the abundance of fallen logs, rocks, and stumps surrounding each pitfall trap. We also measured the distance from the pitfall trap to the nearest fallen log, rock, or stump.

Microhabitat measurements were compared to shrew capture frequencies using Pearson product-moment correlations. We regressed capture frequency of each species against distance to nearest structure (Neter et al. 1990).

## RESULTS

### METHOD COMPARISON

In 3,360 trapnights (TN) at selective transects in 1994 we collected 358 individuals representing four species (Table 1). In 3,360 TN at linear transects we collected 126 individuals from the same four species. *Sorex cinereus* was the most commonly captured shrew, followed by *S. fumeus*, *Blarina brevicauda*, and *S. hoyi*. *Sorex hoyi* was uncommon at our sites and, therefore, was omitted from all statistical analyses. We captured 2.8 times as many individuals in selective as in linear traps, and this ratio was relatively constant among species (Table 1). Consequently, the distribution of shrew captures (relative abundance of each species) did not differ between these two methods ( $G^2 = 0.722$ ;  $P = 0.697$ ;  $df = 2$ ).

Table 1. Number of captures of four species of shrews using two pitfall transect designs, selective and linear, at the Coweeta Hydrologic Laboratory, July 1994. Traps in selective transects were positioned 5-m apart next to structures such as down logs and rocks. Traps in linear transects were set 5-m apart in a straight line.

| Species                   | Transect Type             |                        |       |                           |
|---------------------------|---------------------------|------------------------|-------|---------------------------|
|                           | Selective<br>(TN = 3,360) | Linear<br>(TN = 3,360) | Total | Selective:Linear<br>Ratio |
| <i>Blarina brevicauda</i> | 25                        | 8                      | 3     | 3.1:1                     |
| <i>Sorex cinereus</i>     | 208                       | 78                     | 286   | 2.7:1                     |
| <i>Sorex fumeus</i>       | 116                       | 36                     | 152   | 3.2:1                     |
| <i>Sorex hoyi</i>         | 9                         | 4                      | 13    | 2.3:1                     |
| Total                     | 358                       | 126                    | 484   | 2.8:1                     |

In 2,240 TN at selective transects in 1995 we captured 124 individuals of the same four species captured in 1994 (Table 2), whereas linear transects yielded 52 individuals. Similar to the 1994 data, we captured 2.4 times as many individuals in selective as in linear transects; however, there was greater variation in this ratio among species than in 1994. In 4,040 TN at drift-fence arrays we captured 81 individuals of the same 4 species. Capture frequencies observed at drift-fence arrays differed from both types of transects, and ratios involving drift-fence arrays varied markedly (Table 2). Consequently, the distribution of shrew captures among sampling methods varied in 1995 ( $G^2 = 17.849$ ;  $P = 0.001$ ;  $df = 4$ ).

We were able to construct four independent, four-fold tables using the data collected in 1995. Two of the tables compared captures of *S. cinereus* and *S. fumeus* between the two types of transects ( $G^2 = 0.021$ ;  $P = 0.884$ ;  $df = 1$ ) and between transects (both combined) and arrays ( $G^2 = 3.049$ ;  $P = 0.081$ ;  $df = 1$ ). In neither case did the data support dependence; therefore, capture frequency of these species was not markedly affected by trapping method.

The remaining four-fold tables compared *Sorex* spp. to *B. brevicauda* with respect to trap arrangement. The first of these, a table comparing *Sorex* spp. and *B. brevicauda* captures by transect type, indicated that capture frequencies for these two taxa differed between the two methods ( $G^2 = 6.061$ ;  $P = 0.014$ ;  $df = 1$ ). The odds ratio for this table was greater than unity ( $\theta = 3.17$ ;  $Z = 2.409$ ;  $df = 163$ ), indicating that *Sorex* spp. were more likely than *B. brevicauda* to be captured using selective transects. The second of these tables compared *Sorex*

Table 2. Number of captures of four species of shrews using two pitfall transect designs, selective and linear, and a drift-fence design at the Coweeta Hydrologic Laboratory, August and November 1995.

| Species                   | Transect Type             |                        |                       | Total | Selective:<br>Linear<br>Ratio | Selective:<br>Array<br>Ratio | Linear:<br>Array<br>Ratio |
|---------------------------|---------------------------|------------------------|-----------------------|-------|-------------------------------|------------------------------|---------------------------|
|                           | Selective<br>(TN = 2,240) | Linear<br>(TN = 2,240) | Array<br>(TN = 4,040) |       |                               |                              |                           |
| <i>Blarina brevicauda</i> | 10                        | 12                     | 2                     | 24    | 0.8:1                         | 5.0:1                        | 6.0:1                     |
| <i>Sorex cinereus</i>     | 70                        | 27                     | 61                    | 158   | 2.6:1                         | 1.1:1                        | 0.4:1                     |
| <i>Sorex fumeus</i>       | 33                        | 12                     | 16                    | 61    | 2.8:1                         | 2.1:1                        | 0.8:1                     |
| <i>Sorex hoyi</i>         | 11                        | 1                      | 2                     | 14    | 11.0:1                        | 5.5:1                        | 0.5:1                     |
| Total                     | 124                       | 52                     | 81                    | 257   | 2.4:1                         | 1.5:1                        | 0.6:1                     |

spp. and *B. brevicauda* captures between transects and arrays. Likewise, this table supported dependence ( $G^2 = 8.718$ ;  $P = 0.003$ ;  $df = 1$ ). The odds ratio for this table was less than unity ( $\theta = 0.168$ ;  $Z = -2.375$ ;  $df = 242$ ), indicating that *Sorex* spp. were more likely than *B. brevicauda* to be captured using arrays.

#### MICROHABITAT USE

None of the shrews examined showed strong relationships with the abundance of rocks, logs, and stumps within 2.5 m of the trap stations. There is some evidence that *Sorex fumeus* selectively used habitat structure, as the capture success of this species was significantly correlated with the abundance of rocks ( $r^2 = 0.017$ ;  $P = 0.050$ ) and logs ( $r^2 = 0.018$ ;  $P = 0.047$ ). *Sorex cinereus* was correlated only with the abundance of rocks ( $r^2 = 0.026$ ;  $P = 0.016$ ). Finally, *B. brevicauda* was not correlated with any of the habitat features examined. It should be noted that the correlations presented above are, while statistically significant, exceedingly weak. For example, the abundance of rocks accounts for only 1.7% of the variability in *S. fumeus* capture.

In agreement with our microhabitat correlations, capture success of *S. fumeus* showed a highly significant, although weak, relationship with proximity to structure ( $r^2 = 0.034$ ;  $P = 0.006$ ;  $df = 218$ ). *Sorex cinereus* capture success was not significantly related to proximity to structure ( $r^2 = 0.009$ ;  $P = 0.158$ ;  $df = 218$ ), nor was the capture success of *B. brevicauda* ( $r^2 = 0.002$ ;  $P = 0.481$ ;  $df = 218$ ).

Thus, *S. fumeus* showed the strongest relationship with habitat structure and the greatest positive differences between selective transects and linear transects in 1994 (220%) and 1995 (180%; Tables 1 and 2). Captures of *S. cinereus* were less strongly related to habitat structure and showed smaller, positive differences between selective and linear transects in 1994 (170%) and 1995 (160%). *Blarina brevicauda* was not correlated with the abundance of any structural habitat features or proximity to structure and was the only species to exhibit a negative difference between selective and linear transects (-20% in 1995), reflecting a higher capture success at traps placed without regard to microhabitat features than those traps placed selectively.

#### DISCUSSION

The relative capture frequencies of *Sorex fumeus* and *S. cinereus*, when considered with respect to each other, were not significantly affected by trap arrangement. This suggests that any of the three methods considered would provide a similar depiction of the relative abundance of these species in similar habitats. Furthermore, the capture rates of these species using transects were similar over a two-year period. Thus, our data for *S. fumeus* and *S. cinereus* suggest that in comparisons over time, selective and linear transects provide estimates of rel-

ative abundance that are similar to each other and reasonably stable over two years.

Comparisons involving *Blarina brevicauda* must be considered with some caution due to low sample sizes. However, our study provides some evidence that *B. brevicauda* was less likely than *Sorex* spp. to be captured with trap arrangements utilizing natural or artificial structures to direct movement. On encountering a linear structure, *B. brevicauda* may not have followed the structure lengthwise, which was necessary for capture. It is also noteworthy that *B. brevicauda* is largely fossorial (George et al. 1986) and may not spend as much time moving across the forest floor and encountering drift-fences or natural habitat structures.

Largely because of *B. brevicauda* we found that drift-fence arrays provided a different depiction of the southern Appalachian shrew community than did either of two types of transects. Mitchell et al. (1993) and Dowler et al. (1985) also found differences in species richness and numbers of shrews collected using pitfalls set singly and in conjunction with drift-fence arrays. In 1,750 TN at each trap arrangement, Dowler et al. (1985) captured 47 *S. cinereus* at arrays compared to 29 in isolated pitfalls, but they only captured 2 *B. brevicauda* at arrays compared to 3 at isolated pitfalls. Again, inferences are tenuous due to small capture frequencies, and further studies into the movement patterns and behavior of *Blarina* are recommended.

Overall capture success with transects was 7.2% in 1994 and 3.9% in 1995. This disparity provided evidence that numbers of shrews may have decreased between the two trapping periods, perhaps due to the removal of animals during 1994. Thus, for the purposes of these analyses we have had to make the assumption that this change in overall shrew abundance did not affect patterns of shrew microhabitat use.

Among the 3 shrews we studied (*Sorex hoyi* excluded), *S. fumeus* and *S. cinereus* exhibited weak, but significant, relationships with structures on the forest floor, whereas *B. brevicauda* did not. We are aware of no previous studies of microhabitat use by *S. fumeus*. The observations of MacCracken et al. (1985) in southeastern Montana support the importance of litter cover (dead plant parts) to *S. cinereus*; however, they did not separate downed logs from other types of debris. In contrast, Yahner (1986) found that the mean length and density of logs were lower at trap stations where *S. cinereus* was captured than where this species was not captured, and Getz (1961) concluded that microhabitat features have little or no effect on distributions of *S. cinereus*, emphasizing the importance of moisture. Our results suggest that selective use of microhabitat features by *S. cinereus* may be so weak as to require a very large sampling effort to detect.

Our results agree with Getz (1961) and Yahner (1982) who found no evidence for microhabitat selection in *B. brevicauda*. Conversely, Seagle (1985)

found that *B. brevicauda* seemed to avoid areas with few fallen logs in deciduous forests in Tennessee.

Our perception of the relative abundance of three shrew species was partially a function of the trap arrangement we used to capture them. Each sampling method takes advantage of certain patterns of microhabitat use, which vary among species. We suggest that caution be used when comparing the results of surveys using different trap arrangements, as well as different traps.

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The Water Shrew, *Sorex palustris* Richardson  
(Insectivora: Soricidae), and Its Habitat in Virginia

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ABSTRACT - The water shrew, *Sorex palustris*, known from a single Virginia locality in Bath County as recently as 1991, has been found at four additional sites, all in Highland County. The five sites were above 900 m (mean = 1,000 m; range = 902-1,128 m) elevation. All sites were fully-canopied first or second order streams with habitat characteristics and a macroinvertebrate community typical of relatively pristine, high-altitude, headwater streams. All streams were high gradient (7-14% slope) and had a variety of flow and depth regimes and a predominately well-sorted cobble substrate with abundant woody debris. Channel banks were fully vegetated and had extensive undercut areas and many crevices. Riparian canopy trees at all sites were primarily northern hardwoods, including yellow birch (*Betula lutea*) and sugar maple (*Acer saccharum*). The macroinvertebrate community of the streams was dominated by stoneflies (Plecoptera), mayflies (Ephemeroptera), and midges (Diptera).

Although the water shrew, *Sorex palustris* Richardson, enjoys a broad distribution, including much of Canada, southwestern Alaska, and northern and high elevation regions of the United States (Hall 1981, Beneski and Stinson 1987), the Appalachian water shrew, *S. p. punctulatus* Hooper, is rare and found only in highly-localized boreal environments in the southern Appalachian Mountains. In an overview of distribution and diversity of Virginia mammals, Handley (1992:165) described *S. palustris* as a "high/medium boreal species" that occurs as a relict and is in danger of extirpation in Virginia. Laerm et al. (1995) summarized records of *S. p. punctulatus*, showing its known distribution as only 14 counties in a seven state area extending from southwestern Pennsylvania to northern Georgia.

The water shrew was first collected in Virginia in northwestern Bath County in 1974 (Pagels and Tate 1976) at the then proposed site of the upper reservoir for a pumped-storage electrical generating facility. Although feared lost from this site when the valley was flooded, the shrew was found in an undis-

turbed area just above the reservoir (Pagels 1987). Pagels and Handley (1991:564) subsequently observed, "The water shrew, extremely rare in Virginia, is known to occur in only one small watershed in the state." The Appalachian water shrew was declared a state endangered species in 1990, and a recovery plan was prepared (Pagels et al. 1991). The primary objective of that plan is to prevent extirpation of the water shrew in Virginia, with critical aspects being determination of its distribution, description of its habitat, and investigation of factors that might adversely impact the species.

Herein we report on records of the water shrew and examine biotic and abiotic features at all sites where it has been collected in Virginia. Our objective is to provide basic information on the water shrew that will be of interest to biologists and resource managers who might be concerned with the distribution, ecology, and protection of this species.

## MATERIALS AND METHODS

### SMALL MAMMAL SAMPLING

Efforts to locate the water shrew in Virginia were intensified in the late 1980s in conjunction with development of the recovery plan. Based on published information and knowledge obtained on *S. palustris* habitat during visits to sites where it had been collected in Maryland and West Virginia, a profile of apparently suitable habitat was developed for use in this study. Subsequently, numerous sites were sampled in northern hardwood or northern hardwood-conifer forests along mountain streams at or above about 900-m elevation in Virginia. Emphasis was placed on sampling in Bath, Highland, and Rockingham counties in western Virginia, and Grayson, Smyth, and Washington counties in southwestern Virginia. In addition to efforts by several individuals over many years, portions of approximately 45 first and second order streams were sampled for *S. palustris* by Pagels in the period 1989-1996.

Traps used included Museum Special snap-back traps and Sherman live traps, but most sampling in 1991 to present was completed with use of 2-L plastic pitfall traps. Traps were set as near the water as possible in "most likely" spots, for example, under overhanging banks or root masses of trees, but often a trap was placed in a given spot only because the substrate allowed placement of a pitfall. Number of traps, space between traps, and length of sampling period varied greatly among sites, but whenever trapping was completed in anticipation of perturbative activities, i.e. timbering, pitfalls were usually kept in place for a minimum of 30 days. Most sampling was between April to November as dictated by winter weather and road conditions. All specimens are deposited in the Virginia Commonwealth University Mammal Collection.

Table 1. Habitat parameters measured at streams where *S. palustris* was found in Virginia, 1974-1993. General methodology follows that of Platts et al. (1983).

| Parameter              | Method   |
|------------------------|--|
| Stream order           | method of Strahler (1964)  |
| Elevation              | U.S.G.S. 1:24,000 topographic maps   |
| Channel gradient       | altimeter  |
| Channel width          | bank-to-bank distance  |
| Wetted width           | width of the flowing stream  |
| Water depth            | determined from measurements at points along each transect across a stream   |
| Water velocity         | determined at points along each transect across a stream with a Marsh-McBirney impulse flow meter at six-tenths water depth  |
| Substrate type         | visual estimate of the proportion of each of six sediment particle sizes in the channel (bedrock; boulder = >256 mm; cobble = 64-256 mm; pebble = 16-64 mm; gravel = 2-16 mm; sand = 0.06-2 mm). |
| Riffle-pool prevalence | proportion of the stream channel in riffles, pools and glides  |
| Bank undercutting      | distance that the bank overhangs the channel   |
| Bank water depth       | depth of water at the bank   |
| Wood abundance         | volume of wood in the channel, calculated using the method of Wallace and Benke (1984)   |
| Debris dams            | number of large accumulations of woody debris per 100 m of stream  |
| pH                     | field pH meter   |
| Conductivity           | conductivity meter   |
| Riparian vegetation    | percentage composition of canopy trees within 8 m of both banks  |

#### HABITAT CHARACTERIZATION

Two approaches were used to describe the in-stream and riparian habitat at each stream where *S. palustris* was found. The first approach described 16 general geomorphic and physico-chemical characteristics deemed as potentially significant habitat variables for the shrews (Table 1). Habitat characteristics

were quantified over a 100-m stretch following the general methodology of Platts et al. (1983). Values for in-channel parameters are reported as the mean of measurements made at 5- or 10-m intervals along the entire 100-m stretch. Composition of the riparian vegetation was made from surveys of canopy trees along both banks. All habitat analyses were conducted in a three-day period in June 1995 when streams were at base flow.

The second approach to characterizing stream and riparian habitat was a formal assessment using the U.S. Environmental Protection Agency's (EPA) Rapid Habitat Assessment Protocol (Plafkin et al. 1989). Twelve metrics were used to score habitat condition at each stream (Table 2). All metrics were scored on a 20-point scale, 20 points indicting the best or preferred condition. A portion of the riparian zone and near-channel watershed of one of the sites at which *S. palustris* was collected was timbered between the time that the shrews were collected and the habitat analysis was conducted. Habitat data from this site were not included in our summary.

Table 2. Parameters measured for the habitat assessment of streams where *S. palustris* was found in Virginia. Methodology follows that of Plafkin et al. (1989).

| Parameter             | General Description   |
|-----------------------|---|
| In-stream cover       | abundance of submerged logs, undercut banks, and other forms of stable habitat                    |
| Epifaunal substrate   | abundance of the "most productive benthic habitat," typically riffle areas and/or submerged snags |
| Embeddedness          | degree to which the primary substrate was surrounded by fine sediment                             |
| Velocity/depth ranges | variety of water velocity and depth regimes in the stream   |
| Channel alteration    | evidence of stream channelization   |
| Sediment deposition   | evidence of recent sediment deposition  |
| Frequency of riffles  | prevalence and size of riffles  |
| Channel flow status   | percentage of the channel bed that was wetted   |
| Condition of banks    | evidence of bank stability versus erosion   |
| Bank vegetative cover | percentage of bank that was covered with vegetation   |
| Disturbance pressure  | degree of disruption of riparian vegetation by grazing or other processes                         |
| Riparian vegetation   | width of riparian zone that was vegetated and with minimal human disturbance                      |

Fig. 1. General location of sites where *S. palustris* was found in Virginia, 1974-1993. B and H indicate Bath and Highland counties. Insert map (after Webster 1987:38) shows the range of the species in North America; its range in the southern Appalachian Mountains is solid dark.

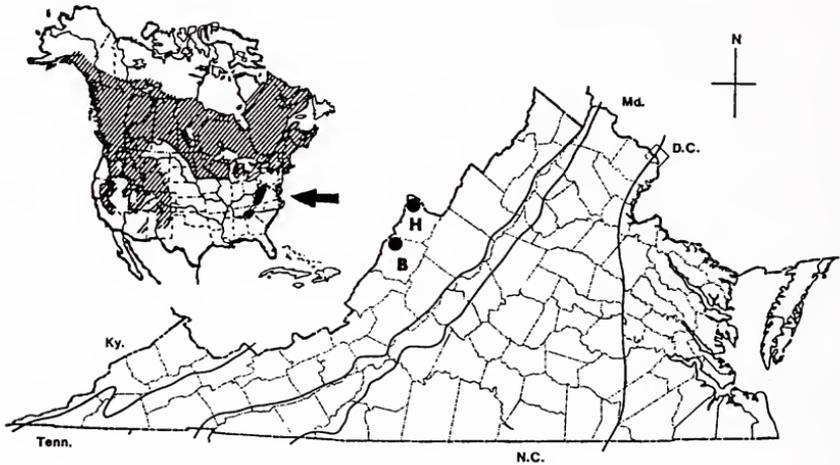


Table 3. Virginia Commonwealth University catalog number, sex, date of capture, and general location of captures of *S. palustris* in Virginia, 1974-1993. Bath County sites (B) include those of Pagels and Tate (1976) and Pagels (1987). Highland County sites are comprised of the private property location (HP) and three sites, H1, H2, and H3, in the Laurel Fork area of George Washington and Jefferson National Forests.

| Catalog Number | sex | Date              | Location |
|----------------|-----|-------------------|----------|
| 557            | F   | 3 August 1974     | B        |
| 558            | F   | 5 October, 1974   | B        |
| 559            | F   | 4 October 1974    | B        |
| 560            | F   | 4 October 1974    | B        |
| 4715           | F   | 29 August 1986    | B        |
| 4742           | F   | 5 August 1986     | B        |
| 10025          | F   | 2 July 1992       | HP       |
| 10491          | F   | 11 September 1992 | H1       |
| 10492          | F   | 11 September 1992 | H1       |
| 10940          | F   | 15 June 1993      | H2       |
| 11261          | M   | 16 July 1993      | H3       |
| 11262          | F   | 16 July 1993      | H3       |
| 11263          | F   | 16 July 1993      | H3       |

## AQUATIC MACROINVERTEBRATES

Aquatic macroinvertebrate communities were sampled in June 1995 at each stream to provide information on the species composition and relative abundance of the shrew's primary food source. A D-frame dip net was used to collect organisms along a 100-m stretch. All primary habitats were sampled, including riffles, pools, bank areas, and woody debris; the material collected was composited into one sample per stream.

Invertebrates were removed from the samples in the laboratory under a stereo-microscope after addition of rose bengal to facilitate the sorting process. A minimum of 200 organisms was randomly picked from the samples; picking ending when no new taxa were observed. Organisms were identified with the taxonomic keys in Merritt and Cummins (1996) and Pennak (1989).

## RESULTS

### DISTRIBUTION

*Sorex palustris* was collected along four streams of the Potomac River drainage in Highland County. Along with the original Little Back Creek site (Pagels and Tate 1976, Pagels 1987) in the James River drainage in Bath County, it is now known from five Virginia localities, all on Allegheny Mountain. Three of the new sites are in the George Washington and Jefferson National Forests in the Laurel Fork area of northwestern Highland County. The other site is on private property just west of Hightown, Virginia, and is the site since timbered by the land owner. The continued existence of the water shrew at this site after timbering has not been confirmed. General locations of the sites where *S. palustris* has been captured in Virginia are given in Figure 1.

Four other species of shrews, the short-tailed shrew (*Blarina brevicauda*), masked shrew (*Sorex cinereus*), smoky shrew (*S. fumeus*), and rock shrew (*S. dispar*), were captured on traplines with *S. palustris* at all Highland County sites except the private property site where no *S. dispar* was taken. *Sorex fumeus* represented 66.5%, *S. cinereus* 17.9%, *S. dispar* 6.9%, *B. brevicauda* 4.6%, and *S. palustris* 4.0% of the 173 shrews taken at the four Highland County sites where *S. palustris* was captured. A summary of all *S. palustris* captured in Virginia, including records in Pagels and Tate (1976), and Pagels (1987), is given in Table 3.

### HABITAT

Habitat characteristics of all streams were typical of relatively pristine headwater streams of the Virginia mountains (Table 4). Streamwater was cool, had a circum-neutral pH, and low to moderate conductivity. All streams were either first or second order and hence had a narrow channel and wetted width. Channel gradients were a relatively steep 7-14%. A variety of flow regimes Table 4. Means, standard errors, and ranges of geomorphic, hydrologic, and

physico-chemical characteristics of the streams where *S. palustris* was found in Virginia, 1974-1993.

| Parameter                                     | Mean  | SE   | Range     |
|---|-------|------|-----------|
| Stream order                                  | 1     | <0.1 | 1-2       |
| Elevation (m)                                 | 1,000 | 37   | 902-1,128 |
| Channel gradient (%)                          | 10    | 1.4  | 7-14      |
| Channel width (m)                             | 4     | 0.7  | 2-10      |
| Wetted width (m)                              | 3     | 0.4  | 1-7       |
| Water depth (cm)                              | 8     | 1.3  | 1-1,510   |
| Water velocity (m <sup>3</sup> /s)            | 0.15  | 0.01 | 0-0.80    |
| Bank undercut (cm)                            | 18    | 0.5  | 0-99      |
| Wood volume (m <sup>3</sup> /m <sup>2</sup> ) | 0.53  | 0.1  | 0.37-0.66 |
| Debris dams (#/100m)                          | 3     | 0.9  | 2-6       |
| pH  | 7.0   | 0.1  | 6.7-7.2   |
| Conductivity (uS/cm)                          | 24    | 9    | 12-52     |

existed in the streams, as reflected by the ranges in water velocity and depths (Fig. 2). Also, although riffles were the predominant habitat (Fig. 3), a distinct riffle-pool geomorphology occurred in all of the streams.

In-stream cover was abundant in all streams. Cobble was the predominant substrate, with boulder, pebble and gravel also being relatively common (Fig. 3). The sediment was well sorted, with little embeddedness by fine-grained particles (Table 5). Woody debris and resulting debris dams were common in the channels of all streams, and growth of moss in the channel was evident at most sites.

The riparian areas of the streams were undisturbed, vegetated, and stable (Table 5). All channel banks had extensive undercut areas (Fig. 4) and areas that were rocky with many crevices and downed wood. Most of the undercuts were not in contact with the flowing stream but rather with dry channel sediment. One site had a broad floodplain and many side channels where water flowed freely through interstitial areas in the rocky floodplain floor.

Yellow birch (*Betula lutea*) was the most abundant canopy tree along the riparian areas of all streams (Table 6). Other common canopy species along the streams were black birch (*B. lenta*), sugar maple (*Acer saccharum*), basswood (*Tilia americana*), black cherry (*Prunus serotina*), red maple (*A. rubrum*), American beech (*Fagus grandifolia*), and Eastern hemlock (*Tsuga canadensis*). The understory was generally undeveloped, typical of mature forests.

Fig. 2. Frequency distribution (mean  $\pm$  SE) of water velocity and depth in four streams at which *S. palustris* was found in Virginia.

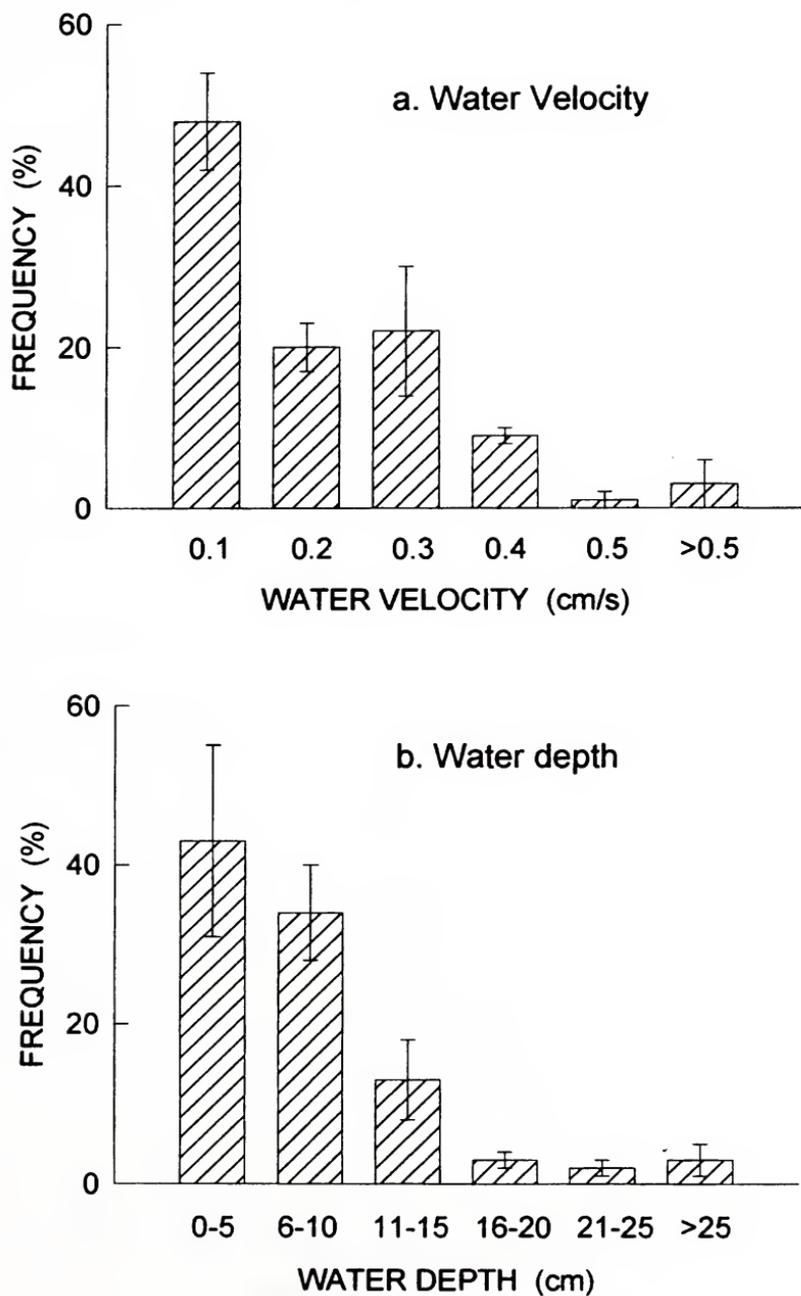


Fig. 3. Frequency distribution (mean  $\pm$  SE) of riffle, pool, and glide areas and sediment particle sizes in four streams at which *S. palustris* was found in Virginia. BED = bedrock, BLD = boulder, COB = cobble, PEB = pebble, GRV = gravel, SND = sand.

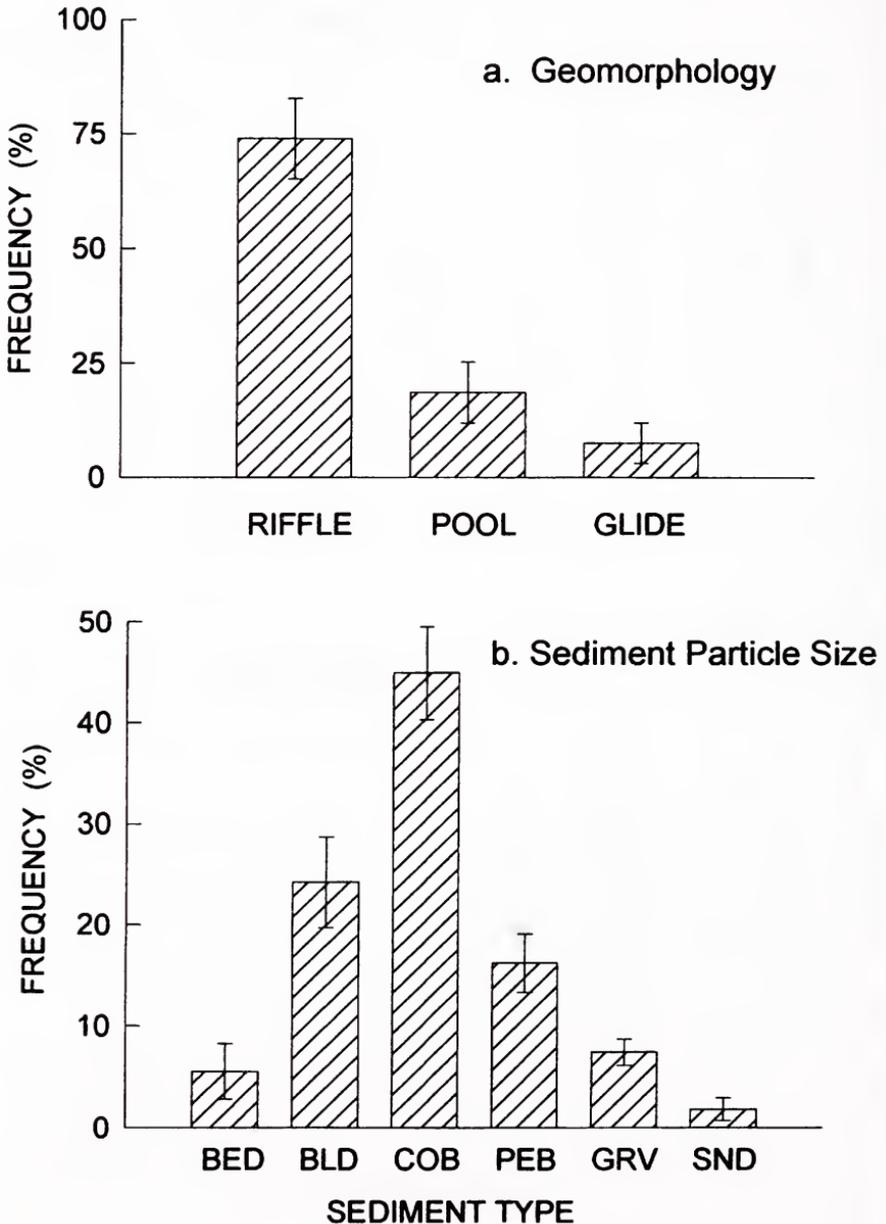


Table 5. Means, habitat assessment metric scores (after Plafkin et al. 1989), standard errors and ranges for five streams in Virginia where *S. palustris* was found, 1974-1993. Values range from 0-20, with 20 indicating the highest quality.

| Parameter                  | Mean | SE  | Range |
|----------------------------|------|-----|-------|
| In-stream cover            | 20   | 0.0 | 20-20 |
| Epifaunal substrate        | 20   | 0.0 | 20-20 |
| Embeddedness               | 18   | 0.2 | 18-19 |
| Velocity/depth ranges      | 15   | 0.2 | 15-16 |
| Channel alteration         | 20   | 0.0 | 20-20 |
| Sediment deposition        | 18   | 1.2 | 15-20 |
| Frequency of riffles       | 20   | 0.0 | 20-20 |
| Channel flow status        | 16   | 1.0 | 13-18 |
| Bank condition             | 19   | 0.2 | 19-20 |
| Bank vegetative protection | 19   | 0.2 | 18-19 |
| Disturbance pressure       | 20   | 0.0 | 20-20 |
| Riparian vegetation        | 19   | 1.0 | 16-20 |

Fig. 4. Frequency distribution (mean  $\pm$  SE) of the extent of bank undercutting in four streams at which *S. palustris* was found in Virginia.

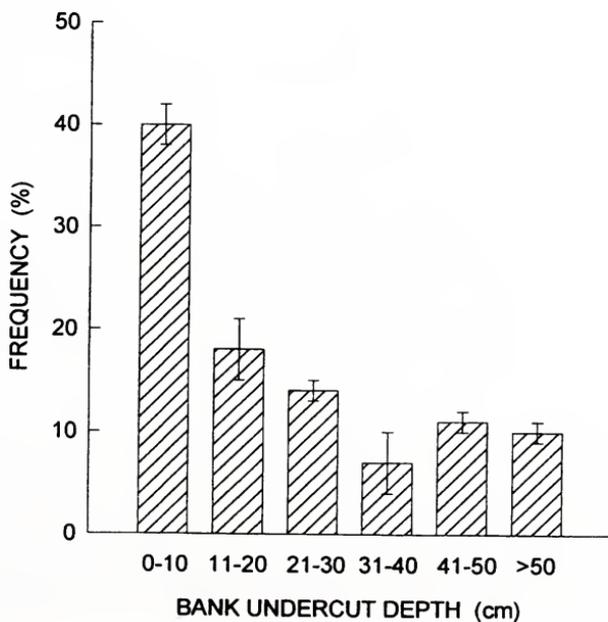


Table 6. Mean percent abundance, standard error, and range of riparian canopy trees at the streams where *S. palustris* was found in Virginia, 1974-1993.

| Species                      | Mean | SE | Range |
|------------------------------|------|----|-------|
| <i>Betula lutea</i>          | 29   | 3  | 22-35 |
| <i>Betula lenta</i>          | 13   | 4  | 0-24  |
| <i>Acer saccharum</i>        | 10   | 2  | 4-17  |
| <i>Tilia americana</i>       | 9    | 4  | 0-22  |
| <i>Prunus serotina</i>       | 7    | 3  | 0-14  |
| <i>Acer rubrum</i>           | 6    | 4  | 0-18  |
| <i>Fagus grandifolia</i>     | 6    | 3  | 0-14  |
| <i>Tsuga canadensis</i>      | 6    | 2  | 0-9   |
| <i>Fraxinus</i> sp.          | 3    | 2  | 0-8   |
| <i>Quercus rubra</i>         | 3    | 1  | 0-7   |
| <i>Robinia pseudo-acacia</i> | 2    | 1  | 0-6   |
| <i>Carya</i> sp.             | <1   | <1 | 0-2   |
| <i>Picea rubens</i>          | <1   | <1 | 0-2   |
| Standing dead trees          | 6    | 2  | 0-9   |

## MACROINVERTEBRATE COMMUNITY

Taxonomic composition and richness were very similar among all streams (Table 7). Taxonomic richness ranged from 26 to 28 taxa, but would have been considerably higher had individuals in the dipteran family Chironomidae (midges) been identified to genus. The macroinvertebrate communities of all of the streams were dominated by species of midges (Diptera), stoneflies (Plecoptera) and mayflies (Ephemeroptera). Non-midge taxa common at most streams included stoneflies in the families Leuctridae and Perlodidae; the mayfly families Heptageniidae, Ephemerellidae, and Baetidae; and the caddisfly families Philopotamidae and Hydropsychidae. Although biomass of macroinvertebrates was not measured, these taxa no doubt dominated the macroinvertebrate biomass because of their generally large size.

## DISCUSSION

In Virginia, Pleistocene remains of *S. palustris* are known from Natural Chimneys in Augusta County, elevation 414 m (Guilday 1962), and Clarks Cave in Bath County, elevation 456 m (Guilday et al. 1977). Indicative of the boreal nature of the sites where *S. palustris* now occurs, certain other boreal species with highly disjunct populations in the southern Appalachians remain associates of *S. palustris* in Virginia, but also no longer occur in the environs of the Natural

Table 7. Taxonomic richness and mean percent contribution (1 SE and range) of macroinvertebrate taxa occurring in four streams at which *S. palustris* was found in Virginia, 1974-1993.

| Taxon         | Number of Genera | Mean Percent Abundance | SE | Range (%) |
|---------------|------------------|------------------------|----|-----------|
| Hydracarina   | 1                | <1                     | <1 | 0-1       |
| Decapoda      | 1                | 1                      | <1 | 0-2       |
| Ephemeroptera | 6                | 26                     | 10 | 6-54      |
| Odonata       | 1                | 1                      | <1 | 1-2       |
| Plecoptera    | 6                | 26                     | 2  | 20-31     |
| Trichoptera   | 8                | 22                     | 4  | 14-31     |
| Coleoptera    | 3                | 3                      | 2  | 1-8       |
| Diptera       | 8                | 22                     | 4  | 11-32     |
| Pelecypoda    | 1                | <1                     | <1 | 0-1       |

Chimneys or Clarks Cave sites. These include the rock vole (*Microtus chrotorhinus*), in the Little Back Creek area of Bath County (Pagels 1990), and the northern flying squirrel (*Glaucomys sabrinus*), at the Highland County sites (Pagels et al. 1990). Handley (1992:159) suggested that these species, along with a few others, probably "...represent the last stages of the recoil of high boreal species from southern latitudes into higher latitudes in the United States and Canada---north and west of Virginia."

*Sorex palustris* was found only at sites where cool, mesic conditions occurred along with considerable cover on the banks of swift-flowing streams. Beneski and Stinson (1987) observed that although it is found in a variety of habitats, rocky crevices, logs, and abundant overhanging areas along stream banks are typical of *S. palustris* habitat throughout much of its range, and likely are critical in warmer, southern areas to provide cool, mesic microhabitats for the shrews. Also, the full canopy of mature forests, as occurred at the sites where the shrews were found, probably is essential for maintaining the cool conditions.

Habitat conditions also are important in affecting the food resources available to the shrews. Both terrestrial and aquatic invertebrates are consumed by water shrews (Beneski and Stinson 1987). Wrigley et al. (1969) suggested that a mesic microhabitat along stream banks was important for supporting terrestrial invertebrates that at times can compose a significant portion of the diets of the shrews (Hamilton 1930, Whitaker and Schmeltz 1973). The primary aquatic organisms consumed by shrews, including stoneflies, mayflies, and caddisflies (Conoway 1952, Conoway and Pfitzer 1952, Sorenson 1962, Linzey and

Linzey 1973) are most abundant in streams with fast current and cobble substrate. Those conditions were prevalent at the five sites at which *S. palustris* was found and these aquatic insect orders were common.

All streams where shrews were found had habitat characteristics indicative of relatively pristine conditions. The Environmental Protection Agency habitat assessment metric scores (Table 4) show the high quality of in-stream, bank, and riparian habitat at all sites. All metrics were scored at 15 or higher, and many scores were at or near the maximum score of 20. Total metric scores of 220-229 points where shrews were found reflect high habitat quality at the streams. The taxonomic composition of macroinvertebrates also is indicative of relatively undisturbed streams. Most taxa we collected are generally intolerant of low habitat or water quality.

We cannot state assuredly that *S. palustris* does not occur along streams that we sampled unsuccessfully, or on streams that possess the habitat conditions reported herein. Laerm et al. (1995:49) observed that despite the great increase in knowledge of shrew species that were formerly thought to be very rare, including both *Sorex hoyi* and *S. dispar* that are now known to be more common than was earlier thought, "...the water shrew appears to be the rarest and most localized shrew in the southeastern United States." New records such as those reported herein, and a low altitude site (808 m) in northern Georgia (Laerm et al. 1995), provide hope that *S. palustris* will be found at additional locations. Baseline data on suitable habitat will make searching for new sites more efficient, and will aid in the development of management programs for protection of known and potential sites.

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Occurrence of the Brook Silverside, *Labidesthes sicculus*  
(Atheriniformes: Atherinidae), in North Carolina

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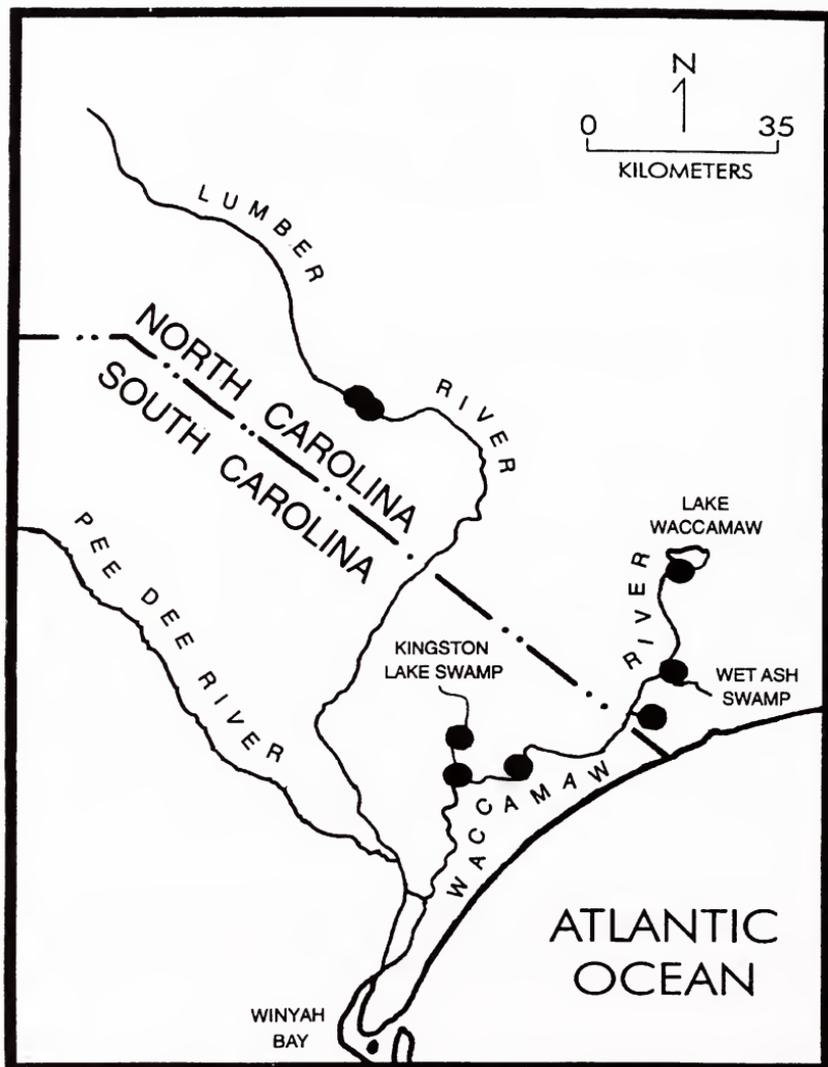
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ABSTRACT- The brook silverside has never been reported from Atlantic slope drainages north of the Santee River in South Carolina. We collected 42 specimens at 6 sites in the Waccamaw River drainage in North and South Carolina and 26 specimens at 5 sites in the Lynches River, South Carolina. We also report the collection of five specimens from the Lumber River and four from the Cape Fear River in North Carolina. Extensive sampling from 1961-1992 in the Waccamaw River drainage failed to collect this species. Therefore, we propose that the brook silverside has expanded its range northward on the Atlantic slope.

The brook silverside, *Labidesthes sicculus* (Cope), occurs in the St. Lawrence River drainage and southern Great Lakes tributaries, the Mississippi River basin, and Atlantic and Gulf drainages from the Santee River in South Car-

olina to the Sabine River in Texas (Etnier and Starnes 1994). Reported occurrences closest to the state of North Carolina are from eastern Tennessee, in the Little Tennessee River drainage (Etnier and Starnes 1994), and from eastern South Carolina, in the Santee River drainage (Rohde et al. 1994). Our sampling indicates that the brook silverside in the southeastern United States has expanded its range northward.

Fig. 1. Distribution of the brook silverside, *Labidesthes sicculus*, in southeastern North Carolina and adjacent South Carolina.



## SURVEY AREA

The Waccamaw River originates at Lake Waccamaw in Columbus County, North Carolina, and flows approximately 63 km south-southwest to the North Carolina/South Carolina border (Fig. 1). The river has a total length of approximately 225 km and joins the Pee Dee River at Winyah Bay, South Carolina (Shute et al. 1981). In North Carolina the Waccamaw River drains 3,255 km<sup>2</sup> of primarily forested land and has a relatively low ratio of base flow to runoff (Bales and Pope 1996). Tributary streams in this system are generally highly colored, low pH, low flow to stagnant, blackwater swamps. Many of these streams exhibit large seasonal changes in depth and flow, with concomitant changes in discharge. Recent studies of streamflow characteristics in this drainage indicate that flow variability has increased the past decade (Bales and Pope 1996).

## METHODS AND MATERIALS

We sampled at 39 sites in the Waccamaw River drainage from May 1994-mid-November 1996. Standardized sampling was conducted at each site using a backpack electroshocker, seine, and/or rotenone. For sites in North Carolina ( $n = 18$ ), we used coated nylon nets (50 m, 1.3 cm-mesh) to block off a 33 m or 66 m reach. Three passes were made through the blocked off area using either a backpack electroshocker or a 3 m x 1.2 m, 3.2-mm mesh seine. For rotenone samples, fish were dipnetted for up to two hours following introduction of rotenone at 1 ppm. Rotenone was then neutralized using a 1 ppm potassium permanganate solution. South Carolina collections ( $n = 21$ ) were made with a 3 m x 1.2 m, 3.2-mm mesh seine, except for one backpack electroshocker collection. Fishes taken, and data on habitat (stream depth, width, and substrate type; current speed; air and water temperatures; pH; dissolved oxygen concentration) were recorded at each site.

All fishes were preserved in 10% formalin upon capture for subsequent examination. Brook silversides were measured to the nearest mm standard length (SL) and deposited at the North Carolina State Museum of Natural Sciences in Raleigh.

## RESULTS AND DISCUSSION

In North Carolina we collected 36 brook silversides. We took 18 specimens in the Waccamaw River 50 m below the Lake Waccamaw dam, Columbus County, on the 14th (5 specimens by electroshocker) and 18th (13 by rotenone) of September 1995 (Fig. 1). Size range of these fish was 29-48 mm SL, and 2-3 size classes were represented. Current velocity at this site was 0.17 m/sec with a pH of 6.4 and dissolved oxygen of 7.2 mg/L. We also took two specimens (34, 40 mm SL) by electroshocker in Wet Ash Swamp, a Waccamaw River tributary, at a point 50 m below the State Route 1300 bridge in Brunswick County, on 14 September 1995 (Fig. 1). Current there was 0 m/sec, pH 5.8, and dissolved oxy-

gen concentration was 8.8 mg/L. A second Waccamaw River tributary, Shingle-tree Swamp, yielded three juveniles on 18 November 1996, and three juveniles and one adult on 11 April 1997. In addition, survey sampling with a boat electroshocker produced five specimens in the Lumber River at the NC Route 711 bridge in Robeson County on 8 May 1995 (Fig. 1). Size range was 57-65 mm SL. Four additional fish (48, 53, 60, and 78 mm TL) were collected with the boat electroshocker from the Cape Fear River at rkm 76 on 24 January 1997.

In South Carolina we collected 15 specimens of the brook silverside from the Waccamaw River drainage and 26 specimens from the Lynches River with a seine. Four specimens were taken on 27 May 1994 in the Waccamaw River at Conway in Horry County. We took eight more fish from Kingston Lake Swamp, a tributary of the Waccamaw River, near Conway, approximately 54 rkm downstream of the North Carolina border, on 10-11 May 1994. Three specimens were also collected in Stanley Creek, a tributary stream approximately 11.8 km northeast of Conway on 18 March 1996. From 13-17 May 1996, we sampled 10 sites in the Lynches River, a tributary of the Pee Dee River. Brook silversides ( $n = 26$ ) were collected at five of these sites from the Route 403 bridge, Florence/Lee counties north to the Route 15 bridge, Kershaw/Darlington counties, a distance of approximately 50 rkm. These localities fill in a gap between the previously known South Carolina records in the Santee River drainage and the new North Carolina records (Rohde et al. 1994).

Is the distribution of the brook silverside expanding, or has the species been overlooked in North Carolina? The sites in the North Carolina portion of the Waccamaw River, as well as other sites in this drainage, have been sampled frequently by E. Menhinick, J. and P. Shute, Wildlife Resources Commission biologists, and by F. Rohde. Twenty-nine collections were made by these biologists at the Waccamaw River site from 1979-1992, and 5 collections in Wet Ash Swamp during 1961-1989. Since 1960, numerous other sites have been sampled on multiple occasions with rotenone (39 sites), seines (38), and electroshockers (10). This intensive sampling over time argues for an increase in brook silverside distribution. In addition, the fact that this species is fragile suggests that the observed range expansion did not result from "bait-bucket" introductions. We propose that the brook silverside has expanded its range northward and may be longer lived than previously thought.

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Winter Mortality in the Green Anole, *Anolis carolinensis*  
(Lacertilia: Polychridae)

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ABSTRACT- Winter behaviors of lizards are poorly documented. Most available information pertains to the formation of aggregations to escape freezing temperatures. During cold weather, lizards may seek shelter under bark, felled trees, or rotting stumps. However, such refugia may not provide adequate protection during abnormally cold conditions. We discovered the remains of 12 adult green anoles (*Anolis carolinensis*) within a Carolina bay located on International Paper Timber Company land in Marion County, South Carolina. The anoles presumably were killed by severe winter temperatures during the winter of 1996.

The winter behaviors of lizards have been poorly documented (Neill 1948, Weintraub 1968, Vitt 1974). Consequently, available information pertains only to the formation of winter aggregations, apparently to escape freezing temperatures. Several species of lizards are known to form these aggregations. Both Hamilton (1948) and Neill (1948) described the occurrence of five-lined skinks (*Eumeces fasciatus*) within felled trees and rotted logs and stumps. Worthington and Sabath (1966) documented winter aggregations of tree lizards (*Urosaurus ornatus*) within limestone outcroppings in Texas, and Weintraub (1968) described aggregations of over 37 individual granite spiny lizards (*Sceloporus*

*orcutti*) in rock crevices in California. Green anoles (*Anolis carolinensis*) have been reported to seek shelter, both individually and in aggregations, underneath felled trees and rotted stumps (Hamilton 1948, Neill 1948).

During severe cold winter spells, otherwise adequate habitat may not provide suitable refugia for winter protection. Lacking protection, lizards may die from freezing temperatures inside their chosen refugia. Such deaths have been documented. Worthington and Sabath (1966) found skeletal remains of over sixteen tree lizards in limestone fragments in Texas. Vitt (1974) found thirteen dead tree lizards and one banded sand snake (*Chilomeniscus cinctus*) within a rotted stump in Arizona. Weintraub (1968) found the remains of granite spiny lizards of all age classes within granite crevices.

Fig. 1. Remains of green anoles (*Anolis carolinensis*) on a Cypress stump within a Carolina bay in the PeeDee River region, South Carolina.



During a herpetofaunal survey on 15 March 1996, we discovered the remains of twelve adult green anoles within a Carolina bay located between the Great Pee Dee and Little Pee Dee Rivers in northeastern South Carolina (Fig. 1). The 1.2-ha Carolina bay was dominated by bald cypress (*Taxodium distichum*) and was semipermanently flooded. The bay was surrounded by a one-year-old clear-cut. The anoles were found beneath the bark of a rotted bald cypress that was still upright within the bay. Eleven of the specimens appeared to have been mummified. One anole skeleton was also found along side the other anoles, indicating that at least one individual had died previously in the same location. All twelve specimens were on the southeast side of the tree.

Although there are several possible explanations for the anole deaths (e.g., disease), the anoles were most likely killed by freezing temperatures during winter, which leads to the question of "why did the anoles choose this particular site to overwinter?" One possibility is that there was no other suitable habitat available (Worthington and Sabath 1966, Weintraub 1968, Vitt 1974). However, the presence of living anoles in the immediate vicinity (within the same Carolina bay) indicates at least some lizards were able to find suitable overwintering habitat. Long-distance migration is unlikely to account for the presence of living anoles, because they were found within the bay shortly after the uncharacteristically cold weather.

Another, more likely explanation is that, under normal circumstances, this particular site would have provided suitable overwintering habitat. However, below-normal temperatures during winter 1995-1996 might have been too extreme for lizard survival in this particular location. According to the South Carolina State Climatology Office, average temperatures during winter 1995-1996 were lower than the average of all temperatures for the Pee Dee region from 1948 to 1996. More importantly, December 1995 and January 1996 each had more than 20 consecutive days with low temperatures below 0 C; February 1996 experienced 15 days below 0 C. Prolonged low temperatures are infrequent in most years in this region. January and February 1996 rank highest in the number of days since 1988 when temperatures fell below the deep freeze point (-2 C). We hypothesize that some wintering habitat, which was suitable in years with normal winter temperatures, might have proven to be unsuitable during the particularly cold winter of 1995-1996. In addition, *Anolis carolinensis* commonly seeks relatively superficial cover (Palmer and Braswell 1995), thus exposing itself to harsher temperatures than other species that select areas with greater protection. As a result, winter temperatures are most likely a controlling factor in the northern distribution of *Anolis carolinensis*.

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# Abundance And Size Of Dominant Winter-Immigrating Fish Larvae At Two Inlets Into Pamlico Sound, North Carolina

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ABSTRACT--Weekly sampling for the larvae of six species of ocean-spawning, estuarine-dependent fishes was conducted from October 1994 to April 1995 inside Oregon Inlet and Ocracoke Inlet, two major inlets into Pamlico Sound, North Carolina. Atlantic menhaden, *Brevoortia tyrannus*, were similar in average density at both inlets; Atlantic croaker, *Micropogonias undulatus*, and summer flounder, *Paralichthys dentatus*, were more abundant at Oregon Inlet; spot, *Leiostomus xanthurus*, pinfish, *Lagodon rhomboides*, and southern flounder, *P. lethostigma*, were more abundant at Ocracoke Inlet. Atlantic croaker were significantly larger at Oregon Inlet at the beginning and end of the ingress season, whereas Atlantic menhaden were significantly smaller at Ocracoke Inlet at the end of the season (ca. 12 mm vs. 27 mm). Abundance data from Oregon and Ocracoke inlets were compared with abundance data collected during the same period at Beaufort Inlet and with data from a previous monthly survey conducted six years earlier at the same stations at Oregon and Ocracoke inlets. Winter temperatures were similar at both inlets, but Ocracoke Inlet was warmer during spring. Oregon Inlet was less saline than Ocracoke Inlet at every sampling event.

Pamlico Sound, the largest barrier island estuary in the United States (5,200 km<sup>2</sup>), supports numerous fisheries either indirectly as juvenile habitat or directly as fishing grounds. Major fisheries include species of Clupeidae, Paralichthyidae, and Sciaenidae. Most species of these families spawn in the ocean, after which their larvae pass through inlets before reaching estuarine nurseries. Data on the ingress through inlets of larvae of these species are essential in understanding variability in annual recruitment. The only publication describing the seasonal abundance of fish larvae in inlets to Pamlico Sound was based on

once-monthly sampling (Hettler and Barker 1993). Since that study, analysis of a daily sampling experiment at Beaufort Inlet concluded that sampling weekly or more often significantly increases confidence in larval abundance estimates (Hettler et al. 1997). The objective of my study was to sample weekly at two of the three inlets connecting Pamlico Sound directly to the Atlantic Ocean (Oregon Inlet and Ocracoke Inlet) to compare their relative contribution as larval fish pathways to the marine species nursery grounds in the sound and adjacent tributaries as identified by Epperly and Ross (1986).

### METHODS

Oregon Inlet is the only inlet into Pamlico Sound north of Cape Hatteras and lies in the temperate Virginian Province near the southern end of the Labrador Current (Fig. 1). Ocracoke Inlet, the largest inlet in North Carolina and one of two inlets connecting Raleigh Bay (located between Cape Hatteras and Cape Lookout) with Pamlico Sound, lies in the subtropical Carolinian Province. These inlets were sampled for 27 consecutive weeks between October 1994 and April 1995 during the ingress of larvae of six targeted species of fall-winter spawning fishes, five of which contribute 85% of the total commercial fish catch in North Carolina (Miller et al. 1984).

Fig. 1. Study location.

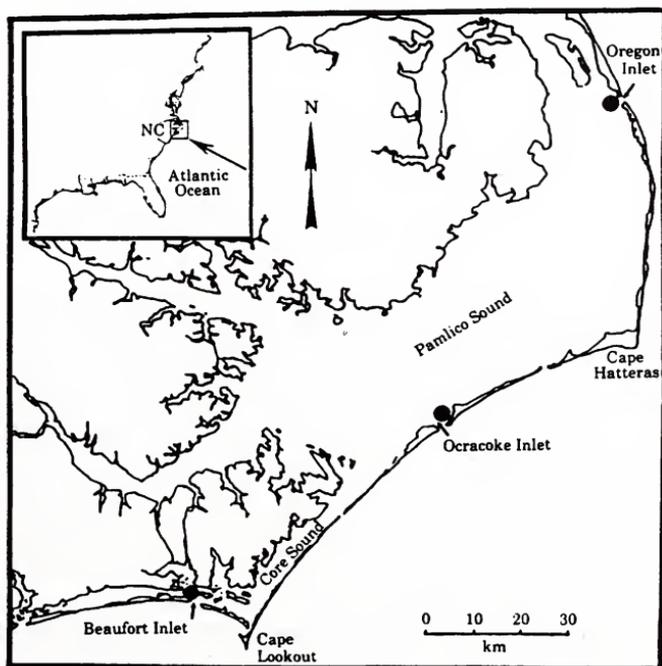
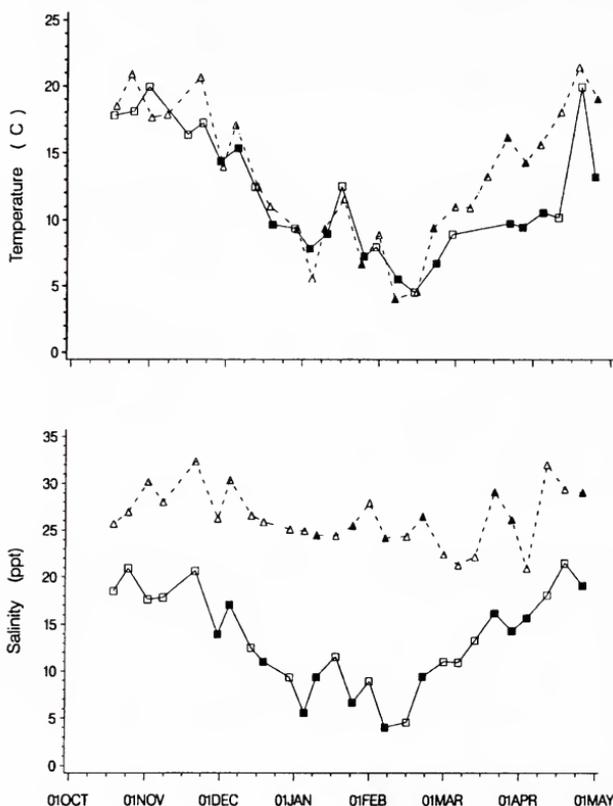


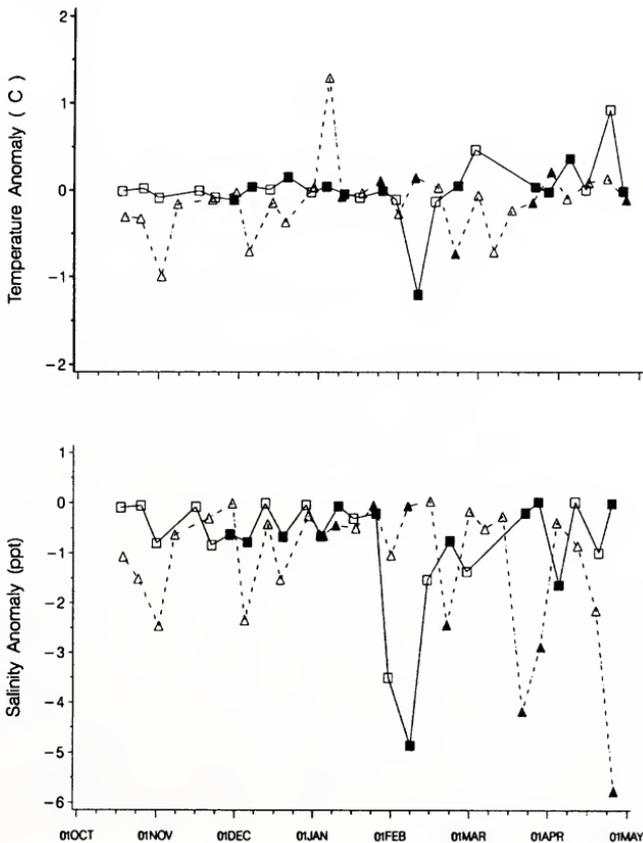
Fig. 2. Mean water column temperature and salinity at Oregon Inlet (solid line, squares) and Ocracoke Inlet (dashed line, triangles), North Carolina, for each weekly sampling trip during the 1994-95 larval fish immigration period. Solid symbols indicate ebb tide samples; open symbols indicate flood tide samples.



Inside each inlet a single sampling station was established in the center of the main flood-tide channel (Oregon Inlet station: 35E 46.3'N, 75E 33.5'W; Ocracoke Inlet station: 35E 06.4'N, 75E 59.5'W). The deepest water at each station was 7 m and the channel width was about 300 m. Inlets were sampled one night each week on adjacent nights (quasi-synoptic). Each night's sampling consisted of 12 repetitive tows, about 10 minutes apart, with a 0.8-m<sup>2</sup>, 800 micron-mesh-net on a 1-m-diameter, sled-mounted, aluminum frame towed at a net speed of 1 m/sec. A tow consisted of actively towing the net in the deepest water along the axis of the channel down to the bottom and back to the surface. Tows were always made into the current. A flow-meter measured the volume of water passing through the net. Each tow took 4 minutes, filtering approximately 200 m<sup>3</sup>

of water. Preceding each tow, temperature and salinity casts were taken with a SeaBird 19 CTD and direction of tidal flow was recorded. CTD data were averaged for the entire water column and all tows on a given date (Fig. 2), because the oblique net tows integrated the larval catch from throughout the water column and the vertical distribution of the larvae was unknown. However, the surface and bottom values were compared to show the amount of temperature and salinity stratification in the channel at each station (Fig. 3). As observed from the vessel, the channel currents were flooding on 15 of the 27 dates at Oregon Inlet and on 20 of the 27 dates at Ocracoke Inlet.

Fig. 3. Difference (anomaly) between the surface and the bottom temperature and salinity at Oregon Inlet (solid line, squares) and Ocracoke Inlet (dashed line, triangles), North Carolina, during the 1994-95 larval fish immigration period. Positive values indicate warmer or more saline water at the surface; negative values indicate warmer or more saline at the bottom. Solid symbols indicate ebb tide sampling; open symbols indicate flood tide sampling.



On board the vessel, larvae were preserved in 70% ethyl alcohol. In the laboratory, larvae were sorted by species and counted. Up to 10 larvae of each species from each tow were measured to the nearest 0.1 mm standard length. Larval abundance was calculated as the number per 100 m<sup>3</sup> and plotted as the weekly mean density ( $\pm 1$  standard error) of the individual tow densities by inlet and date. Lengths were plotted as the mean standard length of up to 120 larvae of each species at each inlet each week ( $\pm 1$  standard error).

Wilcoxon rank sum tests were used to compare densities of species between inlets. To examine the relative contribution by inlet for each species, the seasonal weekly density by species for Oregon Inlet and Ocracoke Inlet was compared with data collected during the same period in a separate study at Beaufort Inlet (Warlen 1994; S. Warlen, NMFS Beaufort Laboratory, personal communication). For this comparison, it should be recognized that the Beaufort Inlet study results are used as proxy data in the absence of data collected with the same methods as at Oregon and Ocracoke inlets. In the Beaufort study, a 2-m<sup>2</sup>, 1000-micron-mesh neuston net was fished passively in the tidal current at the surface. In both studies, however, the data were standardized to densities per unit volume by the use of flow meters.

## RESULTS AND DISCUSSION

### TEMPERATURE AND SALINITY

The inlets were similar in temperature, except that Ocracoke Inlet warmed at a faster rate after late February than did Oregon Inlet (Fig. 2). During February, when abundance of most larval species was low, temperature at both inlets dropped to less than 5C.

Salinity as high as 33 ppt was observed twice at Ocracoke Inlet, once in late autumn and once in early spring, a time when salinity at Oregon Inlet was about 20 ppt. Salinity at Oregon Inlet was always 5-20 ppt lower than Ocracoke Inlet and in February was as low as 4 ppt. Salinities lower than 10 ppt in Oregon Inlet in combination with low temperatures occurred eight times. The physiological consequences of low salinities and temperatures on ocean-spawned larvae is only partially known. For example, *Brevoortia tyrannus* (Atlantic menhaden) larvae died in laboratory experiments at salinities <5 ppt and temperatures <5 C. In these experiments, however, 50% mortality in <48 hours also occurred at high salinity (30 ppt) and low temperatures (<5 C) (Lewis, 1966). In other laboratory experiments, *Leiostomus xanthurus* (spot) were determined to be more cold sensitive at 10 C than *Micropogonias undulatus* (Atlantic croaker), but test salinities were not given (Hoss et al. 1988). Their study concluded that during severe winters many early arriving larvae in estuaries are killed and that only late arriving larvae survive for recruitment into the fishery.

Twice at each inlet, the temperature difference between the surface and bottom water equaled or exceeded 1 C in the 7-m-deep channel, but generally

there was little thermal stratification (Fig. 3). On several occasions the water column was colder at the surface when strong, cold winds were present. On the other hand, salinity was often positively stratified, as much as 6 ppt less saline at the surface. At Oregon Inlet during early February, when there was a 5 ppt difference between the surface and bottom, the surface was 1C colder than the bottom. At this time, the current direction at the surface was ebbing.

Table 1. Average weekly densities (number per 100 m<sup>3</sup> ± 1 standard error) at Oregon Inlet and Ocracoke Inlet (0.8-m<sup>2</sup> net, this study) compared with Beaufort Inlet (2-m<sup>2</sup> net, S. Warlen, NMFS, Beaufort Laboratory, personal communication) during the October 1994 - April 1995 immigration season (n=27 weeks). Values connected with a dashed line are not significantly different (Wilcoxon rank sum test,  $\alpha=0.05$ ).

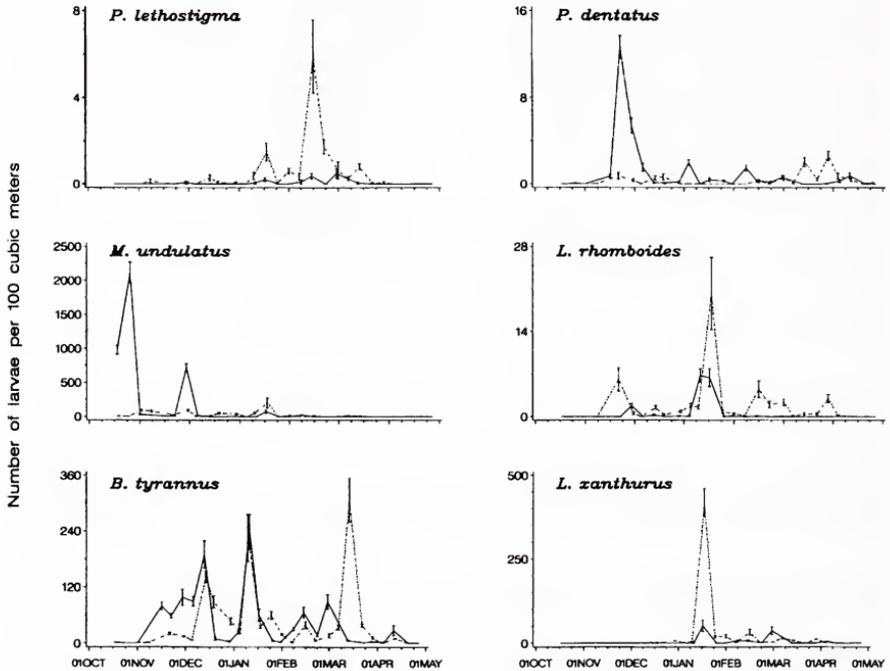
| Species                         | Oregon Inlet  | Ocracoke Inlet         | Beaufort Inlet    |
|---------------------------------|---------------|------------------------|-------------------|
| <i>Brevoortia tyrannus</i>      | 43.2 (± 4.1)  | -----43.5 (± 4.9)----- | -----22.9 (± 8.4) |
| <i>Lagodon rhomboides</i>       | 0.6 (± 0.1)   | 1.7 (± 0.3)            | 12.4 (± 3.9)      |
| <i>Leiostomus xanthurus</i>     | 4.4 (± 1.0)   | 21.1 (" 4.8)           | -----4.8("18.7)   |
| <i>Micropogonias undulatus</i>  | 155.5(± 27.1) | 26.9 (± 3.9)           | -----25.7 (± 6.1) |
| <i>Paralichthys dentatus</i>    | 1.0 (± 0.2)   | 0.3 (± 0.1)            | -----0.3 (± 0.2)  |
| <i>Paralichthys lethostigma</i> | 0.1 (± 0.1)   | 0.5 (± 0.1)            | 0.8 (± 0.3)       |

## ABUNDANCE

Unlike the other five selected species, Atlantic menhaden were not significantly different in average weekly density at any inlet, although fewer appeared to be caught at Beaufort Inlet during the year (Table 1). Spot were less abundant at Oregon Inlet than the other inlets, but Atlantic croaker were most abundant at Oregon Inlet. Pinfish (*Lagodon rhomboides*) and southern flounder (*P. lethostigma*) were different in density among all inlets. Spot, pinfish, and southern flounder increased in density towards the south, whereas Atlantic croaker and summer flounder decreased, which is the expected pattern based on the known distribution of these species (Fahay 1983). North Carolina is the center of the known spawning range of Atlantic menhaden (Freidland et al. 1996),

and similar densities at these inlets is not surprising even though the spawning locations contributing Atlantic menhaden larvae to each inlet is unknown.

Fig. 4. Mean densities of six selected species of fish larvae at Oregon Inlet (solid line) and Ocracoke Inlet (dashed line), North Carolina, during the 1994-95 larval fish immigration period. Error bars equal  $\pm 1$  standard error.



One or more prominent peaks in densities of each species occurred at one or both inlets during the season (Fig. 4). Atlantic croaker were dominant during the early season at Oregon Inlet with a weekly mean density of  $>2000$  per  $100 \text{ m}^3$  in late October. In one tow on 29 October 1994, the catch density was  $3000$  larvae per  $100 \text{ m}^3$ . Another pulse of Atlantic croaker entered Oregon Inlet in early December, a week after summer flounder peaked in density at that inlet. Peak summer flounder densities at Oregon Inlet preceded the period of peak recruitment into Ocracoke by more than 3 months. Summer flounder were found to peak in Beaufort Inlet in February (Burke et al. 1991). The peak abundance of Atlantic croaker and summer flounder larvae observed early in the season at Oregon Inlet compared to the two inlets south of Cape Hatteras, suggests that

these species are coming from spawning areas that have cross-shelf transport routes north of Cape Hatteras. Southern flounder, which were not abundant at Oregon Inlet, peaked at Ocracoke Inlet in mid-February, the same period as reported earlier for Beaufort Inlet by Burke et al. (1991). Gulf flounder (*P. albigutta*), an abundant paralichthyid south of Cape Hatteras, were not caught at Oregon Inlet and therefore are not considered further. The largest numbers of pinfish were caught at both inlets in mid-January. Spot also were most abundant in mid-January, but only at Ocracoke. Early in the season Atlantic menhaden were more abundant at Oregon Inlet than at Ocracoke, but both inlets had high numbers in mid-December and mid-January. The high densities of Atlantic menhaden at Oregon Inlet in November, a month before significant ingress into Ocracoke, suggests that spawning or favorable cross-shelf transport currents supplying these larvae took place north of Cape Hatteras. In early October, concentrations of Atlantic menhaden larvae have been reported as far south as Currituck Beach, North Carolina, about 60 km north of Oregon Inlet (Kendall and Reintjes 1974). If this distribution also occurred in October 1994, larvae would have been in position for transport to the inlet by November. The largest densities of Atlantic menhaden observed during the season came into Ocracoke Inlet in mid-March. Except for southern flounder, the abundance of all other species was low in February at both inlets.

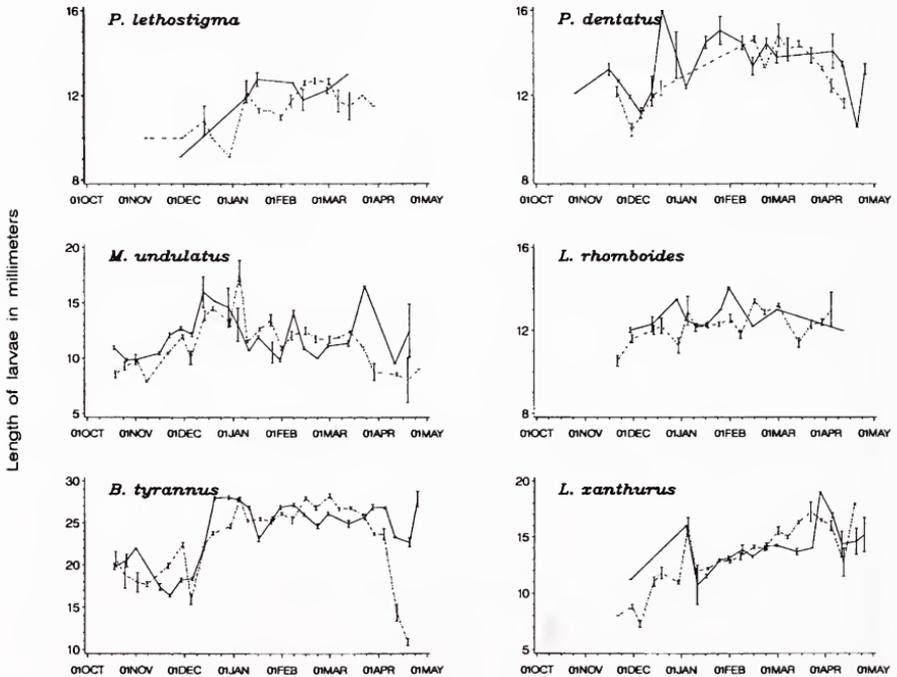
Seasonal density patterns in 1994-1995 were different than those reported for 1988-1989 (Hettler and Barker 1993). In 1988-1989, sampling was conducted monthly with the same 0.8-m<sup>2</sup>, 800 micron-mesh-net on a 1-m-diameter frame at the same stations as in 1994-1995. Because large variability in density estimates can occur as a result of infrequent sampling, monthly densities probably do not represent average monthly values (Hettler et al. 1997). However, in that earlier study, Atlantic menhaden were most abundant at Ocracoke Inlet in February (92 per 100 m<sup>3</sup>) and at Oregon Inlet in March (222 per 100 m<sup>3</sup>), whereas in the present study density was highest in mid-March at Ocracoke Inlet and mid-December at Oregon Inlet. Warlen (1994) also recorded peak menhaden density (130 per 100 m<sup>3</sup>) in February 1989 at Beaufort Inlet, earlier that year than any other year between 1986 and 1992. In 1989, spot densities were less than 10% of their 1995 values at Ocracoke Inlet (27 per 100 m<sup>3</sup>). Flounder densities at any month were low during 1988-1989 (< 1 per 100m<sup>3</sup>) for either species. Southern flounder and pinfish were taken in 1988-1989 only at Ocracoke Inlet.

## SIZE

For all species, significant differences in body size occurred between inlets on many sampling dates (Fig. 5). Average lengths of Atlantic menhaden at Oregon Inlet decreased in length during November and then rapidly increased by about 10 mm in mid-December. Increasing density and decreasing size of Atlantic menhaden larvae in early November at Oregon Inlet indicated that

spawning schools moving south for the winter were approaching the vicinity of the inlet. At Ocracoke larvae increased from about 17 mm in early December to 27 mm by early January. During the remainder of winter, 25-28 mm Atlantic menhaden were caught at both inlets until the end of the season at Ocracoke when the size of larvae decreased to as small as 10 mm. These small menhaden in April probably resulted from spawning south of Ocracoke Inlet by northerly-moving adults. Small Atlantic menhaden were not collected at Oregon Inlet or at Beaufort Inlet in April.

Fig. 5. Mean standard length of six selected species of fish larvae at Oregon Inlet (solid line) and Ocracoke Inlet (dashed line), North Carolina, during the 1994-95 larval fish immigration period. Error bars equal  $\pm 1$  standard error.



Atlantic croaker increased >50% in length at both inlets between late October and late December. Spawning of Atlantic croaker near Cape Hatteras begins at least by early September, peaks in October, and is reduced by late December with perhaps another peak in the spring (Morse 1980). Near Beaufort Inlet, in Onslow Bay, Atlantic croaker were reported to spawn between mid Sep-

tember and late February, with the majority of spawning between late September through November (Warlen 1982). Evidence of summer spawning was presented by Hettler and Barker (1993) who caught 7 mm Atlantic croaker at both inlets in late August 1989. Atlantic croaker this size are probably about 30-days old (Warlen 1982). In April at Ocracoke Inlet, the size of croaker dropped to less than 10 mm due possibly to inshore spawning. The corresponding density data, however, did not indicate the arrival of significant numbers of newly spawned larvae.

Spot increased in length about 2 mm per month after early January and were nearly identical in size at both inlets. At Oregon Inlet no further increase in length was noted until mid-March, when a few early juveniles (>17 mm) were caught. It is difficult to determine if these juveniles had just entered following ocean transport, or were established residents in the inlet or nearby estuary. Juvenile spot (20-26 mm) have been collected in that inlet in May and June 1989 (Hettler and Barker 1993). Spot size data before January and after late March are probably not useful, as few larvae were caught.

The mean lengths of pinfish and both species of flounders increased during the sampling period. Pinfish were typically about 1 mm smaller at Ocracoke than at Oregon Inlet and showed a slight increase in average size at both inlets from December to February. After January, few pinfish were caught at Oregon Inlet. The average lengths of both species of flounder at both inlets increased about 2 mm from December to February. In mid-March at Ocracoke when densities of southern flounder were highest, this species was about 13 mm. When summer flounder peaked in density at Oregon Inlet in mid-December, they also averaged 13 mm.

### CONCLUSIONS

From these quasi-synoptic weekly abundance and size estimates of the winter-immigrating marine fish larvae at two major inlets to Pamlico Sound, it appears that Oregon Inlet imported larger-sized individuals and higher densities of Atlantic menhaden, Atlantic croaker, and summer flounder (important commercial species) significantly earlier than at Ocracoke. In winters with mild temperatures, cohorts of older, larger larvae that establish in the nursery areas within Pamlico Sound early in the season may have a survival advantage over cohorts of larvae entering later through either inlet; in severe winters the converse would apply as inferred by Hoss et al. (1988).

The relative value of each inlet as a larval pathway for future juvenile production and recruitment into the fisheries cannot be extrapolated from these data without comparing analyses of the daily age structure of immigrating larvae with juveniles emigrating Pamlico Sound nurseries. Towards this goal, larval specimens furnished from this study are now undergoing age and growth analyses: Atlantic menhaden (J. Rice, North Carolina State University); Atlantic

croaker and spot (C. Jones, Old Dominion University). In the mean time, the density data provided above should be useful in evaluating the effects of any future anthropogenic modifications (e.g., jetties) to Oregon or Ocracoke inlets on immigrating fish larvae.

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# First Record of Nutria, *Myocastor coypus* (Mamalia:Rodentia), in Tennessee

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**ABSTRACT**—We document the first record of nutria (*Myocastor coypus*) in Tennessee. A specimen was collected in Shelby County in 1996.

In 1899, nutria (*Myocastor coypus*) were first introduced into the United States in California as a furbearer (see Willner 1982). The occurrence of the species in the Southeast probably stemmed from animals that escaped or were released in Louisiana during the late 1930s (Ashbrook 1948, Willner 1982). Choate et al. (1994) pointed out that through new introductions and natural dispersal, nutria have spread rapidly, and the species is common to abundant in Gulf coastal marshes and along major waterways of the Coastal Plain in the south-central United States. Introductions or wild specimens are known from several states in proximity to Tennessee (e.g., Mississippi, Kennedy et al. 1974; Kentucky, Barbour and Davis 1974; Missouri, Schwartz and Schwartz 1981; North Carolina, Lee et al. 1982; Illinois, Hoffmeister 1989; Arkansas, Sealander and Heidt 1990). Sealander and Heidt (1990) showed records of nutria from counties in the Gulf Coastal Plain of Arkansas that bordered or were near the Mississippi River adjoining Tennessee. However, at this time, no previous record exists for this species in Tennessee.

On 22 January 1996, a female nutria was collected (by shooting) from a water-control ditch (ca. 7 m in width) on Eagle Lake Refuge, Shelby County, Tennessee. The adult animal weighed ca. 6 kg. External measurements (mm) were as follows: total length, 903; length of tail, 403; length of hind foot, 140; length of ear, 24. Vegetation along the water-control ditch was early successional grasses and weeds. The ditch was used to control the water level in adjacent agricultural fields and was only a short distance from the Mississippi River.

Since the collection of a single specimen in January 1996, Refuge personnel and sportsmen have reported additional sightings of nutria in adjacent Shelby Forest Wildlife Management Area. Some nutria activity has been observed on beaver lodges in cypress swamps. However, because this species does not endure extremely cold temperatures (Schwartz and Schwartz 1981), we doubt *Nutria* will become very numerous in Tennessee. The specimen reported on herein is deposited in the biological collections at The University of Memphis (No. 16628).

*ACKNOWLEDGMENTS* - The specimen was collected by J. W. Freeman. D. Fuqua and R. Byron (Tennessee Wildlife Resources Agency) made the specimen available to the investigators and provided information relating to their sightings of nutria activity in the area as well as sightings by sportsmen.

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# Prey Selection by Five Species of Vespertilionid Bats on Sapelo Island, Georgia

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ABSTRACT. -- Prey items obtained from fecal samples of 132 individuals representing five species of vespertilionid bats were compared to available prey as determined by insect light trapping in foraging habitats on Sapelo Island, Georgia. Four orders of insects dominated the diet of these bats: Coleoptera, Hymenoptera, Lepidoptera, and Hemiptera. Homoptera and Diptera were present in smaller proportions. All five bat species exhibited significant selection for or against certain insect orders. The evening bat (*Nycticeius humeralis*) consumed Coleoptera and Hymenoptera in proportion to their availability, but significantly fewer Homoptera than were available in the foraging habitats. Differences in feeding selectivity were observed between sexes and age groups. Adult male and juvenile evening bats consumed significantly fewer Coleoptera and more Hymenoptera than were available in the foraging habitats; adult females showed little feeding selectivity. The Seminole bat (*Lasiurus seminolus*) consumed Homoptera and Diptera in significantly lower proportion to their availability. The eastern pipistrelle (*Pipistrellus subflavus*) consumed significantly more Lepidoptera and fewer Coleoptera and Homoptera in proportion to their availability. The big brown bat (*Eptesicus fuscus*) fed mostly on Coleoptera and Lepidoptera, whereas the northern yellow bat (*L. intermedius*) consumed only Coleoptera and Hymenoptera.

Twelve species of bats occur in Lower Coastal Plain ecosystems of South Carolina, Georgia, and northern Florida (Barbour and Davis 1969, Hall 1981). With the exception of Zinn and Humphrey's (1981) study of prey availability and prey selection of the southeastern bat, *Myotis austroriparius* (Rhoads 1897), only anecdotal comments regarding foraging behavior of bats inhabiting

these regional ecosystems are available (Harper 1927, Sherman 1935, 1939, Moore 1949, Ivey 1959, Golley 1962, 1966, Neuhauser and Baker 1974, Sanders 1978, Schacher and Pelton 1979).

In conjunction with mist netting studies relating to roost site selection and habitat use of bats on Sapelo Island, Georgia (Menzel et al. 1995), we undertook a comparative study of prey selection based on analysis of fecal pellet contents collected from five species of bats captured on the island: evening bat, *Nycticeius humeralis* (Rafinesque 1818), Seminole bat, *Lasiurus seminolus* (Rhoads 1895), eastern pipistrelle, *Pipistrellus subflavus* (Cuvier 1832), northern yellow bat, *L. intermedius* Allen 1862, and big brown bat, *Eptesicus fuscus* (Beauvois 1796). To determine the degree of prey selectivity by the bats from among potential prey, we compared fecal pellet contents to available insects collected at vegetational community types on the island where bats foraged.

#### STUDY AREA

The study was conducted on Sapelo Island, McIntosh County, Georgia from 19 June through 24 July 1995. Sapelo Island is located approximately 63 km south of Savannah and 5.5 km off shore (31°27'N, 81°16'W). The island is approximately 16 by 3.2 km in size and is typical of barrier islands of the southeastern Atlantic Bight (Johnson et al. 1974). Seven well-defined vegetational community types characteristic of regional lower Coastal Plain ecosystems are present on the island (Shaw and Fredine 1956). Bats are known to forage in all seven of these communities. Longleaf pine stands (*Pinus palustris*) are restricted to the northern third of the island. The remaining vegetational community types are located throughout and include stands of pond pine (*P. serotina*), loblolly-slash pine (*P. taeda* and *P. elliotii*), mixed pine-oak (upland oaks comprise less than 25 % of the overstory), mixed oak-pine (pines comprise less than 25 % of the overstory), oak stands dominated by live oak (*Quercus virginiana*), and high marsh. Further descriptions of the floral associates of these vegetational communities are provided by Johnson et al. (1974).

The climate of Sapelo Island is characterized by long, warm summers and short, mild winters. Average temperatures for June and July are 26.3 and 27.7 C, respectively. Average monthly rainfall for June and July is 14.58 and 15.65 cm, respectively (National Climatic Center 1983, Johnson et al. 1974).

#### METHODS

**Capture Techniques** - Bats were captured throughout the study using 3 x 12 m mist nets set over or near ponds in all seven major vegetational community types on the island. Nets were opened from dusk until 0200 hours. Bats are known to forage over dunes, marshes, and open salt water. However, no effort was made to mist net in these areas. Bats netted throughout the night were held in a 32-ounce cup, and fecal pellets were collected. All bats were released

within an hour, whether fecal pellets were collected or not. Data recorded from bats included species, sex, and age class (juvenile or adult). Age classes were determined by back-lighting finger joints to examine the level of epiphyseal diaphyseal fusion (Anthony 1988).

**Insect Sampling** - A variety of methods are available to sample insects. All of these have inherent biases (Kunz 1988). While light traps are biased toward phototrophic insects (Bowden 1982), they have been shown to be satisfactory in foraging studies of bats (Taylor and Carter 1961, Brack and LaVal 1985, Jones 1990, Lacki et al. 1995).

Seven, 10-watt, black light insect traps were powered by automotive batteries. One was placed in each vegetational community type. Traps were suspended from 1 to 3 m above the ground and positioned to be visible from most points within a 60-m radius. Traps were operated each night between 2100 and 0300 hours at the same time bats were tracked using telemetry. Insects were removed each night and frozen for subsequent identification. The size of the insects considered to be consumable ranged from 2 to 25 mm for all bats (Gould 1955, Ross 1961, Black 1974, Feldhamer et al. 1995). A total of 8,753 insects in this size range was identified to order, and proportions of orders present were calculated. Regression analysis indicated no changes in relative insect abundance in the respective habitat types over our sampling period. Therefore, we combined data for insects in each habitat type over our sampling period.

**Fecal Analysis** - Fecal samples were placed in a petri dish with 70% ethanol solution and teased apart using probes and forceps (Whitaker 1988). All fecal pellets collected from a single individual were examined together using a dissecting microscope. To eliminate researcher bias, fecal samples were examined using identification numbers that were referenced to the species, age, and sex of the bats. A reference collection of insects collected during the study was used to help identify fecal matter (Whitaker 1988). Most insects were identified to order, some to family or species. Percent volume of prey taxa was visually estimated for each sample, and percent occurrence was calculated. Lepidopterans were often only represented in fecal samples by scales. Therefore, percent volume of this order was estimated using a modified version of Black's method (1972), and were not considered if present in small numbers.

**Selectivity** - Whitaker (1994) noted that to distinguish between opportunistic versus selective feeding by insectivorous bats, it is necessary to assess the insect taxa available to the bats and compare these to prey items actually eaten. We followed Whitaker (1994) in assessing prey taxa availability by sampling insects in the habitats in which the bats were foraging (see below). We then compared prey taxa availability in different habitats to the insect taxa found in

the fecal pellets. If prey availability at sampling sites differed significantly from prey taxa obtained in fecal samples, we assumed the bats were feeding selectively.

One-way analysis-of-variance (ANOVA) and the Bonferonni multiple range test revealed that the diet of the bats remained constant over our sampling period. Therefore, we compared the fecal samples of each species of bat to the samples of insects collected throughout the summer.

Since it is likely that bats feed in more than one vegetational community type and the proportion of available prey may differ between vegetational community types, we again followed Whitaker (1994) by prorating the time spent foraging in different vegetational community types. We used telemetry data to determine the time each bat species spent in each vegetational community type and multiplied this by the proportion of insect taxa collected in that vegetational community type. The prorated time spent in each vegetational community type was then summed to obtain the total proportion of insect taxa in the bat's hypothetical foraging area. Only fecal samples from bats captured while foraging in areas where insects were collected were used in this analysis. Differences between expected and actual diet were determined using an ANOVA (Sokal and Rohlf 1987). Significance was accepted at the  $p < 0.05$  level.

## RESULTS AND DISCUSSION

Fecal samples from 132 individual bats were examined: 99 *N. humeralis* (Table 1), 24 *L. seminolus*, 4 *P. subflavus*, 3 *E. fuscus*, 2 *L. intermedius* (Tables 2). Due to the large sample size of *N. humeralis*, we were also able to analyze this species in three groups: adult males, adult females, and juveniles. Table 1 and 2 summarize fecal analysis data and prey availability comparisons. Samples were collected from bats netted in all vegetational community types except pine-oak, a community in which no bats were captured. Due to the size of insect fragments found in fecal pellets, identification of only six major orders was possible: Coleoptera, Hymenoptera, Lepidoptera, Hemiptera, Homoptera, and Diptera. Other orders may have been present in lower quantities. Percent volume and percent occurrence of insect orders consumed varied among species (Tables 1 and 2). While previous studies suggest that small, insectivorous bats are opportunistic feeders (Kunz 1974, Fenton and Morris 1976, Swift et al. 1985), each of the five species we studied demonstrated statistically significant feeding selectivity for certain insect orders.

### *Nycticeius humeralis*

Fecal samples from 99 evening bats were examined (Table 1). Six orders of prey items were found. Coleoptera were present in 91% of the fecal samples followed by Hymenoptera (69%), Lepidoptera (48.5%), Hemiptera (40.5%), Homoptera (7%), and Diptera (8%). No significant depar-

Table 1.--Percent occurrence (Fec. Occ.), and total volume (Fec. Vol.) of insect taxa recovered from fecal samples of *N. humeralis*, compared with percentage available (Hab. Avl.) in foraging habitats on Sapelo Island, Georgia.

|             | <i>N. humeralis</i><br>(n = 99) |                   |                   | Adult Male<br>(n = 16) |                   |                   | Adult Female<br>(n = 41) |                   |                   | Juvenile<br>(n = 42) |                   |                   |
|-------------|---------------------------------|-------------------|-------------------|------------------------|-------------------|-------------------|--------------------------|-------------------|-------------------|----------------------|-------------------|-------------------|
|             | %<br>Fec.<br>Occ.               | %<br>Fec.<br>Vol. | %<br>Hab.<br>Avl. | %<br>Fec.<br>Occ.      | %<br>Fec.<br>Vol. | %<br>Hab.<br>Avl. | %<br>Fec.<br>Occ.        | %<br>Fec.<br>Vol. | %<br>Hab.<br>Avl. | %<br>Fec.<br>Occ.    | %<br>Fec.<br>Vol. | %<br>Hab.<br>Avl. |
| Coleoptera  | 91                              | 45                | 75                | 87.5                   | 28.5*             | 75                | 93                       | 53.5              | 75                | 90                   | 43                | 75                |
| Hymenoptera | 69                              | 36                | 3.5               | 81                     | 47.5              | 3.5               | 58.5                     | 26.5              | 3.5               | 74                   | 40.5              | 3.5               |
| Lepidoptera | 48.5                            | 7                 | 10                | 62.5                   | 10                | 10                | 40                       | 6.5               | 10                | 52                   | 5.5               | 10                |
| Hemiptera   | 40.5                            | 11                | 2                 | 44                     | 11.5              | 2                 | 46                       | 12                | 2                 | 33                   | 10                | 2                 |
| Homoptera   | 7                               | .03               | 8                 | 6                      | 0*                | 8                 | 10                       | .5*               | 8                 | 5                    | 0*                | 8                 |
| Diptera     | 8                               | .07               | 1                 | 12.5                   | 2                 | 1                 | 12                       | 1                 | 1                 | 2                    | 0*                | 1                 |

Differences between fecal samples and available samples

\* Significant differences ( $P < 0.05$ ).

Table 2.--Percent occurrence (Fec. Occ.), and total volume (Fec. Vol.) of insect taxa recovered from fecal samples of four species of bats, compared with percentage available (Hab. Avl.) in foraging habitats on Sapelo Island, Georgia.

|             | <i>L. seminolus</i><br>(n = 24) |                   |                   | <i>P. subflavus</i><br>(n = 4) |                   |                   | <i>E. fuscus</i><br>(n = 3) |                   |                   | <i>L. intermedius</i><br>(n = 2) |                   |                   |
|-------------|---------------------------------|-------------------|-------------------|--------------------------------|-------------------|-------------------|-----------------------------|-------------------|-------------------|----------------------------------|-------------------|-------------------|
|             | %<br>Fec.<br>Occ.               | %<br>Hab.<br>Avl. | %<br>Fec.<br>Occ. | %<br>Fec.<br>Occ.              | %<br>Hab.<br>Avl. | %<br>Fec.<br>Occ. | %<br>Fec.<br>Occ.           | %<br>Fec.<br>Occ. | %<br>Fec.<br>Occ. | %<br>Hab.<br>Avl.                | %<br>Fec.<br>Occ. | %<br>Hab.<br>Avl. |
| Coleoptera  | 92                              | 76                | 25                | 6*                             | 66                | 100               | 78                          | 74                | 100               | 31                               | 66                | 66                |
| Hymenoptera | 50                              | 3                 | 50                | 4                              | 12                | 0                 | 0*                          | 7                 | 100               | 69                               | 12                | 12                |
| Lepidoptera | 71                              | 11                | 100               | 74*                            | 5                 | 100               | 21                          | 5                 | 0                 | 0*                               | 5                 | 5                 |
| Hemiptera   | 25                              | 2                 | 25                | 12                             | 3                 | 0                 | 0*                          | 2                 | 0                 | 0                                | 3                 | 3                 |
| Homoptera   | 4                               | 7                 | 0                 | 0*                             | 12                | 0                 | 0*                          | 9                 | 0                 | 0*                               | 12                | 12                |
| Diptera     | 4                               | 1                 | 25                | 4                              | 2                 | 33.3              | 1                           | 2                 | 0                 | 0                                | 2                 | 2                 |

Differences between fecal samples and available samples

\* Significant differences ( $P < 0.05$ ).

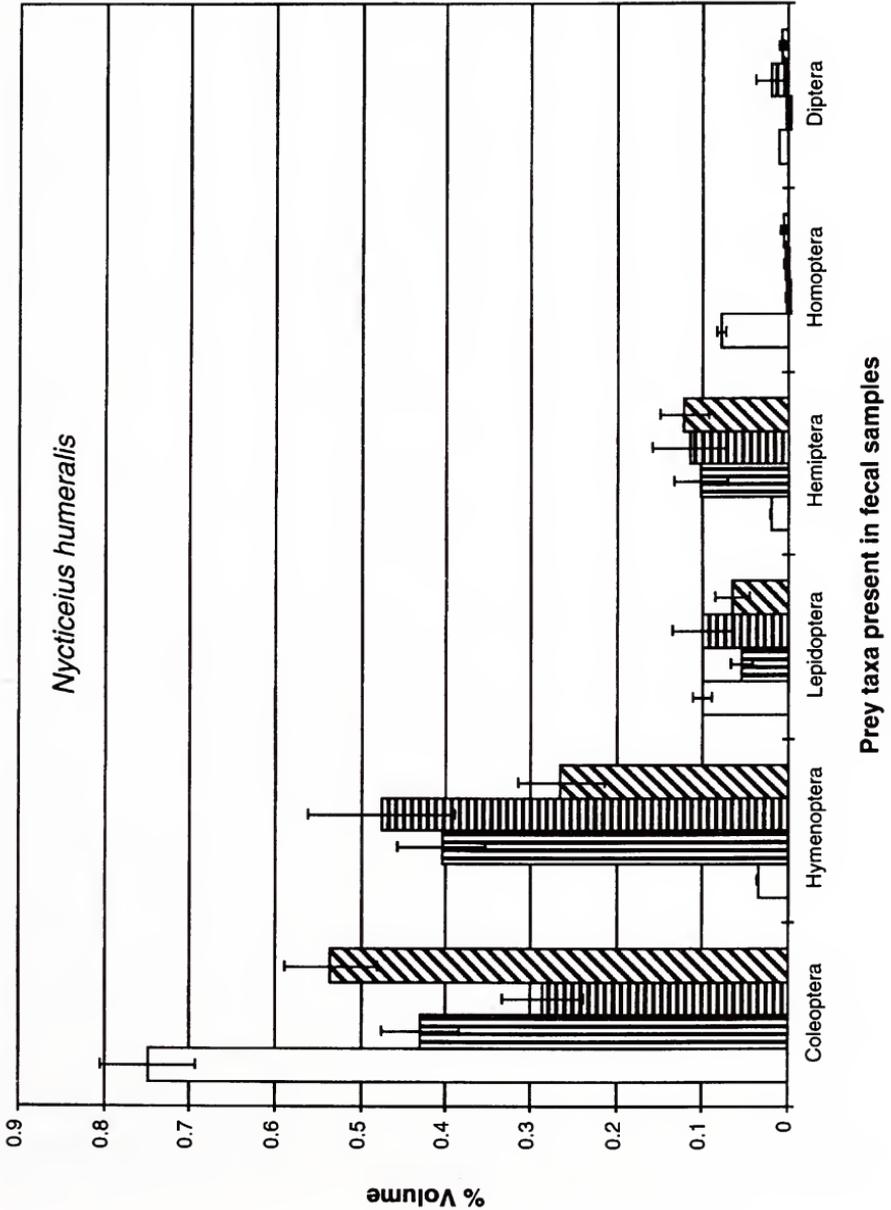
tures between fecal volume and prey availability were noted except that Homoptera occurred in significantly lower volume ( $p < 0.001$ ) in fecal samples than were available in the environment. The relatively large number of evening bats netted allows for a comparison between adult males ( $n = 16$ ), adult females ( $n = 41$ ), and juveniles ( $n=42$ ) of the percent volume of insect taxa in fecal samples to the percent availability in environment (Table 1).

Regardless of sex and age, the fecal volume of evening bats was composed primarily of Coleoptera, Hymenoptera, and Hemiptera (combined these groups comprised 88% or more of the diet). Adult males consumed significantly fewer Coleoptera ( $p = 0.001$ ) and Homoptera ( $p < 0.001$ ) than were available in the environment (Table 1). The large proportion of Hymenoptera in fecal samples of males compared to availability was not significant ( $p = 0.071$ ), but suggests a feeding preference. Adult males consumed smaller proportions of Lepidoptera, Hemiptera, and Diptera than did males or juveniles. Combined, these taxa constituted only 23.5 % of the diet and were consumed in roughly equivalent proportion to their availability in the environment (21%). Adult females showed little feeding selectivity. Homoptera differed significantly ( $p = 0.004$ ) between the percent volume in the fecal samples and their availability in the environment. However, these comprised only a very small portion (0.5 %) of the diet. The taxa comprising over 99.5% of the fecal contents were consumed in equal proportion to their availability in the environment. Juvenile evening bats consumed similar prey to that of adult males and females. However, their prey consisted of significantly fewer Coleoptera ( $p = 0.056$ ), Homoptera ( $p < 0.001$ ), and Diptera ( $p < 0.001$ ) than were available in their environment.

Significant differences in fecal volume of prey species were observed between adult male and female evening bats. Male evening bats consumed significantly fewer Coleoptera ( $p = 0.025$ ) than females and also significantly fewer than in proportion to their availability (Table 1, Figure 1). Males also consumed significantly more Hymenoptera ( $p = 0.039$ ) than females, and in significantly higher proportion to their availability. This might be related to differences in the physiological state and metabolic requirements of males and females during the time of the year of our study (e.g., parturition and lactation). Adult females are expected to be under high levels of nutritional stress and coupled with time constraints imposed by offspring, might not be able to be as selective in their diets as adult males. Juveniles are not as constrained by time or energy as they are by their lack of foraging experience. Juveniles may be less selective, eating whatever they can catch. Adult males are not restricted by time constraints, experience or energy demands, allowing them more dietary selectivity.

A few reports on the foraging habits of the evening bat are available (Ross 1967 in Freeman 1981, Whitaker 1972, Zinn 1977, Whitaker and Clem 1992, Feldhamer et al. 1995). Most of these studies had small sample sizes, and none compared diet to relative prey abundance. Coleoptera were generally

Fig. 1. Comparison of available insect sample percentages (white) with fecal analysis from juvenile (vertical bars), adult male (horizontal bars), and adult female (diagonal bars) *Nycticeius humeralis* captured between 19 June and 24 July 1995, on Sapelo Island, Georgia.



reported to be the most important food source. Although we found Coleoptera to be present in 91% of the fecal samples, we found that significantly fewer Coleoptera were fed upon by adult males and juveniles than were available in environment. Zinn (1977) and Ross (1967 in Freeman 1981) also reported Hymenoptera from fecal pellets of the evening bat. We also found Hymenoptera (mostly flying ants -- Formicidae) to be a major food source.

#### *Lasiurus seminolus*

Six orders of prey items were also found in the fecal samples of 24 Seminole bats (Table 2). In fecal samples of Seminole bats 94.5% of the diet was from three orders: Coleoptera, Hymenoptera, and Lepidoptera. The percent volume of these taxa in fecal samples was not significantly different from their availability in the environment. Smaller proportions of Hemiptera, Homoptera, and Diptera (combined, constituting only 5.5% of the diet) were also found. Percent volumes of Homoptera ( $p < 0.001$ ) and Diptera ( $p < 0.001$ ) in the fecal samples were significantly lower than the percent available in the environment. There have been two reports of this species gleaning (Sherman 1935, Barbour and Davis 1969). Sherman (1939) found Coleoptera, Homoptera, and Diptera in the contents of a single stomach. Zinn (1977) found Coleoptera, Odonata, and Hymenoptera to be food items. These observations combined with our results confirm the importance of Coleoptera and Hymenoptera in the diet of Seminole bats.

#### *Pipistrellus subflavus*

The fecal samples obtained from four eastern pipistrelles suggest the most dramatic foraging selectivity of the five species of bats studied. Five taxonomic orders were present in fecal samples (Table 2). Lepidoptera were present in 100% of the fecal samples. They constituted only 5% of prey taxa available in the environment, but made up 74% of the volume of prey items in fecal samples. Coleoptera, on the other hand, were present in only 25% of the fecal samples. They constituted 66% of taxa available in environment, but made up only 6% of the volume in the fecal samples. Differences for both Lepidoptera ( $p = 0.007$ ) and Coleoptera ( $p < 0.001$ ) were highly significant. No Homoptera were found in the fecal samples, although they made up 12% of the prey available in the environment ( $p < 0.001$ ). Hymenoptera were present in 50% of the fecal samples, and Hemiptera and Diptera in 25% of the samples. Differences between the respective percent volume of these taxa in fecal samples and their percent availability in the environment were not significant.

Whitaker (1972) found that the 23 eastern pipistrelles he examined consumed nearly 30% Coleoptera and only 7.3% Lepidoptera. Other researchers have found Coleopterans present in lower proportions or entirely absent (Sherman 1939, Ross 1967 in Freeman 1981, Zinn 1977, Swift et al. 1985). Sherman

(1939) and Swift et al. (1985) both reported Diptera to be the most important food source for the eastern pipistrelle.

### *Eptesicus fuscus*

Three taxonomic orders of prey were observed in the fecal samples of three big brown bats. Coleoptera and Lepidoptera were found in 100% of the fecal samples, whereas Diptera was only observed in one (Table 2). The diet of these bats was dominated by Coleoptera (78%). Beetles were fed upon in proportions equal to their availability. Lepidoptera appeared to be selectively fed upon. They comprised 21% of the fecal volume, compared to 5% of available insects sampled in the environment ( $p = 0.056$ ). The small proportion of Diptera observed in fecal samples was not significantly different from their availability. Hymenoptera, Hemiptera, or Homoptera were not observed in the fecal samples. The diet of the bats we examined was similar to that reported in previous studies, in that Coleoptera predominated in the diet (Hamilton 1933, Phillips 1966, Ross 1967 in Freeman 1981, Whitaker 1972, Whitaker 1995). Whitaker (1972) found that 4.3% of the diet was composed of non-flying insects, suggesting that big brown bats may occasionally glean from the ground or foliage.

### *Lasiurus intermedius*

The fecal samples of the two northern yellow bats captured were composed entirely of Coleoptera and Hymenoptera (Table 2). Coleoptera and Hymenoptera made up 31% and 69% of the fecal samples by volume, respectively. No significant difference between percent fecal volume and percent availability was observed for Coleoptera. However, differences between fecal volume and availability of Hymenoptera approached significance ( $p = 0.067$ ), suggesting a feeding preference for this taxa.

Previous studies reported Coleoptera as the most frequently consumed prey taxa (Sherman 1939, Zinn 1977). Hymenoptera were also found in lower volumes. Ivey (1959) reported observing northern yellow bats foraging in back dune depressions where mosquitoes and flies were abundant. However, in contrast to Webster et al. (1980), he did not actually witness bats consuming these insects.

## CONCLUSION

Despite small sample sizes, we found significant differences among available and consumed prey in all five species of bats studied. Although there are some biases associated with any type of sampling (Taylor and Carter 1961, Rabinowitz and Tuttle 1982); the comparison of the available prey and prey that represented in the fecal samples gives us a greater insight into the complex foraging habits of some of the bat species found in the Southeast.

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