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Abstract

MCDONNELL, JOELLEN MARIE. Use of Bridges as Day Roosts by Bats in the North Carolina Coastal Plain. (Under the direction of Edwin Jones.)

Anecdotal records and published studies verify that bats use bridges and culverts as roosts in the United States. Few studies, however, have been designed to investigate structural designs of bridges used by bats as day roosts. In 1997 and 1998, I examined 990 bridges and culverts in 25 counties of the North Carolina Coastal Plain for presence of bats. I surveyed 6 bridge types: slab, steel multi-beam, timber multi-beam, concrete I-beam, T-beam, or channel beam; and 2 culvert types: concrete box or steel pipe. I used logistic regression analysis to determine the effects of various structure characteristics (structure type, disturbance under the structure, average daily traffic carried by the structure, amount of water under the structure, age, length, and width of the structure) on the probability that a bridge or culvert would be used by bats as a day roost.

I found bats or guano under 135 structures in 21 counties. I found bats roosting under 81 bridges and culverts, and guano under 54 bridges. I identified 3 bat species using bridges as day roosts: 36 by *Corynorhinus rafinesquii*, 38 by *Pipistrellus subflavus*, and 12 by *Myotis austroriparius*. I was unable to identify species for 3 bridges. I found bats or guano under 7 of 8 structure types. No bats occupied roosts under slab bridges. Only 1 box culvert, 1 pipe culvert, and 2 steel multi-beam bridges were used by bats. I found bats or guano under 14 timber multi-beam bridges, 15 T-beam bridges, 24 I-beam bridges, and 78 channel beam bridges.

Logistic regression analysis indicated a strong association between roosting and structure type. *C. rafinesquii* used I-beam bridges more frequently than other bridge types. *P. subflavus*, *M. austroriparius*, and guano were found under channel beam

bridges more frequently than other bridge types. Channel beam bridges were the only structures frequently used by multiple bat species.

# USE OF BRIDGES AS DAY ROOSTS BY BATS IN THE NORTH CAROLINA COASTAL PLAIN

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## Introduction

Bats spend the majority of their lives within roosts. Roosts are sites for mating, rearing young, digestion, and hibernation (Kunz 1982). Selection of a quality roost may provide bats with protection from weather and predators, reduce costs of thermoregulation and commuting to foraging sites, and improve mating opportunities and maternal care (Alteringham 1996).

Humphrey (1975) discusses four main types of roosts used by bat populations: nursery or maternity, summer male, transient (spring or autumn), and winter. Maternity colonies are used by females to bear and raise young during summer. Summer male populations are often separated from maternity colonies and use roosts simply as daytime resting sites. Transient roosts are used during autumn and spring, and may serve as sites for mating or migratory stopovers. Winter sites are used as hibernacula or daytime resting sites for non-hibernating populations.

In temperate climates, gestation, parturition, and development of young must occur within a period of months before autumn when food supplies begin to diminish (McNab 1982). The rates of these processes increase in warmer temperatures. Clustering of bats and selection of roosting sites where heat can accumulate allows for higher temperatures in maternity colonies, and thus, optimal growth rates of juvenile bats (Racey 1982). Some species may also require high humidity (e.g. *Myotis austroriparius*) within the roost for optimal development of young.

During hibernation and maternity periods, bats may form aggregates of hundreds, thousands, and sometimes millions of individuals within a single roost. This, in addition to low fecundity and long periods of infant dependency (Findley 1993), makes bats vulnerable to population declines if disturbed within the roost. When bats are disturbed, they may be forced to abandon a roost and choose an alternate roost of lower quality. Switching sites may result in a decrease in reproductive success, particularly if maternity colonies are forced to abandon the roost prior to parturition (Brigham and Fenton 1986). Therefore, selection of suitable roosts, especially for sensitive maternity colonies, is paramount to the survival of the species.

Bats use a variety of natural and man-made roosts. Natural roosts may be permanent structures, such as caves and rock-crevices, or ephemeral sites, such as trees, and leaves of plants. Among man-made structures used by bats are buildings, mines, and highway structures such as bridges and culverts (Kunz 1982, Pierson 1998). Selection of roosts is a complex process and may be influenced by availability of roosts and food resources, risk of predation, and energetic costs (Kunz 1982).

Bats commonly change roosts as a result of temporal changes or energetic requirements. For example, bats that hibernate in caves in winter find alternate and warmer roosts during maternity seasons. Bats also make use of night roosts, apart from their day roosts, as places to rest during feeding bouts, ingest food, or escape from predation. Bats often leave their night roost to feed or drink one or more times before returning to their day roost. Studies indicate that solitary bats and small colonies of bats frequently return to their day roost at night, rather than selecting an alternate roost (Kunz 1982).

During summer, bats often change day roosts, or use more than one roost depending upon environmental factors such as disturbance or permanency of a roost site

(Kunz 1982). In a review of roost fidelity, Lewis (1995) found that fidelity is related to the type of roost occupied. High roost fidelity is directly related to roost permanency and inversely related to roost availability. Species that are faithful to a particular site roost in permanent structures such as buildings, caves, and rock crevices, and those that exhibit roost-switching frequently use ephemeral and abundant sites such as foliage, tree trunks, under exfoliating bark, and tree cavities.

The growth of human populations and resulting urban and suburban sprawl have caused declines in diversity and abundance of natural roosting and foraging habitats for bats (Pierson 1998). For some opportunistic species, however, an increase in anthropogenic structures has led to increased abundance and variety of permanent roosting sites. *Eptesicus fuscus* and *Myotis lucifugus*, for example, have adapted so well to man-made structures, they are rarely found in natural sites (Barbour and Davis 1969, Kunz 1982, Alteringham 1996). In fact, Findley (1993) suggests population increases in *Myotis lucifugus* in North America may be attributed to an increase in anthropogenic roosting sites.

Anecdotal records and published studies verify that bats use bridges and culverts as roosts in North America (Eads et al. 1957, Wilson 1960, Constantine 1961, Davis et al. 1962, Davis and Cockrum 1963, Kunz 1982, Hermanson and Wilkins 1986, Fraze 1989, Fraze and Wilkins 1990, Humphrey and Gore 1992, Davis and Schmidley 1994, Fenton et al. 1994, Lewis 1994, Theis 1994, Perlmeter 1995, Whitaker 1995, Perlmeter 1996, Walker et al. 1996, Horner and Maxey 1998, Pierson 1998, Lance et al. 2001). A well known example is the Congress Avenue Bridge in Austin, Texas that is used by more than a million Mexican Free-Tailed Bats (*Tadarida brasiliensis*). Few studies (see Davis and Cockrum 1963, Keely 1997, Lance et al. 2001) however, describe the types of bridges and culverts selected by bats as daytime summer roosts in a particular region.

In a study describing 20 occupied bridges in Arizona, Davis and Cockrum (1963) found three bridge types used by seven species as day roosts. Five species (*Antrozous pallidus*, *Eptesicus fuscus*, *Myotis subflavus*, *Myotis velifer*, and *T. brasiliensis*) used expansion joints of bridges classified as "open expansion joint bridges" as maternity, summer male, and transient roosts. Three species (*Macrotis californicus*, *Myotis yumanensis*, and *Myotis velifer*) used bridges classified as "open end bridges" as maternity colony roosts. The bats used "cavelike chambers" located within the terminal foundations of the bridges. Three species (*A. pallidus*, *E. fuscus*, and *T. brasiliensis*) used openings in wooden railroad bridges as maternity and spring-and-fall-transient sites. The openings were between longitudinal supports separated 1-2 inches apart. Although all occupied highway structures were concrete, and all occupied railroad bridges were wooden, Davis and Cockrum determined that bridge design, rather than construction material, was the critical factor in roost selection by bats.

Keely (1997) designed the Texas Bats and Bridges project to identify roosting preferences of bats in bridges and culverts in Texas. He found 12 species of bats using 23 bridges and 18 culverts as maternity colony sites and migratory stopovers throughout the state. Bats roosted within crevices 0.75-1 inch in length, and 12 inches deep between slabs of concrete bridges. His findings show that bats preferred the largest concrete bridges and culverts in the state, bridges made of diaphragmed or prestressed concrete girders, and structures that lacked vegetation beneath. Keely, too, concluded that bridge design was an important criterion in roost choice. Although rare in the state, bats preferred bridges classified as "box-beam" over other bridge designs.

As human populations continue to expand and natural roosting sites decline, highway structures may become increasingly more important as roosting sites for maternity colonies, male and non-reproductive females, and perhaps, for transient and hibernating colonies.

Documentation of bridge use and analysis of bridges used by bats as day roosts is an important and necessary step in understanding roosting requirements, and ultimate conservation of bats, particularly those species that are rare or in decline.

Clark (pers. comm.) has conducted considerable research on *Corynorhinus rafinesquii*, considered rare, in the Carolinas and Virginia. In recent years, her work on the roosting habits of *C. rafinesquii* has confirmed their use of bridges as day roosts in North Carolina. My study is an extension of that work, and was designed to identify bridges used by *C. rafinesquii*, and peripherally, by other bat species in the North Carolina Coastal Plain.

I tested the following hypothesis:

$H_1$: Structural design of bridges and culverts is significantly associated with day roosting.

The hypothesis for my study was generated from observations made by Davis and Cockrum (1963) and Keely (1997), who found associations between day roosting and bridge design. Prior to this study, no published studies documented bridge use by *C. rafinesquii*. Also, bridge structures vary among geographic regions and bat species have varying roosting requirements, so I made no predictions about which bridges and/or culverts were suitable for day roosting. Specific objectives of the study were (1) to document daytime bridge use by *C. rafinesquii* and other species in the North Carolina Coastal Plain, and (2) to describe structural design of bridges used by bats as day roosts.

## Species

*Corynorhinus rafinesquii*

*C. rafinesquii*, formerly *Plecotus rafinesquii* (Jones 1977), is commonly known as Rafinesque's Big-Eared Bat. It is considered a medium-sized bat with large ears more than 2 cm in length. The dorsal fur is grayish-brown and bi-colored with light tips and dark bases; the ventral fur is white (Barbour and Davis 1969). The average length of an adult bat is 8-11 cm. and the average weight is 7.9–9.5 g for males and 7.9 – 13.6 g for females. Females tend to be heavier in spring and autumn, but lose weight during maternity season (Jones 1977).

*C. rafinesquii* is divided into two subspecies: *C. r. rafinesquii*, which inhabits the mountains of North Carolina, Kentucky, Tennessee, parts of Indiana, and Arkansas, and *C. r. macrotis*, which is found in the southeastern United States in southern Virginia south to Florida, and west to Louisiana and western Arkansas (Barbour and Davis 1969, Jones 1977). In North Carolina, the range of *C. rafinesquii* is restricted to the Mountains and the Coastal Plain. No localities from the central Piedmont have been recorded (Clark 1990).

Throughout its range in the Southeast, *C. rafinesquii* is found in most forest types (Barbour and Davis 1969, Jones 1977). In the Coastal Plain of North Carolina, however, *C. rafinesquii* is most commonly found in bottomland swamp habitats (Clark 1990).

*C. rafinesquii* are moth specialists (Clark 1991, Ellis 1993, Hurst 1997, Hurst and Lacki 1997), and tend to forage within 1.5 km of their day roosts (Clark 1990, Hurst 1997, Hurst and Lacki 1997).

Little is known about the ecology of the species, and it is considered rare throughout its range. The U.S. Fish and Wildlife service designated *C. rafinesquii* as a candidate species (C2) for listing as either threatened or endangered until 1996 when C1 and C2 designations were abolished (USFWS 1989). Currently, the species is labeled "Species at Risk" (USGS-BRD).

*C. rafinesquii* tends to select roosts that are partially lighted (Barbour and Davis 1969, Jones 1977) and close to water (Clark 1990, Belwood 1992). Common roosting sites are man-made structures such as abandoned buildings (Jones 1977, Webster et al. 1985, Clark 1990, Belwood 1992, Horner and Maxey 1998), mines (Barbour and Davis 1969, Clark 1990), and unoccupied trailers (L. Finn, Fly By Night, pers. comm.).

Highway structures are also frequently used by *C. rafinesquii*. They have been observed under bridges in North Carolina (North Carolina State Museum of Natural Science records), Florida (Jeff Gore, pers. comm.), Kentucky (J. Macgregor, USFS, pers. comm.), and Louisiana (Lance et al. 2001), and in culverts in Indiana (Wilson 1960) and Texas (Theis 1994, Horner and Maxey 1998).

Natural roosts used by *C. rafinesquii* include hollows of trees (Barbour and Davis 1969, Jones 1977, Webster et al. 1985, Clark 1990), loose bark of trees (Webster et al. 1985), and caves (Webster 1985, Belwood 1992, Hurst 1997, Hurst and Lacki 1997).

A solitary bat in North Carolina was found using the cavity of an American Sycamore (*Plantanus occidentalis*) as a day roost during the summers of 1989-1990

(Clark, 1990). In Francis Beidler Forest in South Carolina, Clark (unpublished data) found solitary and maternity colonies of *C. rafinesquii* in gum trees (33 *Nyssa aquatica*, and 2 *N. biflora*).

Hurst et al. (1997) monitored four summer roosting sites in Daniel Boone National Forest and Robinson Forest in southeastern Kentucky. The bats occupied three sandstone caves and one sandstone rock shelter in upland oak-hickory forests.

Few published studies describe reproduction and maternity colony habits of *C. rafinesquii*. Copulation is believed to take place in autumn or winter, and maternity colonies, varying in size from a few individuals to 100 or more, begin to form in spring. During nursery season, males are not typically found in maternity colonies, but instead roost as individuals. Females deliver a single pup in late May or early June (Barbour and Davis 1969, Jones 1977). The gestation period for *C. rafinesquii* remains in question, although Trail (Clark 1990) observed copulation between captive adults in February 1990, followed by birth of a stillborn pup in May 1990. Young remain with the adult female for approximately three weeks after birth, at which time they are capable of limited flight. At one month, pups approach adult weight and are capable of sustained flight for foraging (Barbour and Davis 1969, Jones 1977). Males begin breeding in the second year after birth (Jones and Suttkus 1975).

When a colony of bats chooses a roost location, they may cluster or change roosting sites within a specific location depending upon ambient air temperatures and time of year (Jones 1977). Hurst (1997) found that bats roosted in different parts of a cave during summer and winter months. Temperatures were warmer and more stable within the cave for maternity roost sites.

*C. rafinesquii* is a hibernating species (Jones 1977), but they maintain some level of activity throughout winter (Barbour and Davis 1969, Jones 1977, Hurst 1997). Hibernating individuals have been located in caves (Barbour and Davis 1969, Jones 1977), mines (Pearson 1962), culverts (Wilson 1960), and an open cistern in Tennessee (Hoffmeister and Goodpaster 1962).

*C. rafinesquii* has been observed roosting with *Pipistrellus subflavus*, *M. austroriparius* (Jones 1977, Belwood 1992), *E. fuscus* (Jones 1977, Hurst 1997), *Myotis septentrionalis* (Hurst 1997), *M. grisescens*, *M. leibii*, *M. keenii*, *M. lucifugus*, and *M. sodalis* (Jones 1977).

*Myotis austroriparius*

*Myotis austroriparius*, commonly known as the Southeastern Myotis or Southeastern Brown Bat, is a medium-sized bat with wooly fur that is gray to bright orange-brown above, and tan to whitish underneath (Barbour and Davis 1969, Jones and Manning 1989). Females tend to be brighter than males. The average length of an adult bat is 8-9 cm, and the average weight is 5-7 g (Davis and Schmidley 1994).

The distribution of *M. austroriparius* ranges from southeastern Oklahoma and eastern Texas, west to North Carolina and south to middle Florida. The northern range includes parts of Illinois and Indiana (Barbour and Davis 1969). Recent studies by Clark (unpublished data) and Hobson (1998) indicate *M. austroriparius* inhabits coastal North Carolina and southeastern Virginia, respectively.

Prior to 1996, The U.S. Fish and Wildlife Service designated *M. austroriparius* as a candidate species (C2) for listing as either threatened or endangered (USFWS 1989).

Categories 1 and 2 were abolished in 1996, and the species in now considered a "Species at Risk" by the USGS-BRD.

*M. austroriparius* roosts in caves (Rice 1957, Jones and Manning 1989, Humphrey and Gore 1992, Gore and Hovis 1998), hollow trees ( Jones and Manning 1989, Humphrey and Gore 1992, Davis and Schmidley 1994), buildings (Sherman 1930, Rice 1957, Jones and Manning 1989, Humphrey and Gore 1992, Davis and Schmidley 1994), attics (Rice 1957, Davis and Schmidley 1994), mine shafts (Rice 1957), bridges (Hermanson and Wilkins 1986, Davis and Schmidley 1994), culverts (Humphrey and Gore 1992, Davis and Schmidley 1994, Walker et al. 1996, Homer and Maxey 1998), and drain pipes (Davis and Schmidley 1994). Roosts are usually associated with water (Rice 1957, Barbour and Davis 1969, Jones and Manning 1989, Davis and Schmidley 1994).

Most of what is known about maternity colony habits is found in Rice (1957) and Gore and Hovis (1998). Sherman (1930) describes a detailed account of parturition. Copulation is believed to occur in autumn, but in spring for populations in the Florida peninsula (Rice 1957). Maternity colonies begin to form in late March and early April, and parturition occurs from late April through May in Florida (Sherman 1930, Rice 1957, Barbour and Davis 1969, Jones and Manning 1989). Clark (unpublished data), while surveying the Roanoke River bottomlands in North Carolina, found 3 pregnant females on 14 May 1996 and on 9-10 June 1997. Maternity colonies may consist of several thousand adults (Rice 1957, Gore and Hovis 1998), and are comprised mostly of reproductive females. Most males and non-reproductive females roost separately from maternity colonies in buildings and bridges or other exposed roosts (Rice 1957, Hermanson and Wilkins 1986). Adult females give birth to twins (Sherman 1930, Rice

1957, Barbour and Davis 1969, Jones and Manning, 1989), which is unique among *Myotis* species in North America (Rice 1957). Foster et al. (1978) and Hermanson and Wilkins (1986) describe a high mortality rate among neonates. This mortality rate may be attributed to the fact that females produce altricial young and because maternity roosts are located where retrieval of a pup is limited (i.e. roosts over water, in chimneys of buildings, etc., Hermanson and Wilkins 1986). Pups are volant at approximately 5-6 weeks after birth, and young are sexually mature within one year of birth (Rice 1957). Young often roost separately from adults (Sherman 1930).

These bats feed on small beetles, moths, mosquitoes, and other aquatic insects (Humphrey and Gore 1992). Adults emerge from day roosts to forage late in the evening, but do not carry young with them (Rice 1957).

*Myotis austroriparius* hibernate in caves (where available) except in southern Florida where cave temperatures are too high during hibernation periods. In these areas, bats leave caves and hibernate in small numbers in outdoor sites (Barbour and Davis 1969), or remain active except during particularly cold spells (Rice 1957).

*M. austroriparius* has been observed sharing roosts with *Tadarida brasiliensis* (Sherman 1937, Hermanson and Wilkins 1986), *Myotis grisescens*, *Myotis lucifugus*, *Myotis Keenii*, *Pipistrellus subflavus*, *Eptesicus fuscus* (Whitaker and Winter 1977), and *Corynorhinus rafinesquii* (Jones and Suttkus 1975).

Predators of the species include rat snakes (*Elaphe obsoleta*), corn snakes (*Elaphe guttata*), opossums (*Didelphis marsupialis*), and several owl species (Rice 1957). Roaches (*Periplaneta* sp.) prey upon young bats (Rice 1957, Hermanson and Wilkins 1986), as do mites and beetles (Hermanson and Wilkins 1986).

*Pipistrellus subflavus*

*P. subflavus*, commonly known as the Eastern Pipistrelle, is a small bat with small ears 12-14 mm in length. The dorsal fur varies from yellowish-orange to dark reddish-brown. The dorsal fur is tri-colored, with light midsections and dark bases and tips (Barbour and Davis 1969, Fujita and Kunz 1984). The average length of an adult ranges from 7.7 cm – 8.9 cm, and the average weight is 7.5 g for males and 7.9 g for females. Females tend to be lighter during hibernation periods (Fujita and Kunz 1984).

*P. subflavus* is common throughout eastern North America and parts of the Midwest. The species tends to forage along waterways and forest edges, rather than open fields and deep woods (Barbour and Davis 1969, Fujita and Kunz 1984). They are insectivorous, feed primarily on moths and other small insects, and are one of the earliest bats to emerge at night (Fujita and Kunz 1984).

Copulation takes place in autumn and late spring, though Jones and Suttkus (1973) observed copulating *P. subflavus* on 25 January 1957 and on 1 February 1970. They propose that copulation occurs sporadically throughout the winter. Females give birth to two pups (twins) in late May – early June, depending upon location. Pups are born hairless and are volant at approximately three weeks of age. At one month, the young are capable of sustained flight and foraging (Barbour and Davis 1969, Fujita and Kunz 1984).

As with *C. rafinesquii*, *P. subflavus* often select summer roosts that are partially lighted (Fujita and Kunz 1984), though Jones and Suttkus (1973) observed bats roosting in dark ammunition-storage bunkers. *P. subflavus* often choose to roost as individuals, but commonly form small maternity colonies in spring. Males and females typically roost separately during maternity season, but Jones and Suttkus (1973) reported summer roosts containing both males and females, with males outnumbering females during the months of April-October.

Summer roosts for *P. subflavus* include buildings, such as old houses and barns (Wimsatt 1945, Davis and Mumford 1962, Barbour and Davis 1969, Jones and Suttkus 1973, Fujita and Kunz 1984, Winchell and Kunz 1996, Whitaker 1998), foliage of trees (Findley 1954, Davis and Mumford 1962), tree hollows (Davis and Mumford 1962, Fujita and Kunz 1984), caves, rock crevices (Barbour and Davis 1969, Fujita and Kunz 1984), Spanish moss (Davis and Mumford 1962), and bridges (NC State Museum of Natural Sciences records).

Whitaker (1998) monitored several summer colonies of 7-29 adult *P. subflavus* in Indiana. Maternity colonies began to form in mid-late April and parturition occurred from 30 May – 11 July. Adults left the colony after pups were weaned, but young bats remained after adults departed. Whitaker observed that throughout the summer, colony sizes varied, and bats sometimes left the buildings and then returned. He suggests this is evidence the bats were using more than one roost.

Winchell and Kunz (1996) monitored a large maternity colony roosting in a barn in Massachusetts. The bats changed roosts within the barn depending on time of day and season.

Winter hibernacula, which are usually different from summer maternity sites, include caves, mines, and buildings (Davis 1966, Fujita and Kunz 1984, Winchell and Kunz 1996). Davis (1966) and Jones and Suttkus (1973) monitored hibernating male and female *P. subflavus* in caves and storage bunkers, respectively. Davis found that in winter months, males outnumbered females, but Jones and Suttkus observed females outnumbered males within winter hibernacula. *P. subflavus* are often found singularly or in small clusters in hibernacula with *C. rafinesquii*, *Eptesicus fuscus*, and several *Myotis* species (Fujita and Kunz 1984).

## Study Area

My study was conducted in 25 counties (Fig. 1) of the North Carolina Coastal Plain, which consists of two parts: the outer Coastal Plain or tidewater area, and the inner Coastal Plain, which is not directly affected by ocean dynamics (Orr and Stuart 2000).

The Coastal Plain is the warmest part of the state, and is classified as "humid subtropical" with hot, humid summers, and cold, mild winters (Clay et al. 1975). The average annual temperature ranges between 60°-62°F, except for southern parts of Brunswick and New Hanover counties, and eastern parts of Pamlico, Carteret, and Hyde counties where temperatures average higher than 62°F (Orr and Stuart 2000). The average annual precipitation ranges between 46 and 54 inches for most counties in the Coastal Plain, but parts of southeastern counties receive 54-58 inches. Average annual snowfall for northern and central counties is between 4-6 inches, and for most southern counties is 4 inches or below (Orr and Stuart 2000).

The Coastal Plain is affected annually by tropical storms and hurricanes, where sustained winds reach 76 mph or higher. Since September 1989, North Carolina has seen 9 landfall hurricanes including Hugo (1989), Beryl (1994), Allison (1995), Arthur, Bertha, and Fran (1996), Bonnie (1998), Dennis (1999), and Floyd (1999), which was the most destructive hurricane in North Carolina's history.

Most of the Coastal Plain is considered rural, but populations vary among counties, and are influenced by urban centers (Jacksonville and Wilmington), amenities such as beaches and Intracoastal waterways, and the presence of colleges (New Hanover County), and military installations (Craven and Onslow counties, Orr and Stuart 2000). Predictions by state demographers indicate that the populations of most counties in the study area will increase 1%–48% by 2020 (North Carolina Office of State Planning).

One interstate highway (I-40) carries traffic between the coast and central North Carolina. Only four counties in the Coastal Plain (Sampson, Duplin, Pender, and New Hanover) contain land area within 15 miles of the interstate (Orr and Stuart 2000).

Much of the Coastal Plain is agricultural and contains cropland for tobacco, sweet potatoes, cucumbers, peanuts, cotton, Christmas trees, and greenhouse/nursery products. Livestock production is also an important industry in the Coastal Plain, and includes facilities for swine, poultry, and cattle.

Forests cover ~52% of the area, the majority of which are privately owned. There are two major types of swamp forests that occur in the Coastal Plain along rivers and streams: cypress-gum swamps and hardwood swamp forests or bottomland hardwood forests. Cypress-gum swamps are dominated by blackgum (*Nyssa biflora*) and cypress (*Taxodium distichum*). The understory may be comprised of Carolina ash (*Fraxinus caroliniana)* and red maple (*Acer rubrum*), but is usually poorly developed (Schafale and Weakley 1990). These forests occur in wetter areas of the state including back swamps and floodplains of blackwater rivers (Orr and Stuart 2000).

Hardwood forests are dominated by willow oak (*Quercus phellos*), water oak (*Q. nigra*), Cherry bark oak (*Q. rubra*), sweetgum (*Liquidambar styraciflua*), ash (*Fraxinus* sp.), sycamore (*Platanus occidentalis*), riverbirch (*Betula nigra*), and elm (*Ulmus* sp.), and are usually found in higher parts of the floodplain (Schafale and Weakley 1990, Orr and Stuart 2000).

Pocosins are found in several eastern counties, and consist of a dense evergreen shrub layer and widely scattered pond pine (*Pinus serotina*), swamp bay persea (*Persea palustris*), and loblolly sweetbay (*Magnolia virginiana*). The shrub layer is typically less than 1.5 m tall, and is dominated by Lyonia (*Lyonia lucida*), swamp cyrilla (*Cyrilla racemiflora*), and Zenobia (*Zenobia pulverulenta*) (Schafale and Weakley 1990).

Longleaf pine (*P. palustris*) forests are found in the southern half of the Coastal Plain (principally the sand hills region). Upland areas of the inner Coastal Plain contain loblolly pine-mixed hardwood stands that resulted from logging and abandoned agricultural fields. The remaining forests in the area are pine plantations consisting primarily of loblolly pine (*P. taeda*, Orr and Stuart 2000).

Vegetation in the outer Coastal Plain is affected by coastal development and ocean dynamics (i.e., ocean tides, winds, and salt spray). Salt marshes, strongly dominated by *Spartina alterniflora* (Schafale and Weakley 1990), form in flooded areas with brackish water (e.g., behind barrier islands or edges of sounds and estuaries). These marshes range throughout the coastal part of the state, but particularly southern and middle parts of the coast (Schafale and Weakley 1990).

Trees are a valuable resource in coastal North Carolina and are harvested for lumber, furniture, and paper. In recent years, North Carolina has seen a dramatic increase in timber harvest and loss of forested land, due to an increase in population (and thus the need for more houses, schools, etc.), and a decrease in timber harvest in federally owned land, primarily in the western region of the U.S. (Orr and Stuart 2000).

## Bridge and Culvert Design Classifications

The two classes of roadway structures surveyed during the study were bridges and culverts. Bridges were sub-classified according to design and material of bridge decks, which consists of the floor and girders (horizontal beams used to support the bridge). Other structural elements of bridges, including abutments (ground-end supports that span the width of the bridge), piers (vertical supports), and diaphragms (horizontal supporting structures perpendicular to girders [Brown 1993]), were not considered in the classification of bridge types. I classified bridges as one of six structure types: slab, steel multi-beam, timber multi-beam, I-beam, T-beam, or channel beam.

Culverts are used in place of bridges to convey surface water through an artificial barrier, such as an embankment for a highway, street, railway, dam or levee. They differ from bridges, in that the top of the culvert does not serve as a roadway surface (American Iron and Steel Institute 1983). Culverts were characterized according to design and material of the structural components, and classified as either steel pipe or concrete box.

### Slab Bridges

The solid slab bridge is the simplest form of concrete deck (Cusens and Pama 1975). The deck may consist of a single, solid slab of concrete, with uniform thickness.

a slab with a series of parallel expansion joints measuring <0.25-1 inch in width. The nber of expansion joints varies with the width of the bridge, but typically numbers ween 8 and 10. The bridge may consist of one slab or a series of slabs joined together, pending upon the length of the bridge. Slab bridges have concrete abutments and ncrete piers (Fig. 2).

eel Multi-Beam Bridges

Steel multi-beam bridges have composite decks with concrete floors and steel ders. The bridges encountered in my study were typically constructed with concrete ors, but wooden plank and steel floors were not uncommon. The depth of the steel ders is uniform for each structure and is typically 1 foot, but may measure 2 or 3 feet. e distance between girders varies widely, but is frequently between 1.5 and 3 feet. hese bridges are fitted with concrete diaphragms where the slabs of the deck are joined. eel multi-beam bridges have concrete or timber abutments, and concrete or steel piers ig. 3).

mber Multi-Beam Bridges

The deck of a timber multi-beam bridge is composite with timber girders and a imber floor. The floor may be simple wooden plank, or wood lined with a fibrous naterial attached with wire mesh. The girders are uniform in depth for each structure and nong structures, particularly among the wire-mesh bridges. The depth of these girders s 1 foot, and the beams are spaced approximately 1 foot apart. The girders of the ooden plank bridges tend to be placed closer together, approximately 6-10 inches apart.

was frequently measured at 12-18 foot intervals. This arrangement of girders and intersecting diaphragms created large, rectangular chambers under the bridge (Fig. 5).

Occasionally, the floor of a concrete I-beam bridge was fitted with a corrugated, metal lining. On many of these bridges, the end diaphragms were placed approximately 8-12 inches from the parallel abutment, creating a concrete chamber that spanned the width of the bridge. I-beam bridges have concrete abutments and piers.

## T-Beam Bridges

The deck of a T-beam bridge is a continuous structure (i.e., the beams are not separate from the floor) consisting of a concrete floor and parallel concrete beams which are uniform in width (Hambley 1976). The number of beams varies with bridge width, but typically ranges between 4 and 8. The distance between the beams typically varies between 18 inches and 7 feet, and the depth of the beams ranges between 1 and 3.5 feet. Typically, both the distance between beams and depth of beams is uniform for each bridge, but the outermost girders are, occasionally, shallower than and closer to interior girders. Most T-beam bridges have concrete abutments and piers (Fig. 6).

## Channel Beam Bridges

Channel beam decks are similar to T-beam decks in that they consist of continuous concrete floors and concrete beams. The difference lies (for the purpose of my study) in the dimensions and spacing of the beams. The depth of the beams is 12 inches, and is consistent for all channel beam bridges. The thickness of the beams is ~4 inches, and the distance between the beams alternates between 22 inches and 4 inches.

creating "channels" under the bridge. These channels run the length of the bridge, but may be interrupted by vertical supporting walls, depending upon the length of the bridge. Channel beam bridges may have concrete or timber abutments and piers (Fig. 7).

### Steel Pipe Culverts

Steel pipe culverts are designed as a series of corrugated steel pipes or barrels, placed at equal intervals along the length of an embankment. The length of each pipe varies according to the width of the roadway it carries, but is usually less than 200 feet (AISI 1983). The number of barrels used in culvert construction varies with pipe diameter and length of embankment. For this study, the span of each culvert varied between 1 and 5 pipes. The size and shape of each pipe also varied throughout the study, but most pipes were round 8-12 foot-diameter corrugated metal (Fig. 8).

### Concrete Box Culverts

Box culverts are designed with flat tops and vertical sides that span an embankment or other artificial barrier encountered by a stream. A concrete box culvert may be divided into 2 or more sections by vertical, concrete walls. The number of sections is different for each culvert, and varies with the length of the embankment. Most concrete box culverts surveyed were designed with 1-6 sections (Fig. 9).

## Methods

### Bridge Selection

I conducted bridge and culvert surveys during summer months (late May through early August) because most bat species form maternity colonies during this time of year in North Carolina. I surveyed 442 bridges and culverts (29 May - 8 August) in 8 counties during the 1997 field season, and 548 bridges and culverts (8 June - 5 August) in 17 counties during the 1998 field season.

For the initial field season (1997), I chose structures in Bertie, Chowan, Gates, Hertford, and Martin counties in the northern Coastal Plain, and Bladen, Pender and Sampson counties in the south. I chose to survey these counties because previous research on *C. rafinesquii* and *M. austroriparius* was conducted by Clark (North Carolina State Museum of Natural Sciences) in these areas of the state, and localities for *C. rafinesquii* are well documented in these counties.

I classified each bridge and culvert according to structure type based on structure information obtained from the North Carolina Department of Transportation (NCDOT) Bridge Maintenance Facility. The structures were classified as multi-beam/girder, slab, channel beam, T-beam, or culvert. I combined all of the bridges and culverts from each county in the study area and chose a random sample of each structure type.

Some structure types occurred in the study area more frequently than others. For example, multi-beam bridges and culverts were numerous (75% of all structures in the study area), while channel beam and T-beam bridges were rare (11% of all bridges in the study area). During the initial field season, I wanted to survey approximately the same number of bridges of each bridge type. Therefore, I surveyed a higher percentage of the number of rare bridges in the study area, but only a fraction of the number of the common bridges. When I was unable to survey a bridge because it was inaccessible (e.g. a bridge was being repaired), I chose an additional bridge from the appropriate group at random.

During the final field season (1998), I chose structures in Beaufort, Brunswick, Carteret, Columbus, Craven, Dare, Duplin, Hyde, Jones, New Hanover, Northampton, Onslow, Pamlico, Pasquotank, Perquimans, Tyrrell, and Washington counties of the North Carolina Coastal Plain. I chose these counties because they were adjacent to counties with *C. rafinesquii* localities, or contained suitable roosting habitat for the species. Again, I classified the structures according to structure type. However, the 1997 structure classifications designated by NCDOT did not sufficiently characterize each of the bridge structure types for my study. The underside of the multi-beam bridges and interiors of culverts were so different from one another, that I re-classified them according to material type. The structure types were finally designated as slab, concrete I-beam, steel multi-beam, timber multi-beam, channel beam, T-beam, concrete box culvert, and steel pipe culvert. As was the case in 1997, some structure types were more common than other types. Slab bridges, steel and timber multi-beam bridges, and culverts were common (85% of structures in the study area); and concrete I-beam, T-beam, and channel beam bridges were rare (15% of structures in the study area). I grouped all slab, steel multi-beam, and timber multi-beam bridges and culverts from each county and selected a random sample of each structure type for survey. I chose to sample most I-beam, T-beam, and channel beam bridges due to a paucity of these structure types in the study area, and because of the success in locating bats or guano under these structures in 1997.

Data Collection at each Bridge or Culvert

I located bridges and culverts using county bridge maps obtained from NCDOT. Upon locating a bridge or culvert, I examined it for the presence (bats or bat guano) or absence of bats. The bats typically roost under the bridge, so I checked the underside and expansion joints of each bridge and the interior of each culvert. Most of the bridges occurred in rural areas and were sometimes small and low to the ground, which made the environment under the bridge dark and difficult to view without the aid of artificial light. I used a 1,000,000-candlepower *Q-Beam* spotlight powered by a camcorder battery to view potential roosting habitats. Most of the bridges intersected bodies of water that were too deep to wade through; I used a 9-foot *Sevylor* inflatable raft to access these bridges.

When I located a bat under a bridge or inside a culvert, I documented the species, number of bats present, and colony type (solitary bat, maternity colony, multi-species colony, or group of adult bats only). For each colony present, I estimated the number of adult bats and documented whether pups were present. I also made note of the material (concrete, timber) and texture of the roost location. I measured the height of the roost above the ground and identified the substrate underneath the roost and location of the roost under the bridge.

Bat guano is easily recognizable, particularly on concrete where the dark guano contrasts with the light-colored concrete. If I located guano in several areas under a bridge, or a large area of guano on or beneath the bridge, I recorded the amount and location of the guano, and classified the structure as "occupied" by bats.

I recorded the structure type and material type for each bridge and culvert surveyed. Material type characterized the construction material of the girders and underside of deck for bridges and interior for culverts. A bridge classified as steel multi-beam may have had steel girders with a steel deck, steel girders with a concrete deck, or steel girders with a timber-plank deck. A timber multi-beam bridge may have had timber girders and a wire-mesh deck, or timber girders and a timber-plank deck. Concrete I-beam bridges typically had concrete decks, but occasionally were fitted with corrugated metal.

I took measurements of each of the structures: distance between girders, depth of the girders, depth of expansion joints, and height of the bridge deck above the substrate at its highest point. The width and length for each bridge and length of each culvert were obtained from the NCDOT bridge maintenance database. I measured the width of each culvert on site.

I classified the substrate under each bridge and culvert as water, mud, vegetation, or concrete. When more than one substrate type was found directly beneath structures, I estimated the percentage of each.

In an effort to quantify the degree of disturbance underneath the bridge, I rated each bridge from 0-3, where 0 represented no evidence of human disturbance, and 3 represented a high level of disturbance. I rated bridges with low levels of trash, tracks, or graffiti with a 1 (low level of disturbance). Bridges showing evidence of previous fires or human habitation under the bridge were labeled 2 (moderate level of disturbance). The highest degree of disturbance, that is a highway or other major road or railway, were labeled 3.

I obtained other bridge variables from the NCDOT bridge maintenance database: average daily traffic figures (ADT), to quantify the degree of disturbance carried by bridge, date the bridge was built or rebuilt to quantify the age of the bridge, date of last inspection and inspection rotation for each bridge, and latitude and longitude coordinates.

I also noted the habitat type of the general area surrounding each bridge. Many of the bridges surveyed occurred in swamp or bottomland hardwood forest habitats, but I also surveyed bridges found in other habitats. These included pine plantation, rural industrial, residential, agricultural, pocosin, or marsh. The macrohabitat of each bridge or culvert was classified as one of the above habitats. Any bridge that did not fall into one of the above categories was labeled as "other."

## Statistical Analyses

I performed all statistical analyses using SAS (SAS Institute, Inc. 1993). I used logistic regression analyses to determine the effects of various structure characteristics (structure type, disturbance under the structure, average daily traffic carried by the structure, amount of water under the structure, age, length and width of structure) on the probability that a bridge or culvert would be used by bats as a day roost. In order to assess which characteristics were significantly associated with bat roosting, I computed likelihood ratio statistics (type III statistics) for each term in the models.

I excluded type of material with which structures were built as an explanatory variable in models because material type was not independent of structure type. I also excluded habitat type as an explanatory variable in models because the majority of occupied bridges (122 of 135) were found in swamp or bottomland hardwood forest habitats. Average daily traffic figures were transformed logarithmically.

I used the SAS GENMOD procedure (SAS Institute, Inc. 1993) to fit logistic models to 4 sets of data: 1) presence of all bats, 2) presence of *C. rafinesquii*, 3) presence of *P. subflavus*, and 4) presence of guano. I did not perform statistical analyses for *M. austroriparius* data alone because of the small sample size (n=12). In the first data set, I considered all structures that were occupied by a bat or contained guano to be day roosts. For the second data set, I considered only structures occupied by *C. rafinesquii* to be day roosts. Also, because *C. rafinesquii* is most likely found in swamp and bottomland hardwood forests habitats (Clark 1990), I included only structures found in those habitats in data analyses. For the third data set, I considered only structures occupied by *P. subflavus* to be day roosts, and for the fourth data set, I included structures with guano only.

Finally, I used Fisher's Exact tests to determine whether proportions of occupied and unoccupied bridges were significantly different between structure types for each of the data sets.

## Results

I surveyed 990 of 2196 bridges and culverts in 25 counties, and found bats or guano under 135 structures in 21 counties (Table 1). I found bats roosting under 81 bridges and culverts, and guano under 54 bridges. I identified 3 bat species using bridges and culverts as day roosts: 36 by *C. rafinesquii* (44% of observations), 38 by *P. subflavus* (47%), and 12 by *M. austroriparius* (15%). I was unable to identify species for 3 bridges. On 7 occasions, I found 2 or more species using a single bridge, but only once did I observe 2 species occupying the same roost under a single bridge.

I found bats or guano under 7 of 8 structure types surveyed (Table 1). No bats were observed roosting under any of the 161 slab bridges surveyed. A solitary *C. rafinesquii* was found in 1 of 142 steel pipe culverts, and one *M. austroriparius* was found in 1 of 98 concrete box culverts. Only 2 of 141 steel multi-beam bridges were used by bats. I found a solitary *P. subflavus* hanging from a hole in the damaged concrete deck of a steel multi-beam bridge, and a large unidentified colony roosting in the expansion joints of a steel multi-beam bridge. Collectively, slab bridges, steel multi-beam bridges, pipe culverts, and box culverts represent the majority (60.4%) of structures in the study area, as well as the majority (54.7%) of structures surveyed. Timber multi-beam bridges were the most abundant bridges in the study area (22.6%), but only 14 of 157 surveyed were occupied by bats or contained guano. T-beam bridges were the rarest in the state (4.3% of structures in the study area); I located bats under 9 and guano under 6 of 88 surveyed. Concrete I-beams are similar in construction to T-beams, and were only slightly more common in the study area (7.3% of structures). I located bat roosts under 15 and guano under 9 of 90 I-beam bridges. The majority of bridges that contained bat roosts or guano were channel beam bridges; I observed bats under 40 and guano under 38 of 113 surveyed. Interestingly, channel beam bridges were one of the rarest structure types in the study area (5.4% of structures), second only to T-beams. Collectively, T-beam, I-beam and channel beam bridges were the rarest bridges in the study area (17% of structures), but were most frequently used by bats (87% of occupied structures).

Logistic regression analysis indicated an association between roosting and structure type ($\chi^2$=328.36, d.f.=7, P<.0001, n=990) and degree of disturbance under the bridge ($\chi^2$= 7.81, d.f.= 1, p= 0.0052, n=990). I found no association between roosting and average daily traffic ($\chi^2$=3.93, d.f.=1, P= 0.1419, n=990), amount of water under the structure ($\chi^2$= 0.32, d.f.=1, P= 0.5725, n=990), age ($\chi^2$= 1.76, d.f.=1, P= 0.1844, n=990), height ($\chi^2$= 0.06, d.f.=1, P= 0.8109, n=990), length ($\chi^2$= 0.39, d.f.=1, P= 0.5346, n=990), or width ($\chi^2$=0.83, d.f.=1, P= 0.3632, n=990) of the structure. Fisher's Exact tests indicated that bats used channel beam bridges more often than any other structure type (P< 0.0001) and I-beam bridges more often than timber multi-beam bridges (P< 0.0003). There was no statistically significant difference between I-beam and T-beam bridges (P= 0.1478), or between T-beam and timber multi-beam bridges (P= 0.0660, Fig. 11).

*Corynorhinus rafinesquii*

Because *C. rafinesquii* are most often found in swamp and bottomland forest habitats, I included only structures found in those habitats for statistical analyses. I found *C. rafinesquii* under 36 of 679 structures in 12 counties. The majority of bats (81%)

roosted under concrete bridges. I found bats under 6 of 120 timber multi-beam bridges, 13 of 46 I-beam bridges, 6 of 67 T-beam bridges, and 10 of 93 channel beam bridges. All *C. rafinesquii* found under channel beam bridges occupied the larger channels or chambers (width=22 inches) rather than the smaller chambers (width=4 inches). I observed one bat hanging from a mud-dobber nest in a steel pipe culvert (95 surveyed). No *C. rafinesquii* were observed roosting under any of the 105 slab bridges, 87 steel multi-beam bridges, or in 65 box culverts (Table 2, Appendix 1).

The number of adult *C. rafinesquii* found under a bridge ranged from 1 to ~40 individuals. The majority of occupied bridges (25 of 36) had solitary bats. On 5 occasions, I found 2 or more solitary bats under a single bridge. The girders under the bridges created channel or chambers under the bridges, and bats roosted separately in different chambers. Two I-beam bridges had small colonies of *C. rafinesquii*; one housed a small cluster of 3 bats and another a cluster of 9 bats. I located 5 maternity colonies under 2 I-beam bridges, 2 T-beam bridges, and 1 channel beam bridge. The channel beam housed 2 colonies (7 and 8 individuals) in separate channels under the bridge.

On 3 occasions, I observed *C. rafinesquii* and *P. subflavus* roosting under the same bridge. On 2 of these occasions the 2 species occupied separate roosts, and on one occasion they shared the same roost. On 23 June 1998, I discovered a single *P. subflavus* roosting with a colony of *C. rafinesquii* under a channel beam bridge. As I approached the colony, some of the adult *C. rafinesquii* flew to a different chamber under the bridge, exposing the solitary *P. subflavus*. On 2 occasions, I observed solitary *M. austroriparius* and *C. rafinesquii* roosting under the same bridge.

All but one of the occupied bridges were located in swamp or bottomland hardwood forest habitats. I found one *C. rafinesquii* under a timber multi-beam bridge in a pine plantation.

Logistic regression analysis indicated an association between *C. rafinesquii* roosts and structure only ($\chi^2$= 48.56, d.f.= 7, P< 0.0001, n= 679). There was no association between *C. rafinesquii* roosts and degree of disturbance ($\chi^2$=1.24, d.f.=1, P=0.6276, n= 679), average daily traffic ($\chi^2$=3.08, d.f.=1, P=0.0793, n= 679), amount of water under the structure ($\chi^2$=0.04, d.f.=1, P=0.8348, n= 679), age ($\chi^2$=0.46, d.f.=1, P=0.4979, n= 679), height ($\chi^2$=1.3, d.f.=1, P=0.2539, n= 679), length ($\chi^2$=0.36, d.f.=1, P=0.5483, n= 679), or width ($\chi^2$=0.02, d.f.=1, P=0.8818, n= 679) of bridges. Fishers' Exact tests showed that *C. rafinesquii* used I-beam bridges more often channel beam bridges (P=0.0154), T-beam bridges (P= 0.0109), or timber multi-beam bridges (P< .0001). There was no statistical difference between use of channel beam bridges and T-beam bridges (P= 0.7940), between channel beam and timber multi-beam bridges (P= 0.1025), or between T-beam and timber multi-beam bridges (P= 0.2053, Fig. 11).

*Pipistrellus subflavus*

I observed *P. subflavus* roosting under 38 of 990 structures in 12 counties. As with *C. rafinesquii*, the majority of bridges used as day roosts (82%) were concrete bridges. Unlike *C. rafinesquii*, however, most *P. subflavus* (76%) roosted under channel beam bridges. I found 29 of 113 channel beam bridges occupied by *P. subflavus*. Also unlike *C. rafinesquii*, most *P. subflavus* roosted within the smaller chambers (width= 4 inches), rather than the larger chambers (width= 22 inches) of channel beam bridges. I observed *P. subflavus* roosting in the larger chambers on only one occasion. I located *P. subflavus* under 6 of 157 timber multi-beam bridges, 1 of 90 I-beam bridges, and 1 of 141 steel multi-beam bridges. No bats were located under any of the 161 slab bridges, 88 T-beam bridges, 98 box culverts, or 142 pipe culverts (Table 2, Appendix 2).

The number of adult *P. subflavus* found under a bridge ranged from 1 to ~90 individuals. The majority of occupied bridges (22 of 38) had solitary bats. I found 2 or more solitary bats roosting separately under bridges on 7 occasions. I located small clusters or colonies of bats ranging from 2 to 15 individuals under 8 of 29 channel beams, but was unable to determine whether any of these colonies were maternity colonies. On 22 June 1997, I found 2 timber multi-beam bridges in Bladen County (located in proximity to one another) that housed multiple colony roosts. One of these bridges had 2 separate maternity colonies of ~20 adults and their pups, and the other had 5 separate colonies ranging from 10-30 individuals.

I observed *P. subflavus* roosting under the same bridge with *C. rafinesquii* and *M. austroriparius* on 3 and 4 occasions, respectively.

As with *C. rafinesquii*, the logistic regression analysis indicated an association between *P. subflavus* and structure only ($\chi^2$=91.32, d.f.=7, P< 0.0001, n=990). There was no association between *C. rafinesquii* roosts and degree of disturbance ($\chi^2$=0.07, d.f.=1, P=0.7957, n=990), average daily traffic ($\chi^2$=0.73, d.f.=1, P=0 .3914, n=990), amount of water under the structure ($\chi^2$=0.0, d.f.=1, P=0.9960, n=990), age ($\chi^2$=91.32, d.f.=7, P=0.9201, n=990), height ($\chi^2$=91.32, d.f.=7, P=0.1791, n=990), length ($\chi^2$=91.32, d.f.=1, P=0.6218, n=990), or width ($\chi^2$=0.15, d.f.=1, P=0.6956, n=990) of bridges. Fisher's

Exact tests show that *P. subflavus* used channel beam bridges more often than any other structure type (P< 0.0001). There was no statistically significant difference between use of I-beam and T-beam bridges (P= 1.00), between I-beam and timber multi-beam bridges (P=0.4275), or between T-beam and timber multi-beam bridges (P= 0.4268, Fig. 11).

*Myotis austroriparius*

I found *M. austroriparius* under 12 of 990 structures in 9 counties. The majority of bats (83%) roosted under concrete structures. As with *P. subflavus*, the majority of roosts (67%) were located under channel beam bridges. I observed *M. austroriparius* roosting under 8 of 113 channel beam bridges, 2 of 157 timber multi-beam bridges, 1 of 88 T-beam bridges, and 1 of 98 box culverts. No *M. austroriparius* were found under any of the 161 slab bridges, 90 I-beam bridges, 141 steel multi-beam bridges, or 142 pipe culverts (Table 2, Appendix 3).

All but one of the *M. austroriparius* roosts were solitary roosts. On 3 August 1998, I found one channel beam bridge with a colony of 7 adult bats in Jones County. I observed *M. austroriparius* roosting under the same bridge with *C. rafinesquii* and *P. subflavus* 2 and 4 times respectively. All *M. austroriparius* used bridges in swamp or bottomland hardwood forest habitats.

Guano

I found bat guano under 54 bridges, the majority of which (97%) were concrete bridges. I found guano under 38 of 113 channel beam bridges, 9 of 90 I-beam bridges, 6 of 88 T-beam bridges, and 1 of 157 timber multi-beam bridges. No guano was found under any of the 161 slab bridges, 141 steel multi-beam bridges, 142 pipe culverts, or 98 box culverts (Table 2, Appendix 4). Most of the bridges containing guano (93%) occurred in swamp or bottomland hardwood forest habitats. I found guano under 50 bridges in swamp or bottomland hardwood forest habitats, 4 bridges adjacent to agricultural fields, and 1 in pocosin habitat.

Logistic regression analysis indicated an association between presence of guano and structure only ($\chi^2$=159.26, d.f.=7, P< 0.0001, n= 990). There was no association between presence of guano and average daily traffic ($\chi^2$=0.19, d.f.=1, P=0.6602, n= 990), disturbance under the bridge ($\chi^2$=2.33, d.f.=1, P=0.1268, n= 990), amount of water under the bridge ($\chi^2$=0.01, d.f.=1, P=0.9218, n= 990), age ($\chi^2$=3.52, d.f.=1, P=0.0606, n= 990), height ($\chi^2$=0.78, d.f.=1, P=0.3774, n= 990), length ($\chi^2$=1.15, d.f.=1, P=0.2845, n= 990), or width ($\chi^2$=0.03, d.f.=1, P=0.8667, n= 990) of the bridges. Fisher's Exact test indicated that guano occurred more often under channel beam bridges than any other structure type (P<0.0001), under I-beam bridges more often than timber multi-beam bridges (P=0.0006), and under T-beam bridges more often than timber multi-beam bridges (P=0.0095). There was no statistical difference between I-beam bridges and T-beam bridges (P=0.5913, Fig. 11).

## Unidentified Species

In 1997, I located 2 "twin" bridges in Bladen County, which housed large maternity colonies of an unidentified species in the expansion joints of the bridges. One bridge (concrete I-beam) carried the northbound lane of US701, and the other (T-beam) carried the southbound lane. When I approached the bridge, the bats were alert and "chirping." My approach disturbed the colony, and a pup from the colony fell from the roost into the water below. I collected the bat as a voucher specimen of the colony, and for later identification. The following year, Keely (pers. comm.) located another maternity colony in the bridge and identified the species as *Nycticeius humeralis* (Evening Bat).

In 1998, I located a steel multi-beam bridge in Duplin County that contained, within the expansion joints of the concrete deck, a large colony of bats. I was able to hear the bats, but could not identify the species or colony type (Table 2).

# Discussion

The results of this study indicate a strong association between bat roosting and bridge design. Bats used girder bridges more frequently than slab bridges or culverts, and bridges with concrete girders more frequently than bridges with steel or timber girders. These results are similar to those of Lance et al. (2001) who investigated bridge use by bats in the Kisatchie National Forest in west-central Louisiana. They found 100% of *C.*

*rafinesquii* observations under concrete bridges, and 97% under girder bridges. Davis and Cockrum (1963) and Keely (1997) also found associations between bat roosting and bridge design.

No slab bridges and only 1 box culvert surveyed were occupied by bats or contained guano. Slab bridges and box culverts are similar in construction in that they are concrete, and have exposed decks that lack partially enclosed spaces or recesses. These open surfaces leave bats vulnerable to predators and provide little protection from wind or other changes in climate. This may result in an inability for bats to adequately regulate the microclimate of the roost, which is especially important for maternity colonies. Exposure to weather and predators may explain why these structures remained unoccupied by bats during my study. These results are similar to Lance et al. (2001) who found no culverts and only 1 slab bridge occupied by bats.

Pipe culverts are composed of corrugated steel that may provide bats with more protection than box culverts or slab bridges. However, the steel (often dark-colored) absorbs and loses heat quickly, and may not provide bats with the appropriate microclimate for summer day roosting. The surface of the culverts is also relatively smooth (except for nuts and bolts, and sometimes tar) and may not be conducive to roosting. The solitary *C. rafinesquii* I observed in a pipe culvert did not roost directly on steel, but rather on an insect nest inside the culvert.

Unlike slab bridges, box culverts, and pipe culverts, steel multi-beam (girder) bridges had recesses that would protect bats against wind, and provide bats with retreats from predators. The steel girders were often rough due to rust and chipped paint, so bats could have easily roosted on them. Like pipe culverts, steel girders absorb and release heat more quickly than concrete or timber girders, and thus, may provide an unstable microclimate for summer day roosting. I found a large (presumably maternity) colony within several expansion joints of a steel multi-beam bridge with a concrete deck. The steel girders were below the deck and likely had little effect on the microclimate of expansion joints above. The only bat I observed roosting under a steel multi-beam bridge was a solitary *P. subflavus*, which roosted in a cavity within the damaged concrete deck, rather than on a steel girder.

Timber multi-beam was the single-most abundant structure type in the study area and the most frequently surveyed, but was seldom occupied by bats. These bridges had rough timber girders and recesses that would provide bats with a stable microclimate for day roosting and some protection from predators. On one occasion, I observed a solitary *P. subflavus* climb between a girder and the bridge deck of a timber multi-beam bridge to escape my approach. This retreat would have been impossible under any other structure type. Also, timber multi-beam bridges frequently occur in remote areas where there is infrequent disturbance below the bridge and little traffic carried by the bridge. In spite of these (seemingly) ideal roosting conditions, only 9% of surveyed timber multi-beam bridges were occupied. These results are similar to those of Lance et al. (2001) who found no timber bridges occupied by bats. They propose that bats avoided these bridges because the timber used in construction was treated with creosote, an odorous and sticky substance. Kunz (1982) also comments that chemical treatment of wood has led to reduced populations of bat species.

I-beam and T-beam bridges were used by both solitary and maternity colonies of *C. rafinesquii*. Although similar in construction, *C. rafinesquii* used proportionally fewer

T-beam bridges than I-beam bridges. I-beam bridges typically had deeper girders than T-beam bridges that were frequently intersected along the length of the bridges with concrete diaphragms. This arrangement of intersecting girders and diaphragms created deep, rectangular chambers under the bridges, which may have increased protection, and allowed a more stable roosting climate for thermoregulation. This is especially important for maternity colonies, and may explain why *C. rafinesquii* used I-beam bridges more frequently than T-beam bridges. Typically, *C. rafinesquii* does not roost in crevasses or other small spaces, but rather in larger sites (e.g. abandoned buildings, mines, caves, large tree cavities). I-beam bridges may be the most suitable bridges for *C. rafinesquii* because they provide large, cave-like recesses for roosting. Solitary *P. subflavus* were seldom found under I-beam or T-beam bridges, and no *P. subflavus* maternity colonies were observed under these bridges. Rather, the majority of *P. subflavus* were found under channel beam bridges.

Girders of channel beam bridges were shallower and spaced closer together than those of I-beam or T-beam bridges. All *P. subflavus* maternity colonies observed roosted between girders of channel beam bridges and timber multi-beam bridges, with the majority in the smaller recesses of channel beam bridges. This may be an indication that *P. subflavus* (especially maternity colonies) require more confined spaces, available under channel beam or timber multi-beam bridges, for summer day roosting.

Channel beam bridges were also used by *C. rafinesquii* in swamp habitats (though proportionally less than I-beam bridges). I found 2 small maternity roosts and several solitary *C. rafinesquii* under channel beam bridges. All *C. rafinesquii* used the larger recesses under channel beam bridges. Though *C. rafinesquii* may prefer the larger recesses available under I-beam bridges, the wider recesses under channel beam bridges were apparently sufficient for roosting, even for maternity colonies. I suspect that channel beam bridges are more important to *C. rafinesquii* than results of this study suggest, considering the number of channel beam bridges in swamp habitats that contained guano, and the proximity of those bridges to *C. rafinesquii* roosts.

Widespread use of channel beam bridges by *P. subflavus*, *Myotis austroriparius*, and to a lesser degree by *C. rafinesquii*, indicates that channel beam bridges, with girders separated at alternating distances, provide suitable roosting habitats for bats with varying summer roosting preferences.

I was unable to test whether bats preferred one material type to another because material type was not independent of structure type. That is, there were no concrete bridges identical in construction to timber or steel bridges. However, 87% of observations came from concrete structures, which suggests a preference for concrete roosts. These results, and similar observations made by Lance et al. (2001), disagree with Kunz (1982) who states "...bridge designs of steel and concrete... are generally unsuitable for bat roosts." Clark (1990) found solitary *C. rafinesquii* in 2 concrete block houses in North Carolina, but most *C. rafinesquii* records come from old wooden structures. Clark suggests this may reflect sampling bias, rather than a preference by *C. rafinesquii* for wooden structures.

That the vast majority of bridges with guano were concrete girder bridges provides additional evidence that bats prefer concrete to timber or steel bridges, and girder bridges to slab bridges or box culverts. However, the low number of timber bridges that contain guano may reflect observer bias. The dark guano was much easier to see on light-colored concrete than on dark timber or rusty steel girders.

Evidence of guano at bridges may indicate possible roost-switching by bats. Lewis (1995) found that bats that roost in semi-permanent structures (i.e. tree cavities) exhibit roost switching behavior. and Lance et al. (2001) found frequent roost-switching by *C. rafinesquii*. Banded individuals switched roosts among bridges and between bridges and tree cavities. The occurrence of guano under bridges may also be evidence that bats used bridges as night roosts. although Kunz (1982) suggests bats most commonly defecate within the first few hours of returning to day roosts (i.e. early morning). However, the use of bridges as night roosts does not exclude their use as day roosts. Kunz also states that solitary bats and small colonies of bats often return to their day roost at night.

Height of bridges was loosely associated with amount of light affecting roosts. Typically, taller bridges were lighter, provided bridges were not obscured by tall vegetation. Clark (1990) states *C. rafinesquii* are not expected to roost in structures that admit much light, but rather roost in dark tree cavities and abandoned buildings. This preference for low light levels may have been a mechanism for predator avoidance. Contrarily, Barbour and Davis (1969) and Jones (1977) contend that *C. rafinesquii* prefer roosts that are partially lighted. Results from my study support the latter; *C. rafinesquii* selected bridges that were easily accessible and partially lighted. I did not quantify the amount of natural light under bridges, but there was sufficient light to observe and sometimes photograph bats without aid of artificial light.

I found no association between roosting and the amount of water directly beneath bridges. I observed bats roosting under bridges with deep water, patches of water, or no water beneath. I did observe, however, that *C. rafinesquii* and *M. austroriparius* tended to roost towards bridge abutments, particularly when dry bank was adjacent to bridge abutments. Lance et al. (2001) also reported this behavior among *C. rafinesquii*.

My measure of disturbance did not distinguish between intensity and duration of disturbance. I had some difficulty determining the degree of disturbance under bridges because I used the amount of trash, tracks, graffiti, etc. to estimate the degree of disturbance. Studies by Tuttle (1979) and Clark (1990) provide evidence that intensity of disturbance at a roost, especially during maternity season, may be more critical than duration of disturbance. Clark (1990) found that *C. rafinesquii* abandoned roosts after intense vandalism of a site and after periodic visits to roosts by observers during maternity season. Lacki (1998) reported a colony of *C. rafinesquii* abandoned a rock shelter in Kentucky the day a small fire pit was found inside the shelter. My observations support the conclusion made by Clark that *C. rafinesquii* are easily disturbed within partially lighted roosts. Invariably, when I approached solitary or multiple *C. rafinesquii*, the bats relocated to different areas under the bridge, but seldom abandoned bridges. I rarely observed this behavior among *P. subflavus*. Often, I was able to approach the bats and remove them from the bridge for examination.

Although I found no statistical association between degree of disturbance under bridges and *C. rafinesquii*, *P. subflavus*, or guano roosts separately, there was an association between disturbance and bats and guano collectively. The majority of bridges (both occupied and unoccupied) had a disturbance rating of 1 (little evidence of disturbance) or 0 (no evidence of disturbance). I found few bats under bridges rated 2, and no bats under bridges rated 3. The absence of bats under highly disturbed bridges may reflect a lack of mature forests surrounding these bridges. Bridges that were rated with high levels of disturbance were typically found in urban areas where there were few trees and heavy traffic. Often, these bridges were easily accessible and used as recreational areas.

Average daily traffic carried by the bridge was a measure of disturbance above bridge roosts. There was no statistical association between average daily traffic and roosting; however, structure type was not independent of average daily traffic. This is not surprising because larger bridges that carried heavier traffic loads were frequently girder bridges (I-beam, T-beam and steel multi-beam), rather than timber or channel beam bridges. Lance et al. (2001), however, found an association between roosting and type of road carried by bridges. They did not quantify the amount of traffic carried by the bridge, but instead classified roads as either gravel or paved. The probability of a bridge being used as a roost increased when a bridge carried a gravel road.

Although I found no association between roosting and other variables, bats may have chosen bridges, in part, by characteristics not measured in my study. Kunz (1982) suggests major determinants of roost use include roost availability and dimensions, energetic considerations, and risk of predation. Risk of predation was not directly measured in my study, and may have factored into selection of roosts. I found rat snakes in recesses of unoccupied bridges on several occasions.

I also did not quantify the amount of mature forest surrounding bridges, which was likely a contributing factor in roost selection, especially for *C. rafinesquii*. Clark

(1990) found that *C. rafinesquii* generally does not forage more that 1.5 km away from a roost site. A lack of foraging habitat surrounding bridges (i.e. mature forest) may be a major reason why bats were not observed under some bridges. Clark also found that clusters of roosts occupied by *C. rafinesquii* were located adjacent to expanses of closed canopy bottomland forests near river systems. Clark concluded that the primary determinants of roost selection were likely external roost variables (i.e. amount of closed canopy forest, and total area covered by water within a 1.5 km radius of roosts), rather than internal roost variables. Clark found a slightly higher percentage of canopy forest and a higher area covered by water within the 1.5 km radius surrounding occupied roosts than unoccupied roosts. Lance et al. (2001) found an association between roosting and the proportion of mature deciduous forest surrounding bridges. A bridge was 1.03 times more likely to be used as a roost for every percent increase in surrounding mature deciduous forest. I suspect roost choice is a combination of bridge design and the amount and quality of forested habitat surrounding bridges. A lack of mature forest surrounding bridges may explain why no *C. rafinesquii* were found under bridges in disturbed habitats, and why no bats or guano were found under some I-beam, T-beam or channel beam bridges in bottomland hardwood forests. This does not, however, fully explain why so few bats roosted under culverts and slab, steel multi-beam, and timber bridges.

Although I did not investigate roost availability around bridges, absence of bats or guano might also be explained by an abundance of natural roosts (trees) surrounding bridges. Clark (1990) found *C. rafinesquii* regularly used tree cavities when nearby man-made roosts were available, and Lance et al. (2001) observed roost-switching by *C. rafinesquii* between bridges and tree cavities. They banded and monitored 9 individuals;

5 used both tree and bridge roosts, and 4 used bridges only. On average, banded individuals spent most days (63%) in bridge roosts.

Analysis of structure types in the study area indicates that the rarest structures are most suitable for bat roosting. *P. subflavus, M. austroriparius*, and guano were most frequently found under channel beam bridges, which account for less than 7% of bridges in the study area. *C. rafinesquii* also used channel beam bridges, but less frequently than I-beam bridges, also rare in the study area (<10% of structures). I-beam bridges are often used over highway and interstate routes where the intensity of disturbance under bridges is high, and duration is continuous, which may explain why *C. rafinesquii* avoided some I-beam bridges. No bats were found under slab bridges, and few bats were found under steel and timber multi-beam bridges, which collectively account for 78% of bridges in the study area.

Unfortunately, new channel beam bridges will not be built in North Carolina because they are too weak to support the heavy loads of modern-day traffic. Slab bridges and culverts are replacing older channel beam and timber bridges because they are more durable and less expensive to build. Bridge engineers are also phasing-out T-beam bridges because they are too expensive to build. Concrete I-beam bridges will continue to be built, but the bridge decks will be fitted with corrugated metal to reduce construction costs. (D. Idol, pers. comm.).

## Management Recommendations

Efforts must be made to increase the number and availability of day roosts for *C. rafinesquii* and other bat species that may experience population declines due to loss of natural roosting and foraging habitats. Building new bridges and retrofitting pre-existing bridges with structures that are suitable for day roosting are important steps in creating roosting habitat for bats.

Concrete I-beam bridges (frequently used by *C. rafinesquii*) and channel beam bridges (also used by *C. rafinesquii* and other bat species) should be built in place of culverts, concrete slab, steel, or timber bridges when developing in bottomland hardwood forest habitats. Where culverts or "unsuitable" bridges are required, structures that attract bats should be included in bridge designs.

In addition to building new bridges that are suitable as bat roosts, existing bridges should be retrofitted with structures to attract bats. Bat Conservation International (BCI) designed the "Texas Bat-Abode" to attract bats to pre-existing bridges in Texas. These structures are composed of several partitions lined with nylon mesh screens, separated at 0.5-1.25 inch intervals. The partitions are fit between girders of bridges to create roosting crevices for bats. Keely (1997) retrofitted 4 previously unoccup ed bridges with Texas Bat-Abodes, and within 2 months, 2 were occupied.

Results of my study suggest that this design is not appropriate for *C. rafinesquii* because they require larger recesses for roosting. However, alternative structures could be designed and employed to attract bats to unoccupied bridges in North Carolina. These structures should include both large and small recesses, similar to those found under channel beam bridges. Recesses of different sizes would allow species with varying roosting requirements to use these bridges as day roosts. Before a North Carolina "Bat Abode" can be developed and employed, several prototypes must be tested in order to determine optimal recess dimensions and structural material.

Bats are easily disturbed within roosts, and may abandon roosts completely if the duration and intensity of disturbance is high. Disturbance of maternity roosts is especially detrimental to species considered "at risk." Bridges occupied by maternity colonies (or those likely to be occupied) should be avoided during maternity season. Public access to bridges must be restricted during summer months, and regular bridge inspections should be scheduled during winter months to reduce the risk of disturbing maternity colonies. Unfortunately, no data on bridge use by bats during fall and winter months is available. Additional and long-term studies are needed to more fully understand the roosting habits and requirements of *C. rafinesquii* and other bat species in North Carolina.

## Conclusions

1. Solitary and maternity colonies of *C. rafinesquii*, *P. subflavus*, *M. austroriparius*, and *Nycticeius humeralis* used bridges as day roosts in the North Carolina Coastal Plain.

2. Logistic regression analysis indicated that bridge design was significantly associated with summer day roosting.

3. Bats preferred concrete bridges to timber or steel bridges.

4. *C. rafinesquii* used concrete I-beam bridges more frequently than other structure types, while *P. subflavus* and *M. austroriparius* preferred channel beam bridges. Guano was also found more frequently under channel beam bridges than any other structure type.

5. Channel beam bridges, with girders separated at alternating distances, were used by bats with varying summer roosting preferences.

6. Only the rarest bridges in the study area were used regularly by bats as day roosts.

Literature Cited

Alteringham, J.D. 1996. Bats: Biology and Behaviour. Oxford University Press. Oxford. 262 pp.

American Association of State Highway and Transportation Officials. 1973. *Standard Specifications for Highway Bridges*, 11th ed. Washington, D.C.

American Iron and Steel Institute. 1983. Handbook Steel Drainage and Highway Construction Products, 3rd. ed. Washington. D.C.

Barbour, R.W. and W.H. Davis. 1969. Bats of America. University Press of Kentucky. Lexington. 286pp.

Belwood, J. 1992. Southeastern Big-eared Bat. Pages 287-293 *In* S.R. Humphrey. ed. Rare and Endangered Biota of Florida. Volume 1. Mammals. University Press of Florida, Gainesville.

Brigham. R.M., and M.B. Fenton. 1986. The influence of roost closure on the roosting and foraging behaviour of Eptesicus fuscus (Chiroptera: Vespertilionidae). *Canadian Journal of Zoology*. 64:1128-1133.

Brown, D.J. 1993. *Bridges*. Macmillan Publishing Company, New York. 176pp.

Clark, M.K. 1990. Roosting ecology of the eastern big-eared bat, *Plecotus rafinesquii*, in North Carolina. M.S. Thesis, North Carolina State University, Raleigh. 112pp.

Clark, M.K. 1991. Foraging ecology of Rafinesque's big-eared bat, *Plecotus rafinesquii*, in North Carolina. Bat Research News 32:38.

Clay, J.W., D.W. Orr, Jr., and A.W. Stuart (eds.) 1975. North Carolina Atlas: Portrait of a Changing Southern State. University of North Carolina Press, Chapel Hill. 331pp.

Constantine, D.G. 1961. Locality records and notes on western bats. *Journal of Mammalogy*. 42:404-405.

Cusens. A.R., and R.P. Pama. 1975. *Bridge Deck Analysis*. John Wiley and Sons, London. 278pp.

Davis, R. and E.L. Cockrum. 1963. Bridges utilized as day roosts by bats. Journal of Mammalogy. 44:428-430.

Davis, R.B., C.F. Herreid II. and H.L. Short. 1962. Mexican free-tailed bats in Texas. Ecological Monographs. 32:311-346.

Davis, W.B. and D.J. Schmidly. 1994. Mammals of Texas. Texan Parks and Wildlife. Austin. 338 pp.

Davis, W.H. 1966. Population dynamics of the bat *Pipistrellus subflavus*. J. Mammal. 47:383-396.

Davis, W.H. and D.J. Schmidley. 1994. Mammals of Texas. Texas Parks and Wildlife. Austin. 338pp.

Davis, W.H. and R.E. Mumford. 1962. Ecological notes on the bat *Pipistrellus subflavus*. Amer. Midland Nat. 68:394-398.

Eads, R.B., J.S. Wiseman, and G.C. Menzies. 1957. Observations concerning the Mexican free-tailed bat, *Tadarida mexicana*, in Texas. Texas Journal of Science 9:227-242.

Ellis, S.E. 1993. Tabanidae as dietary items of Rafinesque's big-eared bat: Implications for its foraging behavior. Entomological News 104:118-122.

Fenton, M.B., I.L. Rautenbach, S.E. Smith, C.M. Swanepoel, J. Grosell, and J van Jaarsveld. 1994. Raptors and bats: threats and opportunities. Animal Behaviour. 48: 9-18.

Findley, J.S. 1954. Tree roosting of the eastern pipistrelle. J. Mammal. 35:433.

Findley, J.S. 1993. Bats: A Community Perspective. Cambridge University Press. Cambridge. 167 pp.

Foster, G.W., S.R. Humphrey, and P.P. Humphrey. 1978. Survival rate of southeastern brown bats, *Myotis austroriparius*, in Florida. J. Mammal. 59:299-304.

Fraze, R.K. 1989. Observations on the roosting ecology of Tadarida brasiliensis in Bell County, Texas. M.S. Thesis Baylor University. Waco, Texas. 71 pp.

Fraze, R.K. and K.T. Wilkins. 1990. Patterns of use of man-made roosts by *Tadarida brasiliensis mexicana* in Texas. The Southwestern Naturalist. 35:261-267.

Fujita, M.S. and T.H. Kunz. 1984. *Pipistrellus subflavus*. Mammal. Species 228:1-6.

Gore, J.A. and J.A. Hovis. 1998. Status and Conservation of southeastern *Myotis* maternity colonies in Florida caves. Biological Sciences. 61:160-170.

Hambly, E.C. 1976. Bridge Deck Behaviour. Champan and Hall, London. 272pp.

Hermanson, J.W. and K.T. Wilkins. 1986. Pre-weaning mortality in a Florida maternity roost of *Myotis austroriparius* and *Tadarida brasiliensis*. Journal of Mammalogy. 67:751-754.

Hobson, C. 1998. Bat records from southeastern Virginia, including a new resident species *Myotis austroriparius*. Banisteria 12:18-23.

Hoffmeister, D.F. and W.W. Goodpaster. 1963. Observations on a colony of big-eared bats. *Plecotus rafinesquii*. Trans. Illinois State Acad. Sci. 55:87-89.

Horner, P. and R. Maxey. 1998. East Texas Rare Bat Survey: 1997. Final Report. Texas Parks and Wildlife Department, Resources Protection Division, Austin.

Humphrey, S.R. 1975. Nursery roosts and community diversity of Nearctic bats. *Journal of Mammalogy*. 56:321-346.

Humphrey, S.R. and J.A. Gore. 1992. Southeastern Brown Bat. Pages 335-342 *In* S.R. Humphrey, ed. Rare and Endangered Biota of Florida. Volume 1. Mammals. University Press of Florida, Gainesville.

Hurst, T.E. 1997. Foraging area, habitat use, population estimates, and food habits of Rafinesque's big-eared bat in southeastern Kentucky. M.S. Thesis, University of Kentucky, Lexington. 112pp.

Hurst, T.E. and M.J. Lacki. 1997. Food habits of Rafinesque's big-eared bat in southeastern Kentucky. J. Mammal. 78:525-528.

Jones, C. 1977. *Plecotus rafinesquii*. Mammalian Species. 69:1-4.

Jones, C. and R.D. Suttkus. 1973. Colony structure and organization of *Pipistrellus subflavus* in southern Louisiana. J. Mammal. 54:962-968.

Jones, C. and R.D. Suttkus. 1975. Notes on the natural history of *Plecotus rafinesquii*. Louisiana State University Occasional Paper, Museum of Zoology 47:1-4.

Jones, C. and R.W. Manning. 1989. *Myotis austroriparius*. Mammal. Species. 332:1-3.

Keely, B. 1997. Bats and bridges. Available on the Internet at http://www.batcon.org.

Kunz, T.H. 1982. Roosting ecology of bats. *In* Ecology of Bats, T.H. Kunz, ed., pp. 1-55. Plenum Press, New York.

Lacki, M.J. 1998. Monitoring of Virginia big-eared bats and Rafinesque's big -eared bats at Hood Branch Rock Shelter, Natural Bridge State Park Nature Preserve, Powell County, Kentucky. Final Report. Kentucky State Nature Preserve Commission.

Lance, R.F., B.T. Hardcastle, A. Talley, and P.L. Leberg. 2001. Day-roost selection by Rafinesque's Big-eared Bats (Corynorhinus rafinesquii) in Louisiana Forests. Journal of Mammalogy. 82:166-172.

Lewis, S.E. 1994. Night roosting ecology of pallid bats (*Antrozous pallidus*) in Oregon. The American Midland Naturlaist. 132:219-226.

Lewis, S.E. 1995. Roost fidelity of bats: A review. Journal of Mammalogy. 76:481-496.

Libby, J.R., and N.D. Perkins. 1976. *Modern Prestressed Concrete Highway Bridge Superstructures*. Grantville Publishing Company. San Diego. 254 pp.

McNab, B.K. 1982. Evolutionary alternatives in the physiological ecology of bats. *In* Ecology of Bats, T.H. Kunz. ed., pp. 151-200.

North Carolina Office of State Planning: County Growth Patterns 2000-2010, 2010-2020. June 1998. Available on the internet at http://www.ospl.state.nc.us/demog

Orr, D.M., and A.W. Stuart, eds. 2000. North Carolina Atlas: Portrait for a New Century. University of North Carolina Press, Chapel Hill. 461pp.

Pearson, E.W. 1962. Bat hibernating in silica mines in southern Illinois. J. Mammal. 43:27-33.

Perlmeter, S.I. 1995. Bats and Bridges: A Field Study of the Thermal Conditions and Social Organization of Night Roosts in the Willamette National Forest. M.S. Thesis. York University, North York, Ontario. 98 pp.

Perlmeter, S.I. 1996. Bats and Bridges: Patterns of night roost use by bats in the Willamette National Forest. In Bats and Forests Symposium, October 19-21, 1995, Victoria, British Columbia. pp. 132-150. Working Paper 23/1996. Research Branch, Ministry of Forests, Victoria.

Pierson, E.D. 1998. Tall trees, deep holes, and scarred landscapes: conservation biology of North American bats. Pp. 309-325 *In* Bat biology and conservation (T.H. Kunz and P.A. Racey, eds.). Smithsonian Institution Press. Washington, D.C.

Racey, P.A. 1982. Ecology of bat reproduction . *In* Ecology of Bats, T.H. Kunz, ed., pp. 57-104.

Rice, D.W. 1957. Life History and Ecology of *Myotis austroriparius* in Florida. J. Mammal. 38:15-32.

SAS Institute Inc. 1993. SAS Technical Report P-243. SAS/STAT Software: The GENMOD Procedure, Release 6.09 ed. SAS Institute Inc., Cary, North Carolina.

Schafale, M.P., and A.S. Weakley. 1990. Classification of the Natural Communities of North Carolina: Third Approximation. North Carolina Natural Heritage Program, Division of Parks and Recreation. N.C. Department of Environment, Health, and Natural Resources. 325pp.

Sherman, H.B. 1930. Birth of the young of *Myotis austroriparius*. J. Mammal. 11:495-503.

Sherman. H.B. 1937. Breeding habits of the free-tailed bat. J. Mammal. 18:176-187.

Taylor, R.T., and F.J. Keenan. 1992. Wood Highway Bridges. Canadian Wood Council. Ottawa. 193 pp.

Theis, M. 1994. A new record of *Plecotus rafinesquii* (Chiroptera:Vespertilionidae) from east Texas. Texas J. of Sci. 46:368-369.

Tuttle, M.D. 1979. Status, causes of decline, and management of endangered gray bats. *Journal of Wildlife Management*. 43:1-17.

U.S. Fish and Wildlife Service (USFWS). 1989. Endangered and threatened wildlife and plants; annual notice of review. Federal Register 54:554-579.

Walker, W.W., J.K. Sandel, R.L. Honeycutt, and C. Adams. 1996. Winter utilization of box culverts by Vespertilionid bats in southeast Texas. Texas J. Sci. 48:166-168.

Webster, W.D., J.F. Parnell, and W.C. Briggs, Jr. 1985. Mammals of the Carolinas, Virginia, and Maryland. University of North Carolina Press. Chapel Hill.

Whitaker, J.O., Jr. 1998. Life history and roost switching in six summer colonies of eastern pipistrelles in buildings. J. Mammal. 79:651-659.

Whitaker, J.O. 1995. Food of the big brown bat *Eptesicus fuscus* from maternity colonies in Indiana and Illinois. The American Midland Naturalist. 134:346-360

Whitaker, J.O., Jr. and F.A. Winter. 1977. Bats of the caves and mines of the Shawnee National Forest, southern Illinois. Transactions of the Illinois State Academy of Science 70:301-313.

Wilson, N. 1960. A northernmost record of *Plecotus rafinesquii* Lesson (Mammalia, Chiroptera). J. Mammal. 78:525-528.

Wimsatt, W.A. 1945. Notes on breeding behavior, pregnancy, and parturition in some Vespertilionid bats of the eastern Unites States. J. Mammal. 26:23-33.

Winchell, J. M. and T.H. Kunz. 1996. Day roosting activity budgets of the eastern pipistrel bat, *Pipistrellus subflavus* (Chiroptera: Vespertilionidae). Can. J. Zool. 74:431-441.

Table 1. Number of Bridges Total, Surveyed, and Occupied in the Study Area 1997-1998.

| Number of Bridges | Structure Type | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Slab | Steel Beam | Timber | I-Beam | T-Beam | Box Culvert | Pipe Culvert | Channel Beam | Total |
| Total in Study Area | 325 | 471 | 496 | 161 | 95 | 187 | 343 | 118 | 2196 |
| Surveyed | 161 | 141 | 157 | 90 | 88 | 98 | 142 | 113 | 990 |
| Occupied | 0 | 2 | 14 | 24 | 15 | 1 | 1 | 78 | 135 |

Table 2. Number of Occupied Bridges by Species for Each Structure Type 1997-1998

| Species | Structure Type | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Slab | Steel Multi-Beam | Timber | I-Beam | T-Beam | Channel Beam | Box | Pipe | Total |
| *C. rafinesquii* | 0 | 0 | 6 | 13 | 6 | 10 | 0 | 1 | 36 |
| *M. austroripariu.* | 0 | 0 | 2 | 0 | 1 | 8 | 1 | 0 | 12 |
| *P. subflavus* | 0 | 1 | 6 | 1 | 1 | 29 | 0 | 0 | 38 |
| Other | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 3 |
| Guano | 0 | 0 | 1 | 9 | 6 | 38 | 0 | 0 | 54 |
| Total | 0 | 2 | 14 | 24 | 15 | 78 | 1 | 1 | 135 |

Figure 1. Study Area: Counties in Which Bridge Surveys Were Conducted 1997-1998

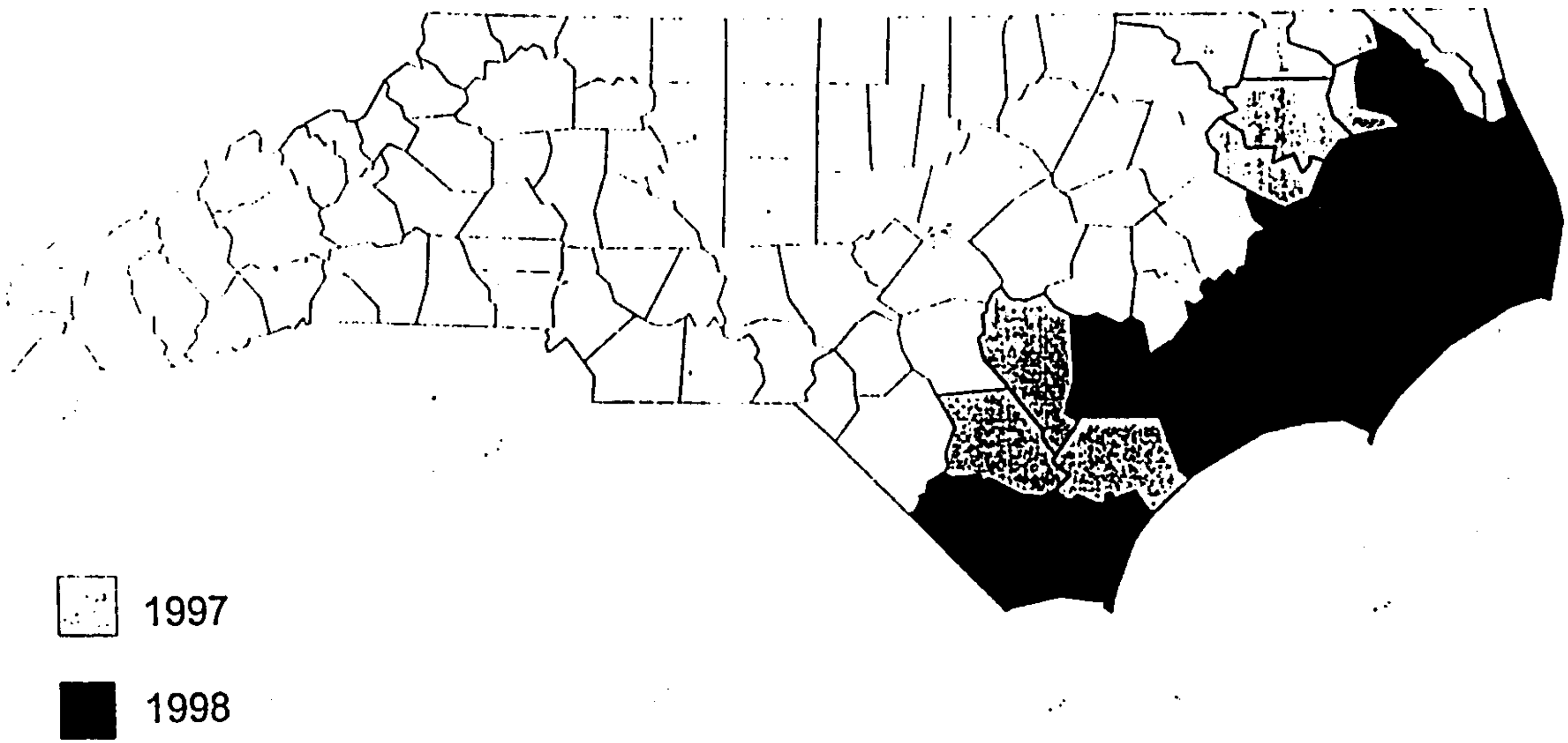
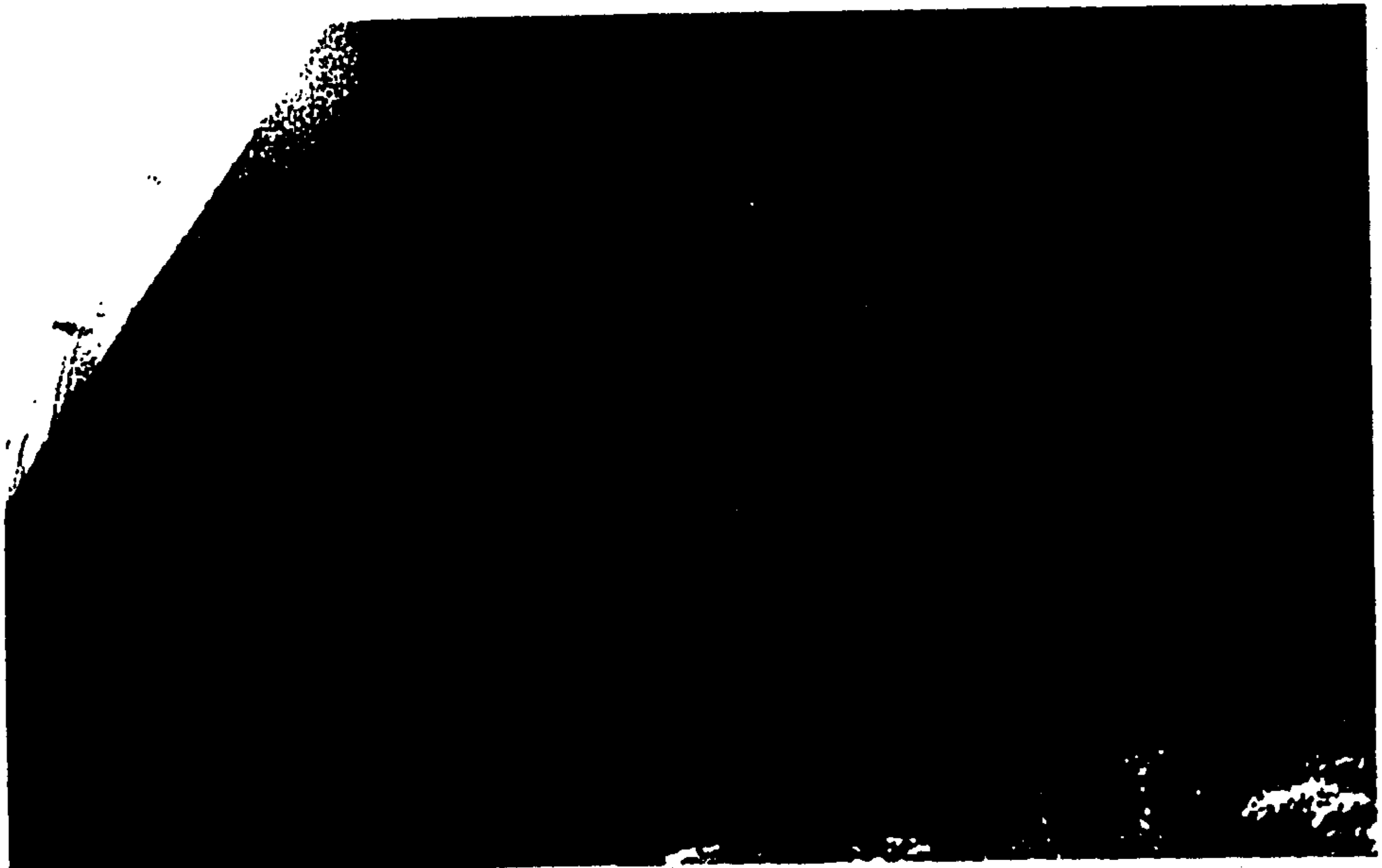


Figure 2. Slab Bridge, Sampson County, NC.



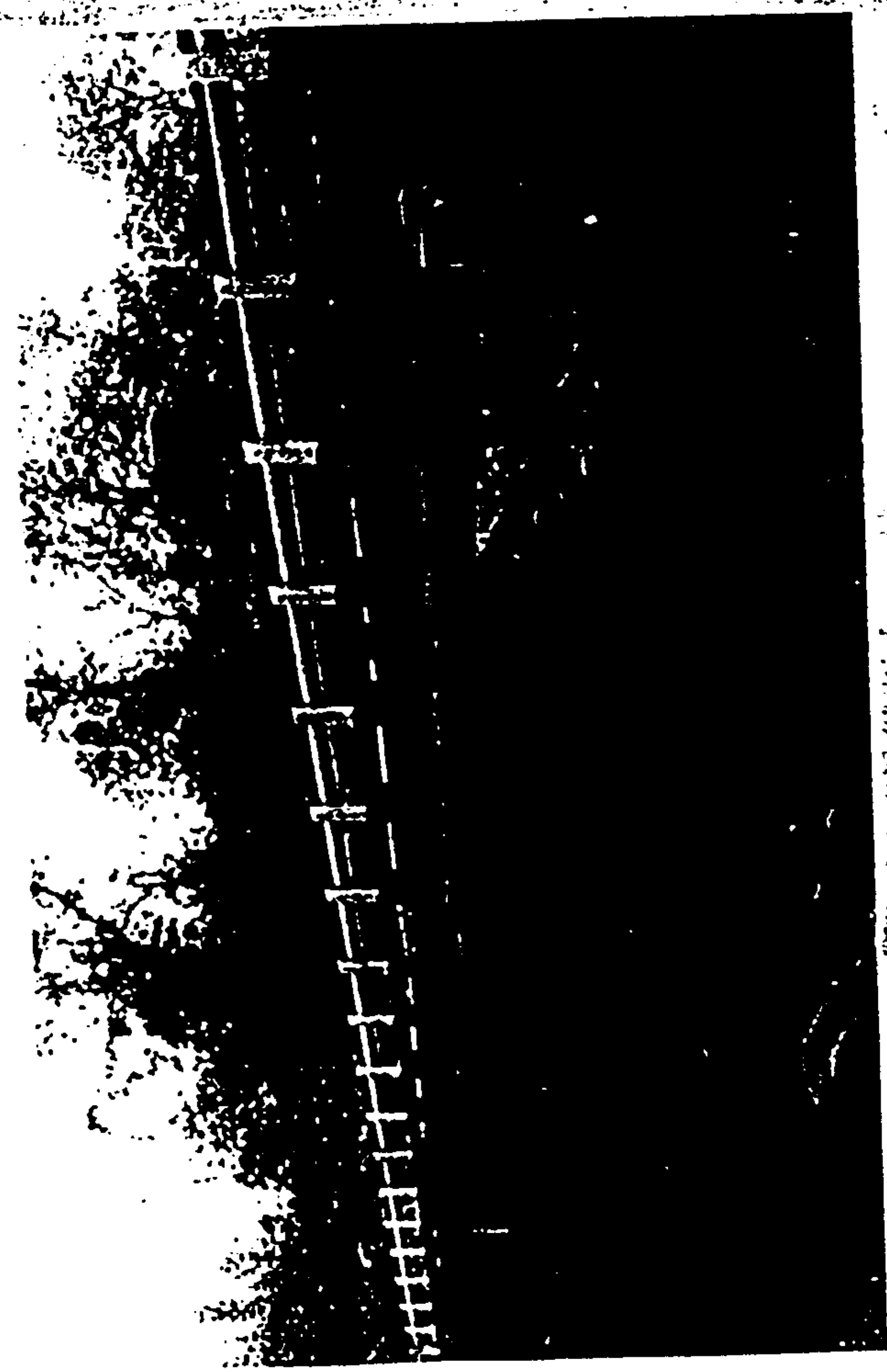


Figure 3. Steel Multi-Beam Bridge, Bertie County, NC

Figure 4. Timber Multi-Beam Bridge, Pender County, NC.

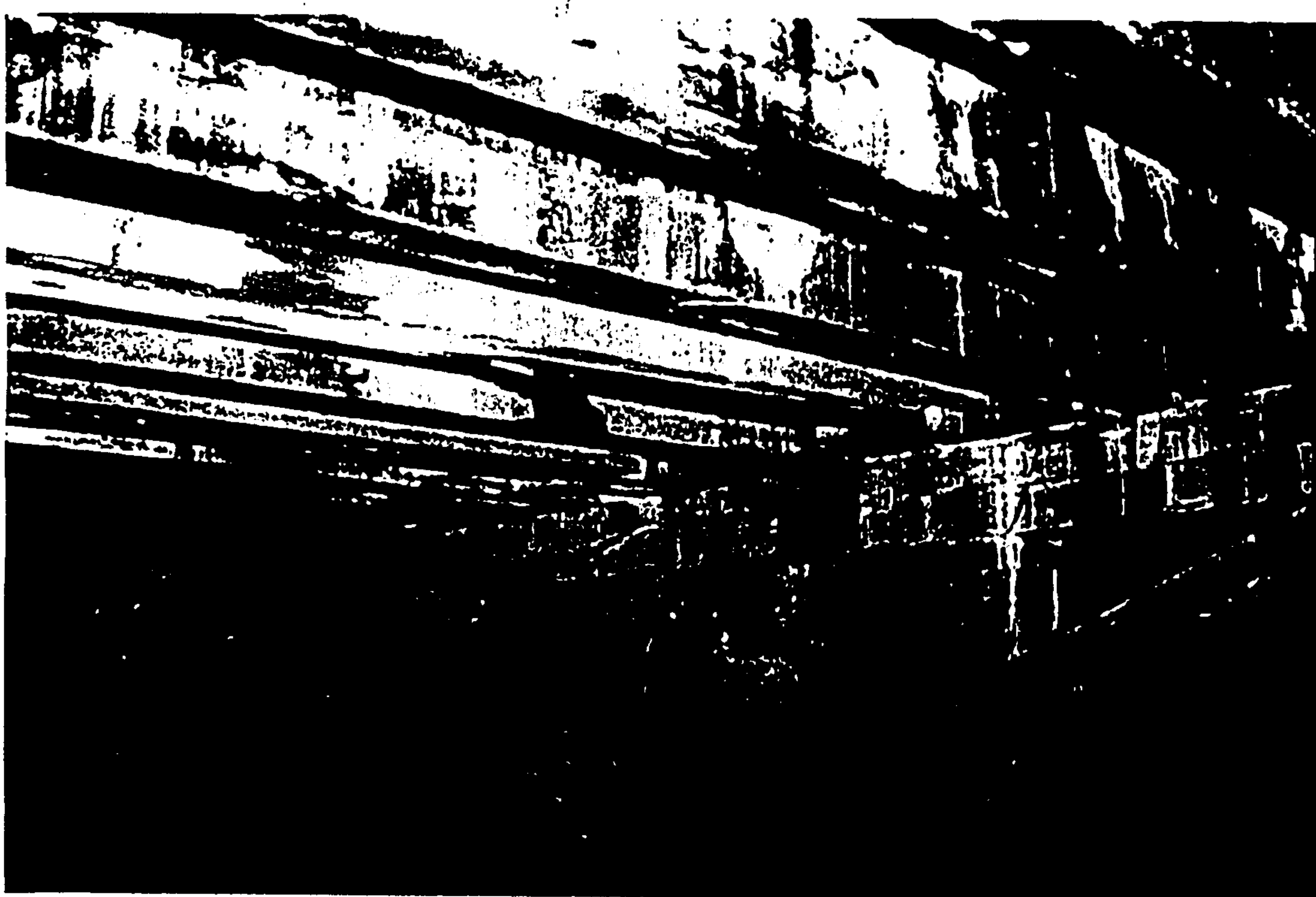


Figure 5. I-Beam Bridge, Bertie County, NC.

Figure 6. T-Beam Bridge, Martin County, NC.

Figure 7. Channel Beam Bridge, Gates County, NC.

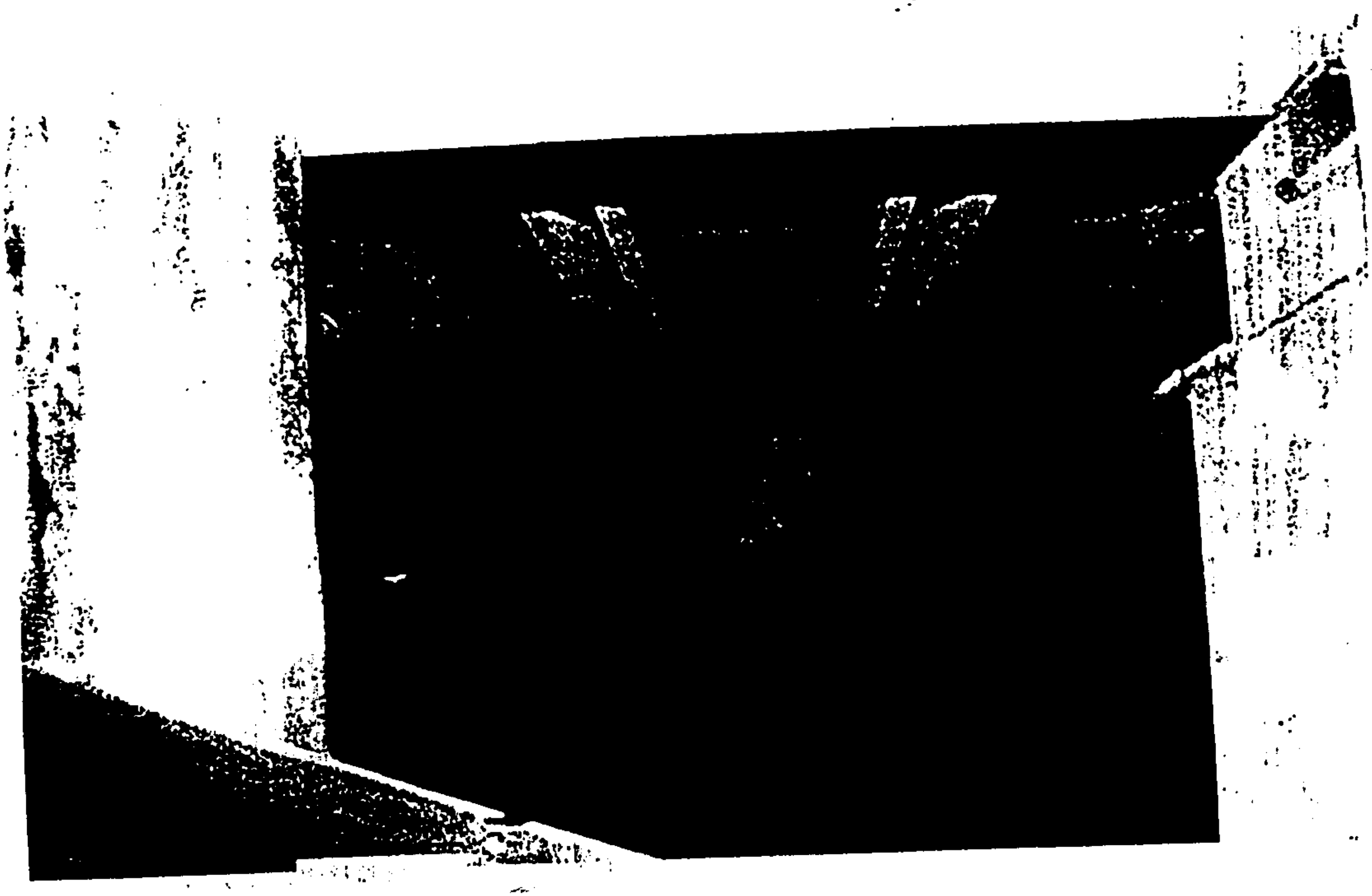


Figure 8. Pipe Culvert, Martin County, NC.

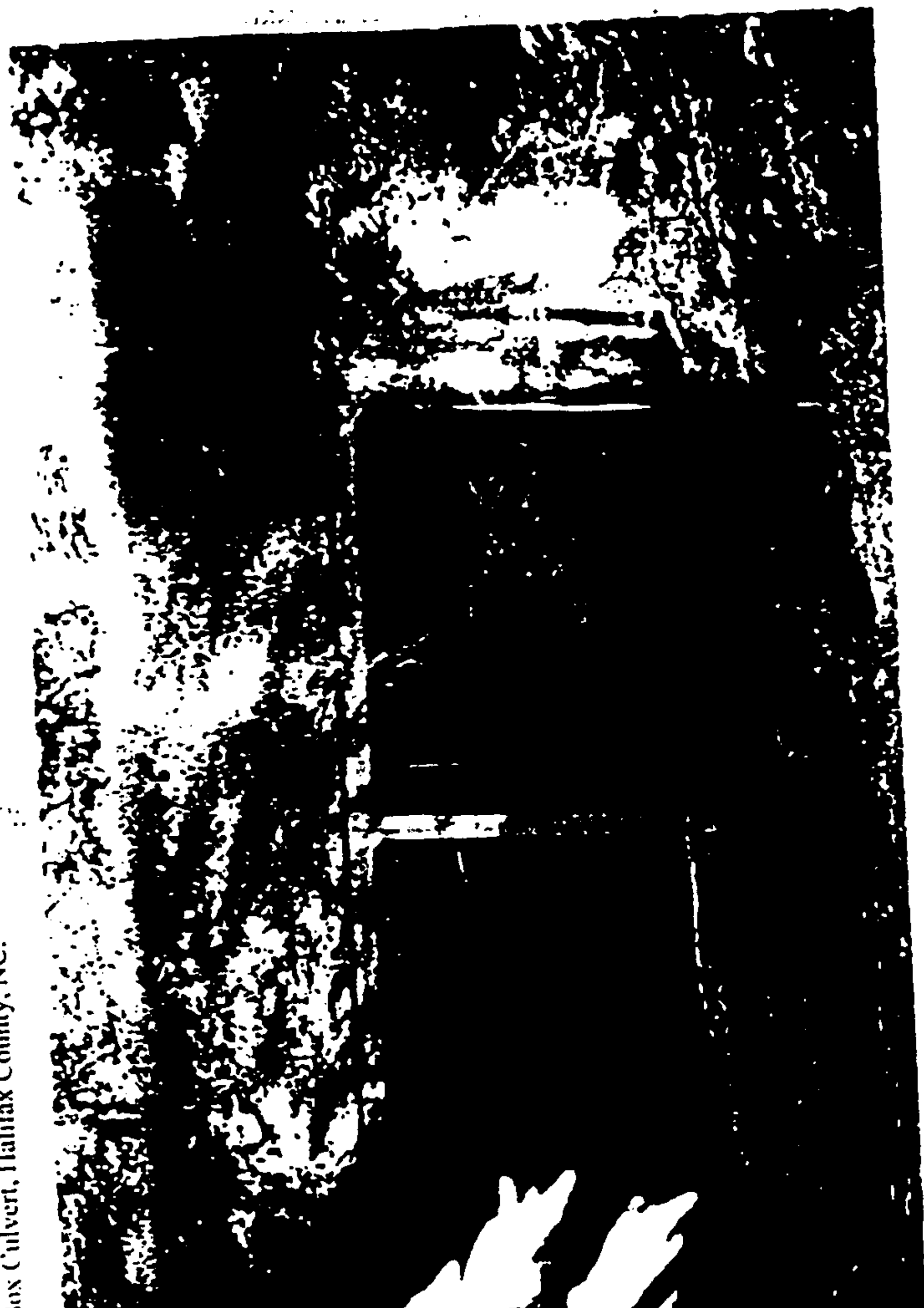


Figure 9. Box Culvert, Halifax County, NC.

Figure 10. Number of bridges total, surveyed, and occupied in the study area 1997-1998.

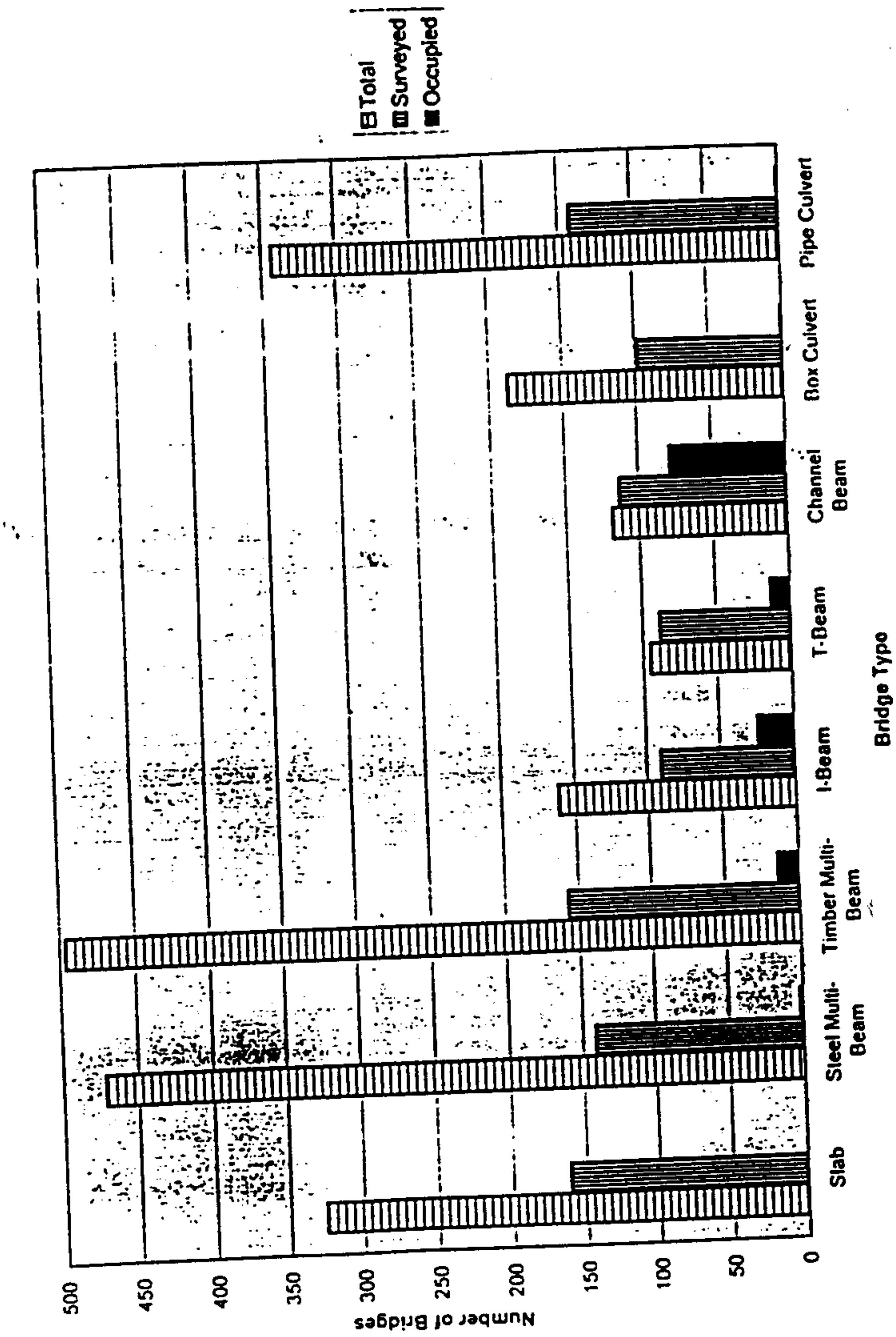
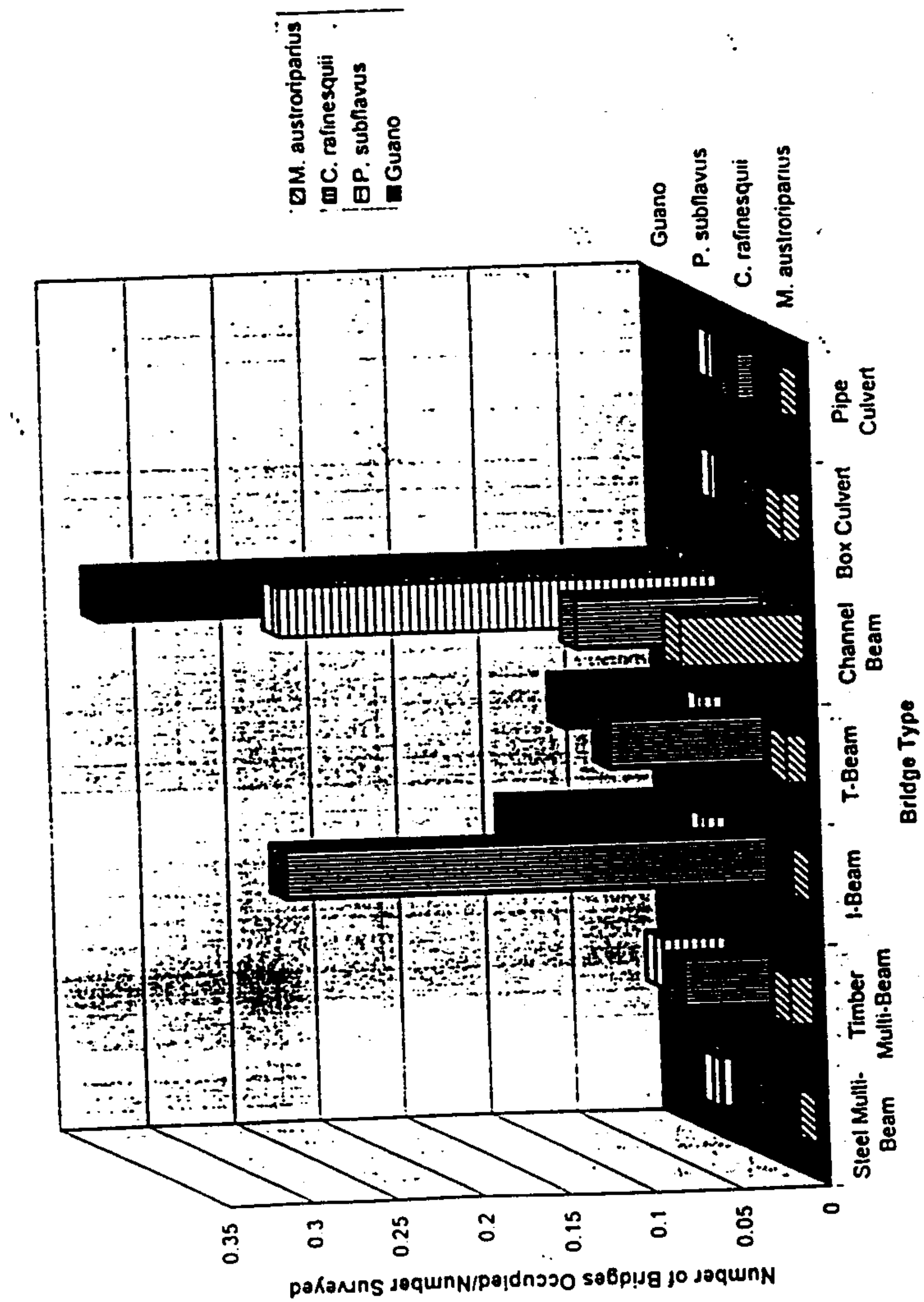

Total
Surveyed
Occupied
Number of Bridges
0
50
100
150
200
250
300
350
400
450
500
Slab
Steel Multi-Beam
Timber Multi-Beam
I-Beam
T-Beam
Channel Beam
Box Culvert
Pipe Culvert
Bridge Type

Figure 11. Number of bridges occupied/ number surveyed for each species and structure type in the study area 1997-1998.


M. austroriparius
C. rafinesquii
P. subflavus
Guano
Number of Bridges Occupied/Number Surveyed
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Steel Multi-Beam
Timber Multi-Beam
I-Beam
T-Beam
Channel Beam
Box Culvert
Pipe Culvert
Bridge Type

Appendix 1. Bridges Occupied by *C. rafinesquii* 1997-1998

| Structure Type | County | Bridge No. | Date | No. *C. rafinesquii* roosts | Roost Type | No. adults | Pups present | Other Species Present |
|---|---|---|---|---|---|---|---|---|
| Channel Beam | Beaufort | CB064 | 14-Jul-98 | 1 | solitary | 1 | | *Pipistrellus subflavus* |
| Channel Beam | Bertie | CB009 | 12-Jun-97 | 1 | solitary | 1 | | |
| Channel Beam | Bertie | CB010 | 12-Jun-97 | 4 | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| Channel Beam | Bertie | CB013 | 12-Jun-97 | 1 | solitary | 1 | | |
| Channel Beam | Bertie | CB013 | 12-Jun-97 | 1 | solitary | 1 | | |
| Channel Beam | Bladen | CB016 | 22-Jun-97 | 1 | solitary | 1 | | |
| Channel Beam | Brunswick | CB037 | 23-Jun-98 | 2 | maternity | 8 | yes | *Pipistrellus subflavus* |
| | | | | | maternity | 7 | yes | |
| Channel Beam | Columbus | CB042 | 26-Jun-98 | 1 | solitary | 1 | | *Myotis austroriparius* *Pipistrellus subflavus* |
| Channel Beam | Hertford | CB034 | 19-Jul-97 | 1 | solitary | 1 | | |
| Channel Beam | Martin | CB005 | 6-Jun-97 | 1 | solitary | 1 | | |
| I-Beam | Beaufort | I024 | 16-Jul-98 | 1 | solitary | 1 | | |
| I-Beam | Bladen | I005 | 22-Jun-97 | 2 | solitary | 1 | | |
| | | | | | colony | 3 | | |
| I-Beam | Brunswick | I019 | 23-Jun-98 | 1 | solitary | 1 | | |
| I-Beam | Brunswick | I020 | 24-Jun-98 | 1 | solitary | 1 | | |
| I-Beam | Craven | I023 | 8-Jul-98 | 2 | maternity | ~20 | yes | |
| | | | | | solitary | 1 | | |
| I-Beam | Duplin | I012 | 10-Jun-98 | 1 | solitary | 1 | | |
| I-Beam | Duplin | I013 | 11-Jun-98 | 1 | solitary | 1 | | |
| I-Beam | Duplin | I014 | 11-Jun-98 | 1 | solitary | 1 | | |
| I-Beam | Gates | I001 | 10-Jun-97 | 1 | maternity | ~40 | yes | |
| I-Beam | Gates | I002 | 10-Jun-97 | 1 | solitary | 1 | | |
| I-Beam | Gates | I003 | 11-Jun-97 | 2 | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| I-Beam | Hertford | I010 | 18-Jul-97 | 1 | solitary | 1 | | |
| I-Beam | Martin | I011 | 18-Jul-97 | 1 | colony | 9 | | |
| Pipe Culvert | Bladen | P001 | 22-Jun-97 | 1 | solitary | 1 | | |
| T-Beam | Brunswick | T006 | 24-Jun-98 | 2 | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| T-Beam | Columbus | T008 | 26-Jun-98 | 1 | solitary | 1 | | |
| T-Beam | Craven | T012 | 8-Jul-98 | 2 | maternity | 7 | yes | |
| | | | | | solitary | 1 | | |
| T-Beam | Northampton | T013 | 4-Aug-98 | 1 | maternity | ~30 | yes | |
| T-Beam | Northampton | T014 | 4-Aug-98 | 3 | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| T-Beam | Pender | T001 | 21-Jun-97 | 1 | solitary | 1 | | |
| Timber Beam | Beaufort | W012 | 15-Jul-98 | 1 | solitary | 1 | | |
| Timber Beam | Bladen | W004 | 20-Jun-97 | 1 | solitary | 1 | | |
| Timber Beam | Duplin | W010 | 11-Jun-98 | 1 | solitary | 1 | | *Myotis austroriparius* |
| Timber Beam | Gates | W001 | 10-Jun-97 | 2 | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| Timber Beam | Gates | W002 | 10-Jun-97 | 1 | solitary | 1 | | |
| Timber Beam | Gates | W003 | 11-Jun-97 | 1 | solitary | 1 | | |

## Appendix 2. Bridges Occupied by *P. subflavus* 1997-1998

| Structure Type | County | Bridge No. | Date | No. *P. subflavus* roosts | Roost Type | No. adults | Pups Present | *Other Species Present* |
|---|---|---|---|---|---|---|---|---|
| Channel Beam | Beaufort | CB061 | 14-Jul-98 | 2 | colony | 9 | | |
| | | | | | solitary | 1 | | |
| Channel Beam | Beaufort | CB063 | 14-Jul-98 | 1 | solitary | | | |
| Channel Beam | Beaufort | CB064 | 14-Jul-98 | 5 | colony | 3 | | *Corynorhinus rafinesquii* |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| Channel Beam | Beaufort | CB066 | 14-Jul-98 | 1 | solitary | | | |
| Channel Beam | Beaufort | CB067 | 14-Jul-98 | 1 | solitary | | | |
| Channel Beam | Bertie | CB008 | 11-Jun-97 | 1 | colony | 15 | | |
| Channel Beam | Bladen | CB018 | 23-Jun-97 | 3 | colony | 3 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 2 | | |
| Channel Beam | Brunswick | CB037 | 23-Jun-98 | 2 | solitary | 1 | | *Corynorhinus rafinesquii* |
| | | | | | solitary | 1 | | |
| Channel Beam | Brunswick | CB039 | 24-Jun-98 | 7 | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| Channel Beam | Brunswick | CB041 | 24-Jun-98 | 1 | solitary | 1 | | |
| Channel Beam | Columbus | CB042 | 26-Jun-98 | 1 | solitary | 1 | | *Corynorhinus rafinesquii*<br>*Myotis austroriparius* |
| Channel Beam | Duplin | CB035 | 11-Jun-98 | 3 | colony | 12 | | *Myotis austroriparius* |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| Channel Beam | Duplin | CB075 | 31-Jul-98 | 2 | solitary | 1 | | *Myotis austroriparius* |
| | | | | | solitary | 1 | | |
| Channel Beam | Duplin | CB076 | 31-Jul-98 | 3 | colony | 2 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| Channel Beam | Jones | CB045 | 7-Jul-98 | 1 | colony | 3 | | *Myotis austroriparius* |
| Channel Beam | Jones | CB047 | 7-Jul-98 | 1 | solitary | 1 | | |
| Channel Beam | Jones | CB048 | 7-Jul-98 | 1 | solitary | 1 | | |
| Channel Beam | Jones | CB049 | 7-Jul-98 | 1 | solitary | 1 | | |
| Channel Beam | Martin | CB001 | 5-Jun-97 | 2 | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| Channel Beam | Martin | CB002 | 5-Jun-97 | 1 | solitary | 1 | | |
| Channel Beam | Martin | CB003 | 5-Jun-97 | 1 | solitary | 1 | | |
| Channel Beam | Martin | CB004 | 5-Jun-97 | 1 | solitary | 1 | | |
| Channel Beam | Martin | CB006 | 6-Jun-97 | 1 | solitary | 1 | | |
| Channel Beam | Martin | CB023 | 10-Jul-97 | 1 | solitary | 1 | | |
| Channel Beam | Onslow | CB073 | 30-Jul-98 | 1 | solitary | 1 | | |
| Channel Beam | Sampson | CB019 | 5-Jul-97 | 1 | solitary | 1 | | |
| Channel Beam | Sampson | CB021 | 6-Jul-97 | 2 | solitary | 1 | | |
| | | | | | solitary | 1 | | |

Appendix 2. Bridges Occupied by *P. subflavus* 1997-1998

| Structure Type | County | Bridge No. | Date | No. *P. subflavus* roosts | Roost Type | No. adults | Pups Present | *Other Species Present* |
|---|---|---|---|---|---|---|---|---|
| Channel Beam | Sampson | CB028 | 15-Jul-97 | 5 | colony | 9 | | |
| | | | | | colony | 6 | | |
| | | | | | colony | 2 | | |
| | | | | | solitary | 1 | | |
| | | | | | solitary | 1 | | |
| Channel Beam | Washington | CB071 | 16-Jul-98 | 1 | solitary | 1 | | |
| I-Beam | Gates | I004 | 11-Jun-97 | 1 | colony | 2 | | |
| Steel Beam | Duplin | SB002 | 10-Jun-98 | 1 | solitary | 1 | | |
| T-Beam | Duplin | T005 | 12-Jun-98 | 1 | solitary | 1 | | |
| Timber Beam | Beaufort | W013 | 15-Jul-98 | 1 | solitary | 1 | | |
| Timber Beam | Bladen | W005 | 22-Jun-97 | 2 | maternity | ~20 | yes | |
| | | | | | maternity | ~20 | yes | |
| Timber Beam | Bladen | W006 | 22-Jun-97 | 5 | colony | ~30 | unknown | |
| | | | | | colony | ~20 | unknown | |
| | | | | | colony | ~18 | unknown | |
| | | | | | colony | ~12 | unknown | |
| | | | | | colony | ~10 | unknown | |
| Timber Beam | Brunswick | W011 | 24-Jun-98 | 2 | colony | 10 | | |
| | | | | | colony | 5 | | |
| Timber Beam | Duplin | W014 | 31-Jul-98 | 1 | solitary | 1 | | |
| Timber Beam | Sampson | W009 | 14-Jul-97 | 1 | solitary | 1 | | |

Appendix 3. Bridges Occupied by *M. austroriparius* 1997-1998

| Structure Type | County | Bridge No. | Date | No. M. austroriparius Roosts | Roost Type | No. Adults | Other Species Present |
|---|---|---|---|---|---|---|---|
| Box Culvert | Onslow | B001 | 30-Jul-98 | 1 | solitary | 1 | |
| Channel Beam | Chowan | CB007 | 10-Jun-97 | 1 | solitary | 1 | |
| Channel Beam | Columbus | CB042 | 26-Jun-98 | 1 | solitary | 1 | *Corynorhinus rafinesquii* *Pipistrellus subflavus* |
| Channel Beam | Duplin | CB075 | 31-Jul-98 | 1 | solitary | 1 | *Pipistrellus subflavus* |
| Channel Beam | Duplin | CB035 | 11-Jun-98 | 1 | solitary | 1 | *Pipistrellus subflavus* |
| Channel Beam | Hyde | CB069 | 15-Jul-98 | 1 | solitary | 1 | |
| Channel Beam | Jones | CB045 | 7-Jul-98 | 1 | colony | 7 | *Pipistrellus subflavus* |
| Channel Beam | Northampton | CB078 | 3-Aug-98 | 1 | solitary | 1 | |
| Channel Beam | Onslow | CB074 | 30-Jul-98 | 1 | solitary | 1 | |
| T-Beam | Columbus | T009 | 26-Jun-98 | 1 | solitary | 1 | |
| Timber Beam | Gates | W001 | 10-Jun-97 | 1 | solitary | 1 | *Corynorhinus rafinesquii* |
| Timber Beam | Sampson | W007 | 5-Jul-97 | 1 | solitary | 1 | |

Appendix 4. Summary Data for Occupied Bridges and Culverts 1997-1998

| Structure Type | County | Bridge No. | Date | Species |
|---|---|---|---|---|
| Box Culvert | Onslow | B001 | 30-Jul-98 | *Myotis austroriparius* |
| Channel Beam | Beaufort | CB056 | 13-Jul-98 | guano |
| Channel Beam | Beaufort | CB057 | 13-Jul-98 | guano |
| Channel Beam | Beaufort | CB058 | 13-Jul-98 | guano |
| Channel Beam | Beaufort | CB059 | 14-Jul-98 | guano |
| Channel Beam | Beaufort | CB060 | 14-Jul-98 | guano |
| Channel Beam | Beaufort | CB061 | 14-Jul-98 | *Pipistrellus subflavus* |
| Channel Beam | Beaufort | CB062 | 14-Jul-98 | guano |
| Channel Beam | Beaufort | CB063 | 14-Jul-98 | *Pipistrellus subflavus* |
| Channel Beam | Beaufort | CB064 | 14-Jul-98 | *Corynorhinus rafinesquii*<br>*Pipistrellus subflavus* |
| Channel Beam | Beaufort | CB065 | 14-Jul-98 | guano |
| Channel Beam | Beaufort | CB066 | 14-Jul-98 | *Pipistrellus subflavus* |
| Channel Beam | Beaufort | CB067 | 14-Jul-98 | *Pipistrellus subflavus* |
| Channel Beam | Bertie | CB008 | 11-Jun-97 | *Pipistrellus subflavus* |
| Channel Beam | Bertie | CB009 | 12-Jun-97 | *Corynorhinus rafinesquii* |
| Channel Beam | Bertie | CB010 | 12-Jun-97 | *Corynorhinus rafinesquii* |
| Channel Beam | Bertie | CB011 | 12-Jun-97 | *Corynorhinus rafinesquii* |
| Channel Beam | Bertie | CB012 | 12-Jun-97 | guano |
| Channel Beam | Bertie | CB013 | 12-Jun-97 | *Corynorhinus rafinesquii* |
| Channel Beam | Bertie | CB014 | 12-Jun-97 | guano |
| Channel Beam | Bertie | CB015 | 13-Jun-97 | guano |
| Channel Beam | Bladen | CB016 | 22-Jun-97 | *Corynorhinus rafinesquii* |
| Channel Beam | Bladen | CB018 | 23-Jun-97 | *Pipistrellus subflavus* |
| Channel Beam | Brunswick | CB037 | 23-Jun-98 | *Corynorhinus rafinesquii*<br>*Pipistrellus subflavus* |
| Channel Beam | Brunswick | CB038 | 24-Jun-98 | guano |
| Channel Beam | Brunswick | CB039 | 24-Jun-98 | *Pipistrellus subflavus* |
| Channel Beam | Brunswick | CB040 | 24-Jun-98 | guano |
| Channel Beam | Brunswick | CB041 | 24-Jun-98 | *Pipistrellus subflavus* |
| Channel Beam | Carteret | CB054 | 10-Jul-98 | guano |
| Channel Beam | Carteret | CB055 | 10-Jul-98 | guano |
| Channel Beam | Chowan | CB007 | 10-Jun-97 | *Myotis austroriparius* |
| Channel Beam | Columbus | CB042 | 26-Jun-98 | *Corynorhinus rafinesquii*<br>*Myotis austroriparius*<br>*Pipistrellus subflavus* |
| Channel Beam | Columbus | CB043 | 30-Jun-98 | guano |
| Channel Beam | Craven | CB053 | 08-Jul-98 | guano |
| Channel Beam | Duplin | CB035 | 11-Jun-98 | *Myotis austroriparius*<br>*Pipistrellus subflavus* |
| Channel Beam | Duplin | CB036 | 12-Jun-98 | guano |
| Channel Beam | Duplin | CB075 | 31-Jul-98 | *Myotis austroriparius*<br>*Pipistrellus subflavus* |
| Channel Beam | Duplin | CB076 | 31-Jul-98 | *Pipistrellus subflavus* |
| Channel Beam | Hertford | CB033 | 19-Jul-97 | guano |
| Channel Beam | Hertford | CB034 | 19-Jul-97 | *Corynorhinus rafinesquii* |
| Channel Beam | Hyde | CB068 | 15-Jul-98 | guano |
| Channel Beam | Hyde | CB069 | 15-Jul-98 | *Myotis austroriparius* |
| Channel Beam | Jones | CB044 | 07-Jul-98 | guano |
| Channel Beam | Jones | CB045 | 07-Jul-98 | *Myotis austroriparius*<br>*Pipistrellus subflavus* |
| Channel Beam | Jones | CB046 | 07-Jul-98 | guano |

Appendix 4. Summary Data for Occupied Bridges and Culverts 1997-1998

| Structure Type | County | Bridge No. | Date | Species |
|---|---|---|---|---|
| Channel Beam | Jones | CB047 | 07-Jul-98 | *Pipistrellus subflavus* |
| Channel Beam | Jones | CB048 | 07-Jul-98 | *Pipistrellus subflavus* |
| Channel Beam | Jones | CB049 | 07-Jul-98 | *Pipistrellus subflavus* |
| Channel Beam | Jones | CB050 | 07-Jul-98 | guano |
| Channel Beam | Jones | CB051 | 07-Jul-98 | guano |
| Channel Beam | Jones | CB052 | 07-Jul-98 | guano |
| Channel Beam | Martin | CB001 | 05-Jun-97 | *Pipistrellus subflavus* |
| Channel Beam | Martin | CB002 | 05-Jun-97 | *Pipistrellus subflavus* |
| Channel Beam | Martin | CB003 | 05-Jun-97 | *Pipistrellus subflavus* |
| Channel Beam | Martin | CB004 | 05-Jun-97 | *Pipistrellus subflavus* |
| Channel Beam | Martin | CB005 | 06-Jun-97 | *Corynorhinus rafinesquii* |
| Channel Beam | Martin | CB006 | 06-Jun-97 | *Pipistrellus subflavus* |
| Channel Beam | Martin | CB023 | 10-Jul-97 | *Pipistrellus subflavus* |
| Channel Beam | Martin | CB024 | 10-Jul-97 | guano |
| Channel Beam | Martin | CB025 | 10-Jul-97 | guano |
| Channel Beam | Martin | CB030 | 18-Jul-97 | guano |
| Channel Beam | Martin | CB031 | 18-Jul-97 | guano |
| Channel Beam | Martin | CB032 | 18-Jul-97 | guano |
| Channel Beam | Northampton | CB077 | 03-Aug-98 | guano |
| Channel Beam | Northampton | CB078 | 03-Aug-98 | *Myotis austroriparius* |
| Channel Beam | Onslow | CB072 | 30-Jul-98 | guano |
| Channel Beam | Onslow | CB073 | 30-Jul-98 | *Pipistrellus subflavus* |
| Channel Beam | Onslow | CB074 | 30-Jul-98 | *Myotis austroriparius* |
| Channel Beam | Pender | CB017 | 22-Jun-97 | guano |
| Channel Beam | Pender | CB029 | 16-Jul-97 | guano |
| Channel Beam | Sampson | CB019 | 05-Jul-97 | *Pipistrellus subflavus* |
| Channel Beam | Sampson | CB020 | 05-Jul-97 | guano |
| Channel Beam | Sampson | CB021 | 06-Jul-97 | *Pipistrellus subflavus* |
| Channel Beam | Sampson | CB022 | 06-Jul-97 | guano |
| Channel Beam | Sampson | CB026 | 13-Jul-97 | guano |
| Channel Beam | Sampson | CB027 | 15-Jul-97 | guano |
| Channel Beam | Sampson | CB028 | 15-Jul-97 | *Pipistrellus subflavus* |
| Channel Beam | Tyrrell | CB070 | 15-Jul-98 | guano |
| Channel Beam | Washington | CB071 | 16-Jul-98 | *Pipistrellus subflavus* |
| I-Beam | Beaufort | I024 | 16-Jul-98 | *Corynorhinus rafinesquii* |
| I-Beam | Bladen | I005 | 22-Jun-97 | *Corynorhinus rafinesquii* |
| I-Beam | Bladen | I006 | 23-Jun-97 | *unknown |
| I-Beam | Brunswick | I019 | 23-Jun-98 | *Corynorhinus rafinesquii* |
| I-Beam | Brunswick | I020 | 24-Jun-98 | *Corynorhinus rafinesquii* |
| I-Beam | Craven | I022 | 08-Jul-98 | guano |
| I-Beam | Craven | I023 | 08-Jul-98 | *Corynorhinus rafinesquii* |
| I-Beam | Duplin | I012 | 10-Jun-98 | *Corynorhinus rafinesquii* |
| I-Beam | Duplin | I013 | 11-Jun-98 | *Corynorhinus rafinesquii* |
| I-Beam | Duplin | I014 | 11-Jun-98 | *Corynorhinus rafinesquii* |
| I-Beam | Duplin | I015 | 12-Jun-98 | guano |
| I-Beam | Duplin | I016 | 12-Jun-98 | guano |
| I-Beam | Duplin | I017 | 12-Jun-98 | guano |
| I-Beam | Duplin | I018 | 12-Jun-98 | guano |
| I-Beam | Gates | I001 | 10-Jun-97 | *Corynorhinus rafinesquii* |

Appendix 4. Summary Data for Occupied Bridges and Culverts 1997-1998

| Structure Type | County | Bridge No. | Date | Species |
|---|---|---|---|---|
| I-Beam | Gates | I002 | 10-Jun-97 | *Corynorhinus rafinesquii* |
| I-Beam | Gates | I003 | 11-Jun-97 | *Corynorhinus rafinesquii* |
| I-Beam | Gates | I004 | 11-Jun-97 | *Pipistrellus subflavus* |
| I-Beam | Hertford | I010 | 18-Jul-97 | *Corynorhinus rafinesquii* |
| I-Beam | Jones | I021 | 07-Jul-98 | guano |
| I-Beam | Martin | I011 | 18-Jul-97 | *Corynorhinus rafinesquii* |
| I-Beam | Pender | I009 | 16-Jul-97 | guano |
| I-Beam | Sampson | I007 | 13-Jul-97 | guano |
| I-Beam | Sampson | I008 | 13-Jul-97 | guano |
| Pipe Culvert | Bladen | P001 | 22-Jun-97 | *Corynorhinus rafinesquii* |
| Steel Beam | Duplin | SB001 | 10-Jun-98 | unknown |
| Steel Beam | Duplin | SB002 | 10-Jun-98 | *Pipistrellus subflavus* |
| T-Beam | Bladen | T002 | 23-Jun-97 | *unknown |
| T-Beam | Brunswick | T006 | 24-Jun-98 | *Corynorhinus rafinesquii* |
| T-Beam | Columbus | T007 | 26-Jun-98 | guano |
| T-Beam | Columbus | T008 | 26-Jun-98 | *Corynorhinus rafinesquii* |
| T-Beam | Columbus | T009 | 26-Jun-98 | *Myotis austroriparius* |
| T-Beam | Columbus | T010 | 01-Jul-98 | guano |
| T-Beam | Craven | T011 | 08-Jul-98 | guano |
| T-Beam | Craven | T012 | 08-Jul-98 | *Corynorhinus rafinesquii* |
| T-Beam | Duplin | T004 | 11-Jun-98 | guano |
| T-Beam | Duplin | T005 | 12-Jun-98 | *Pipistrellus subflavus* |
| T-Beam | Northampton | T013 | 04-Aug-98 | *Corynorhinus rafinesquii* |
| T-Beam | Northampton | T014 | 04-Aug-98 | *Corynorhinus rafinesquii* |
| T-Beam | Pender | T001 | 21-Jun-97 | *Corynorhinus rafinesquii* |
| T-Beam | Perquimans | T015 | 05-Aug-98 | guano |
| T-Beam | Sampson | T003 | 13-Jul-97 | guano |
| Timber Beam | Beaufort | W012 | 15-Jul-98 | *Corynorhinus rafinesquii* |
| Timber Beam | Beaufort | W013 | 15-Jul-98 | *Pipistrellus subflavus* |
| Timber Beam | Bladen | W004 | 20-Jun-97 | *Corynorhinus rafinesquii* |
| Timber Beam | Bladen | W005 | 22-Jun-97 | *Pipistrellus subflavus* |
| Timber Beam | Bladen | W006 | 22-Jun-97 | *Pipistrellus subflavus* |
| Timber Beam | Brunswick | W011 | 24-Jun-98 | *Pipistrellus subflavus* |
| Timber Beam | Duplin | W010 | 11-Jun-98 | *Corynorhinus rafinesquii* |
| Timber Beam | Duplin | W014 | 31-Jul-98 | *Pipistrellus subflavus* |
| Timber Beam | Gates | W001 | 10-Jun-97 | *Corynorhinus rafinesquii*<br>*Myotis austroriparius* |
| Timber Beam | Gates | W002 | 10-Jun-97 | *Corynorhinus rafinesquii* |
| Timber Beam | Gates | W003 | 11-Jun-97 | *Corynorhinus rafinesquii* |
| Timber Beam | Sampson | W007 | 05-Jul-97 | *Myotis austroriparius* |
| Timber Beam | Sampson | W008 | 13-Jul-97 | guano |
| Timber Beam | Sampson | W009 | 14-Jul-97 | *Pipistrellus subflavus* |