BULLETIN

of the
FLORIDA STATE MUSEUM
Biological Sciences

Volume 34 1988 Number 1

ASPECTS OF THE BIOLOGY OF THE FLATTENED MUSK TURTLE, *STERNOTHERUS DEPRESSUS* IN NORTHERN ALABAMA

C. Kenneth Dodd, Jr., Kevin M. Enge, and James N. Stuart

UNIVERSITY OF FLORIDA GAINESVILLE

Numbers of the BULLETIN OF THE FLORIDA STATE MUSEUM, BIOLOGICAL SCIENCES, are published at irregular intervals. Volumes contain about 300 pages and are not necessarily completed in any one calendar year.

Communications concerning purchase or exchange of the publications and all manuscripts should be addressed to: Managing Editor, Bulletin; Florida State Museum; University of Florida; Gainesville FL 32611; U.S.A.

This public document was promulgated at an annual cost of $2568.00 or $2.568 per copy. It makes available to libraries, scholars, and all interested persons the results of researches in the natural sciences, emphasizing the circum-Caribbean region.

ISSN: 0071-6154 CODEN: BF 5BA5

Publication date: 11/23/88 Price: $2.75

ASPECTS OF THE BIOLOGY OF THE FLATTENED MUSK TURTLE, *STERNOTHERUS DEPRESSUS*, IN NORTHERN ALABAMA

C. Kenneth Dodd, Jr., Kevin M. Enge, and James N. Stuart*

ABSTRACT

The flattened musk turtle, *Sternotherus depressus*, is endemic to streams and rivers of the Warrior River Basin in northern Alabama. Threats of habitat alteration and commercial collecting led to its listing as a threatened species under U.S. federal law. The life history of the species is poorly known. From April through September 1985 we surveyed 1 km sections of 10 streams to determine life history information, population structure, and habitat use. We further evaluated the effects of habitat degradation on turtle populations as a result of coal mining. The results suggest that mining siltation has a negative impact on the distribution and population structure of the flattened musk turtle. Turtle populations in mine-impacted sites were small with population structures skewed toward old individuals compared with sites not impacted by mining. Only the population at Sipsey Fork, unaffected by mining, had a large population of *S. depressus*, but numbers and total biomass were less than literature reports for other kinosternid turtles. Another population unaffected by mining was small but showed good recruitment while two additional unaffected populations showed population structures reflecting commercial collecting. Except at Sipsey Fork (with approximately 600 flattened musk turtles), there were too few turtles with which to make reliable population estimates despite intensive sampling. The overall sex ratio was 1.5 males per female, but varied substantially between populations.

The environmental variables correlated with viable turtle populations were low conductivity, a pH between 6.5 and 7.5, and an oxygen value > 7.0 ppm. Turtles avoided deep slow-moving pools, shallow sandy areas, and areas affording little cover. *S. depressus* remains in a small area most of the time, with occasional long distance movements of unknown purpose.

Turtles moved from 0 m to 460 m overnight, with males moving more often and for longer distances than females. Neither local nor occasional long distance movements were influenced by weather variables. Individual turtles overlapped both in movement and cover site selection, and there was no evidence of competition for cover sites.

We recorded 67 instances of basking. Basking platforms included branches, logs, rocks, a rock face, and land. Turtles selected sites over deeper (> 450 mm) water. Turtles basked aerially

* The senior author is a Research Zoologist and the junior authors were Biological Technicians at the National Ecology Research Center, U.S. Fish and Wildlife Service, 412 N.E. 16th Avenue, Gainesville FL 32601. The senior author is also a Field Associate at the Florida State Museum, University of Florida, Gainesville.

DODD, C.K., JR., K.M. ENGE, and J.N. STUART. 1988. Aspects of the Biology of the Flattened Musk Turtle, *Sternotherus depressus*, in Northern Alabama. Bull. Florida State Mus., Biol. Sci. 34(1):1-64.

in the direct sun and were alert, but many appeared sick. Cloacal temperatures were as high as 33.1°C.

Power function exponents of regressions of weight on carapace length were near 3.0, as expected. Regressions of weight on carapace width, plastron length, and plastron width were also near 3.0 indicating similar growth relationships among these characters. Regressions of other morphological comparisons were often significant but explained only a small amount of variance.

Past and present threats of habitat degradation from mining, agricultural and municipal sources, and impoundments have combined to isolate the remaining populations of this species. Habitat fragmentation may be the most serious threat to the long-term survival of the flattened musk turtle.

RESUMEN

La tortuga almizclera aplanada, *Sternotherus depressus*, es endémica en ríos y corrientes de la cuenca del Warrior River en el norte de Alabama. Se ha denominado especie amenazada según la ley federal de los E.U.A. debido a alteración de ambiente y recolección comercial. Se conoce poco de su historia natural. De abril a septiembre de 1985 hemos estudiado tramos de 1 km en 10 corrientes para determinar datos de historia natural, estructura poblacional y uso del ambiente. Ademas, hemos evaluado los efectos de degradación ambiental por minas de carbón. Los resultados sugieren que sedimentación causada por las minas tiene un impacto negativo en la distribución y población de la tortuga. Poblaciones en areas afectadas por minería eran pequeñas y tenían mayor proporción de individuos viejos, comparadas con sitios no alterados por minería. Solamente Sipsey Fork, donde no hay minería, tenía una gran población de *S. depressus*, pero los números y la biomasa eran menores comparados con datos publicados sobre otras tortugas kinosternidas. Otra población no afectada por la minería era pequeña pero mostraba buen restablecimiento, mientras que dos otras areas sin minería mostraban poblaciones afectadas por la recolección comercial. Con la excepción de Sipse Fork (con aprox. 600 tortugas por km), habían muy pocas tortugas para hacer un cálculo confiable de poblaciín, a pesar del muestreo intensivo. Habían 1.5 machos por hembra, pero la relación variaba notablemente entre poblaciones.

Los variables ambientales relacionados con poblaciones viables de tortugas eran: conductividad baja, pH entre 6.5 y 7.5, y más que 7.0 ppm de oxígeno. Las tortugas evitaban charcos hondos y lentos, areas arenosas de poca profundidad, y areas sin vegetación o escóndite. *S. depressus* normalmente queda en una area reducida, haciendo de vez en cuando viajes más largos de motivo desconocido.

Las tortugas viajaban de 0 m a 460 m durante la noche, con los machos mudándose con mayor frecuencia y a mayores distancias. Factores meteorológicos no influían ni en los movimientos locales ni en los movimientos fortuitos de larga distancia. Tortugas individuales coincidían en movimiento y en selección de escóndite, y no había evidencia de competición por escóndites.

Registramos 67 casos de asoleamiento. Plataformas para asolear incluían ramas, troncos, piedras y tierra. Las tortugas escogían sitios encima de agua relativamente honda (más que 450 mm). Se asoleaban en el aire y sol directo y eran vigilantes, pero muchas parecían enfermas. Temperaturas cloacales llegaban hasta 33.1°C.

El resultado de regresiones de peso respecto al largo de carapacho era aprox. 3.0, como se esperaba. Regresiones de peso respecto al ancho de carapacho, y largo y ancho del plastrón tambien daban aprox. 3.0, indicando relaciones similares de crecimiento entre estas características. Regresiones de otros aspectos morfológicos eran significantes con frecuencia, pero explican una pequeña parte de la variabilidad.

Las amenazas históricas y actuales de degradación ambiental por minería, agricultura y fuentes municipales, y represas han combinado para aislar las poblaciones restantes de esta especie. La fragmentación del ambiente pueda ser la amenaza más seria para la sobrevivencia de *S. depressus*.

TABLE OF CONTENTS

INTRODUCTION

The flattened musk turtle, *Sternotherus depressus*, was described by Tinkle and Webb (1955) from specimens collected in the Mulberry Fork of the Black Warrior River. The turtle is endemic to the Warrior River Basin above the Fall Line (Tinkle 1959; Mount 1975). Since its description, the biological information that has appeared on it has centered on the turtle's distribution, taxonomic status, and reproductive biology (Tinkle 1958; Estridge 1970; Mount 1975; Iverson 1977a, 1977b; Seidel and Lucchino 1981; Seidel et al. 1981; Close 1982).

Throughout the Warrior Basin, major habitat changes have occurred within the last 20 years because of increased human population and associated development, industrial expansion, and agriculture. Detrimental impacts from pollution and siltation result from a variety of sources, including municipal development, strip mines, clearcutting, and agricultural runoff (U.S. Fish and Wildlife Service 1987). Although quantitative data are lacking, observations by Alabama biologists during the late 1960s and early 1970s suggested that the flattened musk turtle was decreasing in abundance because of these combined impacts (R. Mount pers. comm.). In 1980 and 1983, the U.S. Fish and Wildlife Service and the Alabama Coal Association, respectively, issued contracts to assess the turtle's status (Mount 1981; Ernst et al. 1983). Mount's (1981) report recommended Federal protection but Ernst et al. (1983) thought the turtle merited a "special concern" status.

In 1985, we received a contract to assess the effects of coal mining on the flattened musk turtle and to make suggestions to reduce future mining impacts. In addition to surveying turtle populations, we collected comparative data on the life history, population structure, and habitat of *Sternotherus depressus*. Since few studies have concentrated on stream-dwelling species, these data could assist in understanding the ecology of freshwater turtles in different habitat types and under adverse environmental conditions. This paper reports results, in part, from our surveys. The turtle is now protected by Alabama State Law, and has been listed as threatened under provisions of the Endangered Species Act of 1973 (U.S. Fish and Wildlife Service 1987).

ACKNOWLEDGEMENTS

We thank the following for advice and assistance during this study: Robert Mount, Ken Marion, Carl Ernst, Herbert Boschung, R. Bruce Bury, John Christian, Ricky Ingram, John Pulliam, Jose Gallo, Dale Jackson, Justin Congdon, Randy Johnson, Sharon Henson, Bill Harris, John Brewer, Larry Hedrick, Jim Hughes, and Dick Evans. We also thank the numerous residents of the Warrior Basin who told us about themselves, the rivers, and the animals of the rivers, while we were catching turtles.

We thank Herbert Boschung (University of Alabama), Peter Meylan (formerly of the Florida State Museum), Robert Mount (Auburn University), and Robert Reynolds and George Zug (U.S. National Museum) for allowing us to examine specimens in their respective collections.

Dona Bentzien, R. Bruce Bury, Carl H. Ernst, J. Whitfield Gibbons, and J. B. Iverson provided constructive comments and criticism of various drafts of the manuscript. Luana Whitehead and Anita Brand typed early drafts, and Anita Brand helped extensively with the administration of this project; we could not have carried out the study without her almost daily assistance.

This study was conducted under contract No. 14-16-0009-84-1896 between the Office of Surface Mining, Department of the Interior, and the U.S. Fish and Wildlife Service. Collecting was authorized under Scientific Collecting Permit No. 172, as amended, from the Alabama Department of Natural Resources.

PHYSIOGRAPHY AND WATER QUALITY OF THE WARRIOR BASIN

The Warrior Basin comprises approximately 16174.5 km^2 in north central Alabama. The area is part of the Cumberland Plateau Physiographic Provence and lies between the Tennessee Valley to the north, the Appalachian Mountains to the east, and the Coastal Plain and Fall Line to the south and west. The land is a peneplain dissected by rivers and streams producing many gorges. Much of the rock is comprised of Pennsylvanian Age sandstone of the Pottsville Formation which reaches a thickness of approximately 366 m in Winston County (Wahl et al. 1971). Much streambed load consists of naturally eroded sand.

The major river in the drainage is the Warrior (or Black Warrior) River. The drainage area within the range of *S. depressus* above Bankhead Dam is approximately 10308.3 km^2 and includes three major tributaries: Locust (3131 km^2), Mulberry (1463 km^2), and Sipsey Forks (2580 km^2). Within the range of *S. depressus*, there are three major impoundments: Bankhead Lake, completed over 60 years ago; the lake behind Holt Dam, created in 1968; and Lewis Smith Lake, created in 1961. The upper reaches of Bankhead and Lewis Smith are known to contain *S. depressus* (Mount 1981; Ernst et al. 1983).

The Warrior Basin includes the most productive of Alabama's three coal mining regions, the Warrior Coal Basin, and accounts for 89.9% of Alabama's coal production. The Basin underlies a substantial portion of the flattened musk turtle's range, including parts of Blount, Cullman, Jefferson, Walker, and Winston counties. The coal, in general, is high grade bituminous noted for its low percentage of sulfur and ash.

As of 1983, there were 167 area and contour surface mines in the Warrior Basin accounting for 55% of the coal production in Alabama (Tolson 1984). Blount, Cullman, Jefferson, Walker, and Winston counties account for 67.9% of surface mining production. Tolson (1984) estimated disturbed acreage from surface mining based on aerial surveys in 1978 within the range of the flattened musk turtle as follows: Blount 7657, Cullman 4711, Jefferson 23190, Walker 36640, and Winston 5077. The area (acres) permitted for surface mining in 1982-3 in the same counties were: Blount 279, Cullman 3353, Jefferson 10466, Walker 13793, and Winston 2415. In 1983, these five counties contained 103 active surface mines.

In 1949, the water quality within the basin was considered reasonably good, although Village Creek, Valley Creek, and Five Mile Creek were "grossly polluted" (Anon. 1949). This paper provided baseline data on water quality for many of the streams known to contain *S. depressus*. Water pollution has adversely affected the fishery resources of the Warrior Basin (U.S. Fish and Wildlife Service 1987, and references therein).

THE BIOLOGY OF *S. DEPRESSUS*

The flattened musk turtle is a relatively small turtle with the largest known individual 119 mm in carapace length (CL) (Mount 1981). Estridge (1970) reported carapace measurements for a hatchling of 25 mm long by 12 mm wide. Hatching took about 12 h and the carapace flattened within 13 days.

Close (1982) reported males required 4-6 years to reach sexual maturity whereas females required 6-8 years. Tinkle (1958) thought maturity occurred in males at 75 mm CL and in females at 90-100 mm CL. Close (1982) noted that males of 60-65 mm CL may have sperm in their epididymus and suspected females mature at 70-75 mm CL. Longevity is unknown but individuals of other species of *Sternotherus* have lived > 25 years in the wild (Ernst 1986).

The flattened musk turtle lays from 1 to 3 eggs per clutch, and two clutches per season appear normal, as is common in kinosternids (Close 1982; Wilbur and Morin 1988). Close (1982) reported an average reproductive potential of 4.2 eggs, and found evidence for a third clutch in at least one individual. The average length of incubation was 92.4 days (N = 17) (Close 1982), but the egg hatched by Estridge took 122 days to hatch. Neither author reported incubation temperature. Ovulation by most turtles initially occurs in May, with a second clutch in June (Close 1982). Ovulation stops and oviposition has been completed by early July, and Close (1982) estimates the last clutch is deposited between mid-June and early July.

Little is known concerning population structure. Of the type series, a large percentage were juveniles (Tinkle and Webb 1955). Indeed, 55% of the *S. depressus* collected prior to 1970 were juveniles. Of the turtles collected by

Mount (1981) and Ernst et al. (1983), 14% and 16.7%, respectively, were under 70 mm CL. Tinkle (1958) gave a male:female sex ratio of 1:3, but stated that the uneven sex ratio might be due to sampling bias rather than a bias toward females in the population.

Mount (1981) reported *S. depressus* to be opportunistic feeding on mollusks when present, and arthropods when mollusks were scarce or absent. Tinkle (1958) noted a prevalence of hapliplid beetles in the feces of juveniles. In a more extensive food analysis, K.R. Marion (pers. comm.) and his students found snails comprise 75% by weight of the diet, with *Corbicula* (12%), insects and larvae (8%), crayfish (3%), fish (1%), and plant material (1%) constituting the remainder.

The flattened musk turtle is principally a stream-dwelling turtle, although the upper reaches of reservoirs are inhabited. Ideal habitat includes submerged rocks, crevices, and logs (Fig. 1). Juveniles often are found in shallow riffles and weed beds. Mount (1981) reported optimal habitat conditions as follows: (1) drainage area between 130 and 1295 km^2; (2) a depth averaging 60 cm with vegetated shallows alternating with deeper pools; (3) pools containing a detectable current; (4) abundance of submerged rocks and crevices; (5) low silt load and minimal silt deposits; (6) abundant molluscan fauna; (7) relatively low nutrient content and bacterial count; (8) moderate temperature; and (9) minimal pollution. Ernst et al. (1983) noted that *S. depressus* was found in sandy habitats if adequate cover and food were nearby.

The earliest in the season *S. depressus* has been collected is April 18 and the latest is October 20 (D. Close pers. comm. to R. Mount); this activity period is similar to that reported for some other *Sternotherus* (e.g. Ernst 1986). Overwintering habits are unknown.

METHODS

Site Selection.— We plotted locality data from Mount (1981) and Ernst et al. (1983) on U.S. Geological Survey (U.S.G.S.) 1:250000 topographical maps (Birmingham and Gadsden quadrangles) along with statements by these investigators as to the suitability of the habitat and the status of the *S. depressus* population. Sites then were located on both the Geological Survey of Alabama drainage map for the Upper Black Warrior Basin (Scott 1978) and U.S.G.S. 7.5 minute series topographic maps. After on-site visits, we selected ten areas for intensive study (Fig. 2).

The main criteria for site selection on streams not affected by mining were that they contain a known population of flattened musk turtles, were free from obvious degradation due to mining, were at least 8 km downstream from any known direct contamination or stream discharge from a mining operation, and were as free as possible from other sources of sedimentation.

We selected mine-affected study sites either adjacent to or immediately downstream from mining operations in streams containing known populations of flattened musk turtles. We selected streams that were not affected, or affected as little as possible, by other sources of sedimentation. We determined when mines were operated as well as when permits were issued for active mines presently operating. Because no public records of mining activities exist prior to 1970

Figure 1. Optimum habitat of the flattened musk turtle. The water should be clean with abundant crevices for cover. Sipsey Fork.

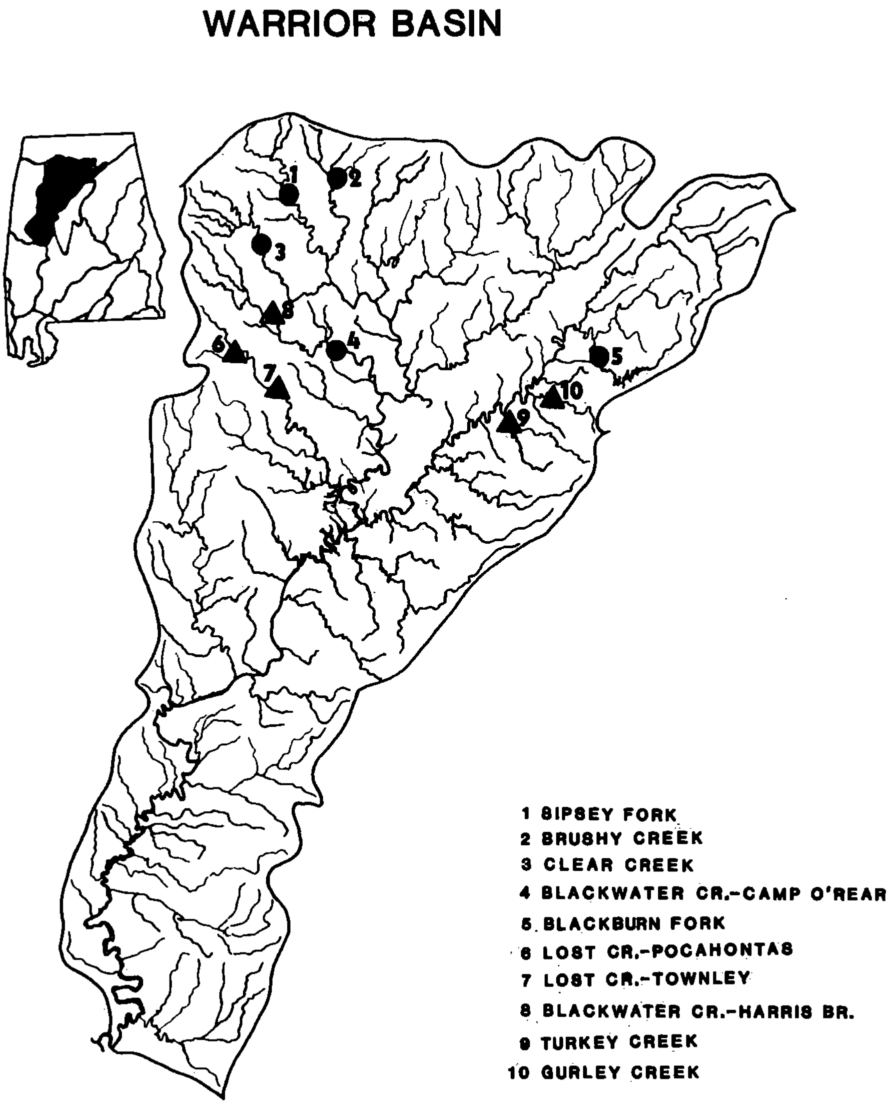

Figure 2. Map of the Warrior Basin showing the location of study sites. The circles represent sites unaffected by mining, and the triangles represent mine-affected sites.

(R. Johnson, Alabama Surface Mining Commission, pers. comm.), dates of operation were estimated through comparison of old and updated topographic maps, and through discussions with local residents.

Site Description.— The sites unaffected by mining were as follows:

1) Sipsey Fork (T9S R8W S33 and 34). Sipsey Fork primarily consists of stretches of sluggish water separated by short riffle zones. Water clarity is excellent and tree cover averages 10%.

   The stream banks, other than for some sandstone bluffs, are moderately steep, sandy, and well-vegetated. The stream bottom is bedrock overlain by patches of sand and slab-like boulders. Water depth ranges from a few centimeters in riffle areas to a maximum of about 1 m. Sand-covered areas primarily consist of extrusions below riffles. Log debris is present and generally clustered near the shorelines. The stream rises in the Sipsey Wilderness and flows through Bankhead National Forest.
2) Brushy Creek (T9S R7W S23). Habitats range from deep quiet water to shallow rapids, and some areas are similar to Sipsey Fork. Cover on the stream bottom is provided by boulders, although some log debris also is present. Tree cover averages 25%. The stream banks are generally steep and vegetated, and water clarity is good except in areas of deeper water and downstream from the confluence of Capsey Creek. The stream flows through Bankhead National Forest.
3) Blackwater Creek - Camp O'Rear (T13S R7W S14, 15, 22, and 23) - This site lies 17 km downstream of the Harris Bridge site and about 6.5 km downstream of the Musgrove Country Club dam. The stream flow is moderate to fast with an average depth of 0.5 m. The bottom consists of fissured and broken bedrock, blackish in color, overlain by rock slabs and irregular boulders. Sand and gravel occur in small patches. Banks are sandy, abrupt but fairly low, and well-vegetated. Tree cover averages 10%. Water clarity tends to be fair to good, although the water is "tea-colored," possibly due to tannin staining. The river flows through wooded and pasture land.
4) Clear Creek (T11S R9W S1). Clear Creek is comparable to Blackwater Creek (Camp O'Rear) in its steady flow and bedrock bottom, but lacks an extensive bottom cover and sand-free crevices. Long stretches of exposed, convoluted bedrock predominate, interspersed with sand-filled depressions. Overall tree cover averages 25%, and the stream banks are steep, sandy, and well-vegetated. Water depth averages about 0.5 m, and the current is a continuous swift flow in midstream and along most of the shoreline. This stream flows partly through Bankhead National Forest, and there is some pasture land adjacent to it and in its headwaters.
5) Blackburn Fork (T13S R1E S30). At this site, the stream is fairly slow, with intermittent small riffles and several deep holes. The stream banks are abrupt and moderately steep in most places, and there are some rocky bluffs. Most of the adjacent terrain is wooded hillside except for one large pasture. Tree cover averages 40%. Sharp-edged bedrock shelving, arranged perpendicular to and angled into the current, is found in four widely separated stream sections. This site is located below Inland Lake and the stream flows through a valley lined with woods and pastures.

The mine-affected sites were as follows:

1) Lost Creek-Pocahontas (T13S R9W S28 and 29). This site differs from the downstream site near Townley in its rockiness and lack of extensive sedimentation. The stream banks are rather steep due to erosion 300 m downstream from station 0. Below this station, the banks tend to be low to moderate and well-vegetated. Tree cover averages 33%. Water clarity tends to be fair to good except in deeper water. The confluence of Mill Creek occurs

within the study area. Near the beginning of our study area, the site abuts a strip mine worked prior to 1975.

2) Lost Creek-Townley (T14S R8W S7). Located about 14 km downstream from the Pocahontas site, this portion of the stream lacks large rocks or exposed bedrock bottom. A mixture of sand, gravel, and silt containing abundant fragments of coal and coal fines covers much of the bottom. Log debris is abundant. Tree cover averages 45% with a pronounced canopy overhang due to bank erosion. The site is adjacent to an abandoned strip mine operated > 11-15 years ago, and late in 1985 mining operation resumed. An active mine is operated across the stream. Drummond's large Cedrum mine is located about 3 km above this site.

3) Blackwater Creek-Harris Bridge (T13S R8W S13). This segment bears little resemblance to the downstream site at Camp O'Rear. Boulders and cobbles are either lacking or covered by sediment. The bottom is mostly sand or silt, with little exposed bedrock.

   Log debris is extensive and completely covers the bottom in some places. The stream banks are steep, 1-2 m high, and heavily eroded giving the stream an "entrenched" appearance. Tree cover averages 45% and is accentuated by leaning bankside trees. Two small polluted seepages and a larger channel carrying little water enter the stream. Water clarity is poor to fair, with noticeable staining. Water depth averages 1.0-1.5 m. This site is approximately 17 km upstream from Camp O'Rear, and abuts an abandoned strip mine. It appears this mine has not been worked since the late 1940s, but aerial photographs show a small operation a few kilometers upstream, and there is a large number of abandoned mines still farther upstream.

4) Turkey Creek (T15S R3W S2). At this site, there is a series of rapids separated by stretches of calm water. Water depth ranges from shallow riffles to pools over 1.0 m. Tree cover averages 10%. Shorelines are characterized by fairly steep banks, rock walls, or low cobble-covered flats. Water clarity is poor to good. There are two active mines operated > 3.5 km upstream. Drummond Coal Company's Morris mine is near this site, as are several reclaimed mines. In addition, Interstate Highway 65 has cut through reclaimed mines directly to the west.

5) Gurley Creek (T14S R2W S14, 23, and 24). Gurley Creek is variable at this location, with very shallow riffles to deep, still pools. Tree cover averages 35%. The streamside slope varies from steep to almost non-existent. Water clarity is good to excellent in shallow areas, but becomes poor in deeper spots. This site is adjacent to an abandoned mine and large strip pit operated approximately 20 years ago.

Detailed site descriptions and maps are provided in Dodd et al. (1986).

Study Design.— Each study site was measured in 100-m sections from a position in the center of the stream for 1 km and marked. The station farthest upstream was designated Station 0.

Trapping was conducted at approximately 14-day intervals, depending on water conditions, between 18 April and 16 September 1985 using 2.54 cm mesh wire basket traps (Iverson 1979) baited with sardines. Cans were partially opened or punctured and placed in the bottom of the trap. Two traps were set in the vicinity of 10 trap stations located approximately 100 m apart. Traps were set in areas likely to have turtles, i.e. along logs and in the vicinity of rock crevices, and were placed in such a manner that the trapped turtles could breathe. Traps were set between 1700 and 1830 h each evening and retrieved between 0800 and 0930 h the next morning. The amount of time the traps were in the water and the time spent wading were recorded to the nearest 0.5 h.

Habitat Characterization.— Before setting traps, data on incident light, time of light reading, air temperature, water temperature at the shore, in the center surface of the stream, and at a depth of 1 m, oxygen, pH, conductivity, water visibility, weather conditions, and water level, were taken from approximately the same location. Sediment particle size was measured using screens with U.S.G.S. mesh sizes 10, 18, 35, 60, 120, and 230.

We estimated the depth of the water and bottom conditions throughout the study site four times: during the initial location of stations, the first trap set, in the middle of summer, and late in the season. To determine the relative amounts of substrate types, we estimated the percentage of bedrock, boulders, cobble, pebbles, sand, and silt at stations 2 and 8, and averaged them.

Water quality was measured for alkalinity (bicarbonate), calcium, chloride, total dissolved solids, hardness, iron, magnesium, nitrate, phosphorus, and sulfide using a LeMotte Chemical kit model AM-21. Samples were taken during the second and third weeks in July when 7-day low flows might be expected (Hayes 1978).

Samples (N = 17) reflecting different sediment conditions were collected and analyzed for % organic matter, phosphorus, potassium, magnesium, calcium, pH, hydrogen, cation exchange capacity, % base saturation of K, Mg, Ca, and H, and ppm iron. Analyses were performed by A & L Agricultural Laboratories, Memphis, Tennessee. Samples were taken during the second and third weeks in July. We collected samples from seven locations at the five sites unaffected by mining activities, and from ten locations at mining-affected sites. These locations were chosen to reflect a variety of bottom conditions. For instance, three locations were selected at Turkey Creek, one from the center of the stream with a sandy bottom, one from the mouth of a tributary draining a former strip mine now disturbed by road construction, and one from a slow-moving section of stream where the bottom was covered by soft ooze. When the bottom characteristics of the stream were largely uniform, only one sample was taken.

Maximum and minimum temperatures, and daily rainfall, were recorded at Haleyville, Alabama, using a maximum-minimum thermometer and a rain gauge (Fig. 3).

Data Collection.— Carapace length (CL), plastron length (PL), carapace width (CW) (measured between pleural 3-4), shell depth (SD) (measured between pleural 3-4), the length and width of the second pleural (PL2L, PL2W), the length and width of the gular (GL, GW), and interhumeral length (IL) were recorded to the nearest O.1 mm. Sex was recorded; turtles > 70 mm CL were considered adults (Close 1982). Mass was recorded to the nearest 0.5 g. The same measurements, except for mass, were taken for *S. depressus* in the following museum collections: Auburn University, 32366, 32367, 32368, 32370, 32388, 32554, 32555, 32686, 32689; University of Alabama-Tuscaloosa, 52-1065 (Paratype); University of Florida/Florida Museum of Natural History, 57632, H3275, H3276, H3277; United States National Museum of Natural History, 221785, 230330, 230331, 247950-247975. For morphological analyses, these data were pooled with data collected during field surveys.

Each turtle was assigned an individual identification number (ID) by notching marginal scutes (Cagle 1939). Carapace erosion was noted and drawn on a diagram that included the turtle's identification number, location, and capture date. Unusual scars, missing limbs, abnormal scute arrangements, and excessive algae were noted on the diagram. Each turtle was photographed for future reference.

Telemetry.— In Sipsey Fork, 13 adults were fitted with LF-1 transmitters with 803 lithium batteries weighing approximately 3.7 g (Custom Electronics, Urbana, Illinois). Transmitters were attached to the turtle's carapace with an industrial strength adhesive (Hardman Inc., Belleview, N.J.) and coated with a silicon seal. The whip antenna was not sealed to the carapace and remained free. Turtles were retained 24 h prior to release to ensure that transmitters were properly affixed.

Activity was monitored daily from 1 July to 31 July and from 14 August to 6 September using a CE-12 dual band receiver (Custom Electronics, Urbana, Illinois) and a hand-held yagi antenna. Tracking took place during morning hours; water conditions, water temperature, and weather conditions were recorded daily. When a turtle was located, its position was plotted and the type of cover site, distance from previous location, and whether the turtle was sighted were recorded. Turtles were periodically examined to determine the condition of the transmitter, antenna, and tightness of the seal.

We chose Sipsey Fork as the study site for radio-telemetry because of its large *S. depressus* population, the clarity and shallowness of the water, and its proximity to our field camp.

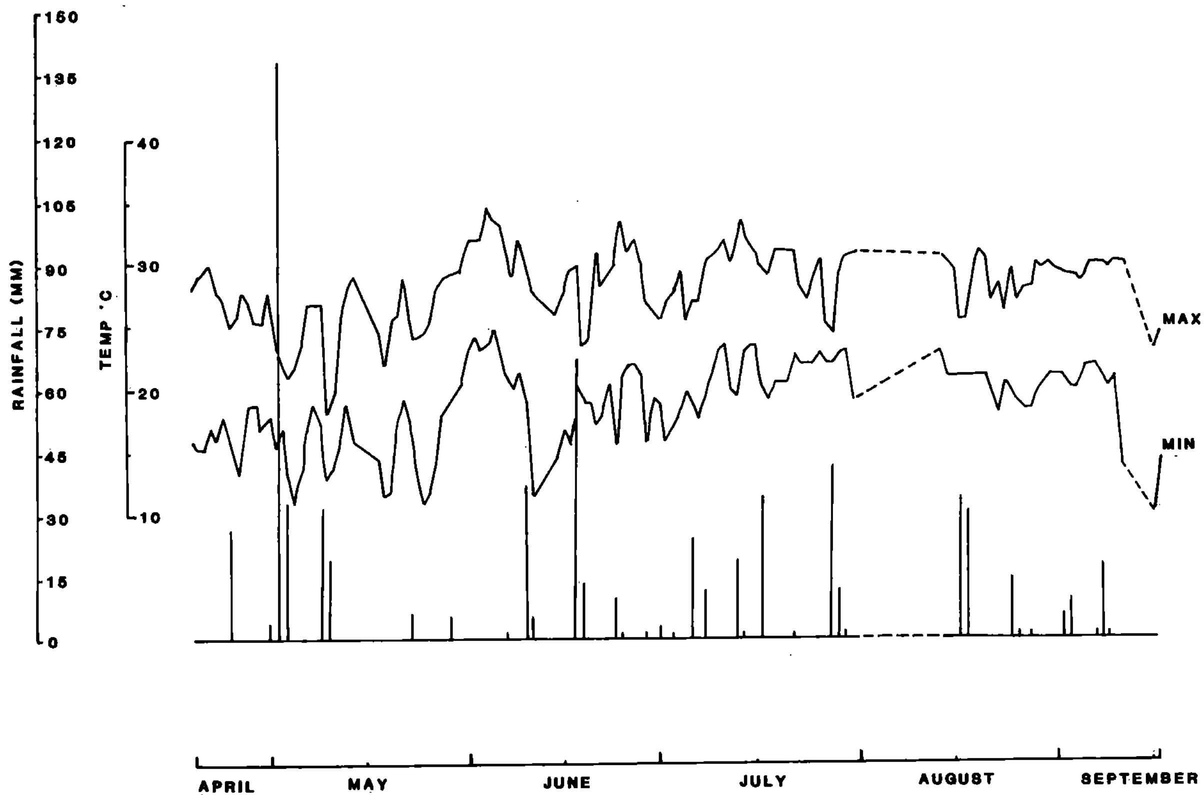

Figure 3. Rainfall and temperature data recorded at Haleyville, Alabama.

Basking.— Early in the season, we saw few instances of basking. However, during the course of daily radio-tracking on Sipsey Fork, basking *S. depressus* were frequently sighted. We therefore made observations on basking incidental to the tracking study. If a turtle was observed basking, we attempted to catch it before it escaped. The cloacal temperature was taken using a quick-reading cloacal thermometer (Miller & Weber, Ridgewood, New York). We noted whether the turtle was in the sun or shade, whether it was alert, and if the turtle had any signs of disease (Dodd 1988b). The type of basking platform (rock, branch, log, or land) was noted, as was its width, height above water, and the depth of the water directly beneath the basking platform. Basking locations were plotted on a map of the study site.

Statistical Analysis.— For statistical analyses, we applied parametric procedures whenever possible. Levene's Test of Equality of Variances (BMDP 1979) was used to determine if variances were equal. In cases where variances were equal, we applied parametric procedures, e.g. an analysis of variance for a repeated measures design with one grouping factor (example: mesh data), or a multivariate analysis of variance (MANOVA) where we had different dependent variables or measurements (example: pH, conductivity, oxygen data).

To determine which environmental factors (various temperature readings, 0_2, conductivity, pH, etc.) affected trapping success, we ran a stepwise regression to determine which factors to use as covariates. Once these factors were determined, we used a multivariate analysis of variance to compare affected and unaffected sites, and a general linear models procedure to compare individual variables.

We examined trapping success to determine differences between stations (treatments) and sampling days (blocks) at a location using a randomized block design to control variability from day to day. Because planned comparisons were involved, we used the Waller-Duncan procedure (Milliken and Johnson 1984) to determine where differences were occurring.

In cases where the variances were unequal, we used the following nonparametric procedures: MRANK procedure in SAS (SAS Institute, Inc. 1985); Friedman's test; Mann-Whitney U test; X^2 test of independence. Because three chi-squares were obtained and the experiment-wise error rate was not controlled for in the overall analysis, the level of significance was set at 0.05/4 or $\alpha = 0.0125$. In all other analyses, the level of significance was set at $\alpha = 0.05$.

To determine if the overall sex ratio varied from 1:1, we first used a Mann-Whitney U test to determine if a difference existed between affected and unaffected sites. Because it did not, we carried out a test to determine if a significant difference existed among the ratios based on a chi-square where:

$$X^2 = \frac{1}{\bar{p}\bar{q}} \sum_{i=1}^{m} n_i (p_i - \bar{p})^2$$

$$p = \frac{n.1}{n..}$$

ni. = total in sample i
n.. = total sample size
n.1 = total having one of the characters, e.g. males
$pi = \frac{ni1}{ni.}$ ni1 = total with character 1 in sample i

Morphological data were analyzed by sex using Pearson Correlation Coefficients. The data were plotted, and a linear regression line ($y = a + bx$) was fitted to the plotted points. When the plots indicated that a curvilinear relationship might be more appropriate, data were fitted to the general allometric equation $y = ax^b$, in the form $\log y = \log a + b(\log x)$, by the method of least squares regression analysis.

Ratios of CW/CL, PW/PL, PL2W/PL2L, and GW/GL were generated. Standard deviations accompanying means are intended as a relative measure of character variability, without implication of statistical significance, because character ratio values may not be normally distributed (Atchley et al. 1976; Atchley and Anderson 1978).

RESULTS

Turtle Capture

During the course of this study, 712 *S. depressus* were captured, the majority (549 captures and recaptures) at Sipsey Fork. Of the total, 663 were caught at sites unaffected by mining while 49 were captured at sites where mining influenced stream quality. Trapping accounted for 461 *S. depressus*, or one turtle every 59.7 trap hours (Table 1). A total of 27,503 trap hours and approximately 653 man-hours wading were spent at all sites.

Of the mine-unaffected sites, *S. depressus* was trapped at all except Clear Creek. Of the affected sites, we also obtained *S. depressus* from four of five sites, but we trapped only one turtle from another site, Lost Creek-Townley. The smallest *S. depressus* trapped was 51.7 mm at Blackwater Creek-Camp O'Rear.

There was a significant difference in trapping success between mine-affected and unaffected sites although our trap effort was equal between site type ($F = 0.98; p > 0.35$). At unaffected sites, the trap success was 1:33.1, while at affected sites, the success was 1:287.9 (Table 1). These figures include results from Clear Creek and Blackwater Creek-Harris Bridge, neither of which yielded *S. depressus*. We further determined trapping success of previous studies at the same or a nearby site (Table 1). Ernst et al. (1983) had better trap success at each location except Gurley Creek and Blackwater Creek-Harris Bridge.

Turtles were evenly distributed in Blackwater Creek at Camp O'Rear and at Brushy Creek where the habitat was largely uniform (Table 2). At other sites, the turtles avoided pools with deep sediment layers (Station 7 at Turkey Creek and Stations 2-3 at Gurley Creek), or very shallow areas with little cover (Stations 6-7 at Blackburn Fork; Station 7 at Blackwater Creek-Camp O'Rear; Stations 4-5 at Gurley Creek). At a few sites, such as at Lost Creek-Pocahontas, *S. depressus* was found to be spatially limited, although suitable habitat appeared to be available elsewhere within these sites. Turtles in Sipsey Fork were found less often in riffle areas (Station 9), areas of shallow water and extensive sand deposits (Station 10), and areas of bedrock with few cover sites (Station 6).

The environmental factors most correlated with turtle capture were low conductivity ($F = 3.75, p < 0.05$), a pH between 6.5 - 7.5 ($F = 9.50, p < 0.01$), and oxygen values > 7.0 ($F = 5.43, p < 0.05$). There were no differences between mine affected and unaffected sites ($F = 1.53, p > 0.05$) in overall trap success x environmental factors. However, conductivity values were significantly higher at affected sites, and were inversely correlated with trap success ($F = 6.05, p < 0.05$).

Table 1. Comparison of trapping success ratios in three studies of *S. depressus* in northern Alabama.

Location	Trap hours	No. turtles	Turtles/ hour
Unaffected Sites			
Sipsey Fork	2640	320	1:8.3
	707	198	1:3.6#
Brushy Creek	2727	42	1:64.9
	806	29	1:27.8#
Clear Creek	2755	0	0
	671	2	1:335.5#
Blackburn Fork	2813	30	1:93.8
	871	33	1:26.4#
Blackwater Creek	2750	21	1:131.0
(Camp O'Rear)	1079	33	1:32.7#
Total	13685	413	1:33.1
Affected Sites			
Turkey Creek	2701	29	1:93.1
	931	26	1:35.8#
Gurley Creek	2772	7	1:396.0
	907	0	0#
Lost Creek	2755	11	1:250.5
(Pocahontas)	490	11	1:44.5#
Lost Creek (Townley)	2775	1	1:2775.0
Blackwater Creek	2815	0	0
(Harris Br.)	214	0	0#
Total	13818	48	1:287.29
Overall Total	27403	461	1:59.7
Mount (1981)	3808*	110	1:34.6
Ernst et al. (1983)	20170	509	1:39.6

Data from Ernst et al. (1983) at the same or a nearby site.

* Estimate provided by R. Mount (pers. comm.) based on 272 trap nights and 14 hours per trap night.

Table 2. Results of trapping and wading for *S. depressus* by station at sites in northern Alabama, 1985. These results only include data from the sampling period and not turtles collected incidental to radio-telemetry observations on Sipsey Fork. F values represent comparisons of differences within sites.

Location	0	1	2	3	4	5	6	7	8	9	10	F
Sipsey Fork	34	53	51	45	63	40	32	44	36	23	20	3.32*
Brushy Creek	4	5	9	5	1	6	8	6	4	2	2	1.12
Blackwater Creek (Camp O'Rear)	2	5	3	3	1	0	3	0	4	2	0	1.19
Blackburn Fork	7	3	4	2	8	3	0	0	1	7	4	2.10*
Turkey Creek	1	10	3	4	0	0	5	0	1	1	4	2.11*
Gurley Creek	0	1	0	0	0	0	1	3	0	0	2	2.07*
Lost Creek (Pocahontas)	0	0	1	2	7	0	1	0	1	0	0	2.07*
Lost Creek (Townley)	0	0	1	0	0	0	0	0	0	0	0	1.00

* $p < 0.05$

Habitat Characteristics

Water Quality.— Conductivity, pH, and oxygen content varied considerably during the course of the summer (Table 3). We found no significant effects of oxygen and pH between mine-affected and -unaffected sites ($F = 1.49$; $p > 0.30$). The average pH of mine-unaffected sites was 7.0 compared with 7.3 for affected sites. Oxygen averages were nearly equal, although with considerable variation both within and among sites. Conductivity values were significantly different, with an average of 83 μmhos for unaffected sites versus 325 μmhos for affected sites ($F = 5.92$; $p < 0.05$). The highest conductivities were found at Lost Creek-Townley (1000 and 1100 μmhos) and at a tributary to Turkey Creek (1000 μmhos). Similar chloride, iron, nitrate, phosphorus, and sulfide values were found among mine-unaffected and -affected sites. Values for alkalinity, calcium, total dissolved solids, hardness, and magnesium were all higher at mine affected sites than unaffected sites. However, Blackburn Fork often had values closer to the average of mine-affected sites, whereas Blackwater Creek-Harris Bridge had values closer to the mine-unaffected sites (see Dodd et al. 1986, for values).

Sediments.— There was considerable variation in the results of sediment analyses among sites. Mine-unaffected sites had lower percentages of larger

Table 3. Comparison of pH, conductivity, and oxygen values for mine-affected and unaffected sites inhabited by *S. depressus* in northern Alabama, 1985. Conductivity in μmhos, oxygen in ppm.

	pH		Conductivity		Oxygen	
	average	range	average	range	average	range
Unaffected Sites						
Sipsey Fork	7.3	6.4-7.9	58.4	44-71	8.2	6.6-9.8
Brushy Creek	6.5	5.8-7.4	32.4	25-38	7.4	6.5-8.6
Clear Creek	6.3	5.4-7.2	32.4	25-38	7.4	6.5-8.6
Blackburn Creek (Camp O'Rear)	7.3	6.8-8.2	77.2	50-111	7.0	5.9-9.1
Total	7.0		82.8		7.6	
Affected Sites						
Turkey Creek	7.6	6.7-8.0	295.5	220-330	8.9	7.3-11.6
Gurley Creek	7.6	7.1-8.1	192	30-250	7.4	5.8-11.0
Lost Creek (Pocahontas)	7.4	6.9-7.9	520	230-730	7.8	6.9-10.5
Lost Creek (Townley)	7.4	6.8-8.4	551	220-1100	7.6	6.5-9.9
Blackwater Creek (Harris Br.)	6.6	6.1-7.1	66.5	55-88	7.2	6.0-8.6
Total	7.3		325		7.8	

For all observations at Brushy Creek, N = 9. At other sites, N = 10 for pH and conductivity and N = 9 for oxygen. Observations began 22 April and ended 13 September.

particles (meshes 10 and 18) and silt (meshes 120 and 230), and higher percentages of sand (meshes 35 and 60) than mine-affected sites. However, there were no statistical differences between affected and unaffected sites ($F = 0.94$; $p > 0.35$), particle size distribution within sites ($F = 1.45$; $p > 0.2$), or particle size x site interaction ($F = 1.17$; $p > 0.3$). These values reflect the average percentages of bottom sediments at particular points in time at a particular spot in the stream, and small sample sizes make the interpretation of these results difficult.

While there was variation in individual sediment chemical measurements, there were no clear-cut differences between sites unaffected and affected by mining. For instance, high levels of magnesium were found at Brushy Creek, Lost Creek, Gurley Creek, and Turkey Creek, the last three affected by mining. Even within a stream, there was considerable variation; for example, calcium levels ranged between 70 and 830 ppm in Turkey Creek. Extremely high iron concentrations were recorded at Turkey Creek (Station 0), at Lost Creek-Pocahontas above the highway bridge, and in Brushy Creek. These probably result from natural iron seeps rather than acid mine pollution. Values from all analyses are provided by Dodd et al. (1986).

Population Biology

Sex Ratio.— The overall sex ratio of *S. depressus* was 1.5 males per female (230 males, 148 females) (Table 4) and is significantly different from 1:1 (X^2 = 12.76; $p < 0.05$). At unaffected sites, the ratio was 1.6:1 whereas at affected sites the ratio was 1.4:1. There were no significant differences in the sex ratios between affected and unaffected sites (U = 0.3725; $p > 0.05$). There were more males at all sites except Brushy Creek and Lost Creek-Pocahontas, and

Table 4. Sex ratio and recapture information on *Sternotherus depressus* at sites in northern Alabama, 1985.

Location	Number	Recap	M	F	J	Sex ratio
Unaffected Sites						
Sipsey Fork	549 *	198	165	98	83	1.7:1
Brushy Creek	53	12	11	10	10	1:1.8
Clear Creek	0	0	0	0	0	
Blackburn Fork	39	3	22	11	3	2:1
Blackwater Creek (Camp O'Rear)	22	2	8	2	10	4:1
Total	663	215	206	131	110	1.6:1
Affected Sites						
Turkey Creek	29	4	15	10	0	1.5:1
Gurley Creek	7	2	4	1	0	4:1
Lost Creek (Pocahontas)	12	0	5	6	1	1:1.2
Lost Creek (Townley)	1	0	1	0	0	
Blackwater Creek (Harris Br.)	0	0	0	0	0	
Total	49	7	24	17	2	1.4:1
Overall Total	712	222	230	148	112	1.5:1

* Total includes one adult for which sex was not determined.

male bias was greatly in evidence at Blackwater Creek-Camp O'Rear and at Gurley Creek.

Population Estimate.— Many turtle studies have used the Lincoln Index, Schnabel, or Schumacher-Eschmeyer tests to estimate population size. Since we were working with open populations with repeated sampling, it is impossible to satisfy the conditions of these tests (Caughley 1977). The limited amount of movement of *S. depressus* within Sipsey Fork (see below) might have allowed using the Schumacher-Eschmeyer test and treating the population as closed assuming no immigration or emigration. However, we had known mortality from disease (Dodd 1988b), and hatchlings were common during the latter part of the summer indicating recruitment. In order to estimate the population size at Sipsey Fork, we therefore used the Jolley-Seber method (Caughley 1977). As the season progressed, the estimate increased from 278 (95% confidence limits = 200-356) to 644 (95% C.L. = 442-824) during the sixth sample in early July (Fig. 4). However, from early July onward, the estimates declined dramatically; the mid-July estimate was only 310 (95% C.L. = 195-411). Because the mid-July estimate was only two weeks later than the highest estimate in early July, and because the Jolly-Seber method is cumulative, a population decline was indicated.

Even though the conditions of the Schumacher-Eschmeyer test may not be rigorously satisfied, we nevertheless computed an estimate of 600 (95% C.L. = 498-762) for Sipsey Fork, and 88 (95% C.L. = 68-127) for Brushy Creek. There were not enough turtles captured at other locations to allow even crude estimates of population size.

Size Class Structure.— For combined data, the population structure showed a preponderance of adults and a substantial proportion of juveniles and younger adults (Fig 5). A different picture emerged when size classes were compared between unaffected and affected sites (Fig. 6). Indeed, the majority of turtles in the smaller size classes in Fig. 5 can be attributed to Sipsey Fork alone (Fig. 7A). The population at Brushy Creek, although small, was rather healthy in terms of its composition, whereas Blackwater Creek-Camp O'Rear contained a preponderance of younger individuals. At Blackburn Fork (Figs. 7B, C), there were few small individuals and the population was skewed toward large and old adults.

Populations at mine-affected sites were even more weighted toward very large adults (Fig. 6). Almost no recruitment is indicated, and except at Turkey Creek, there were few small adults (Figs. 7C, D).

Biomass.— Those sites unaffected by mining activities supported an average of 3.75 kg of *S. depressus*/ha versus 0.80 kg/ha in mine affected sites (Table 5). The highest values were at Sipsey Fork (10.72 kg/ha). The high percentage of

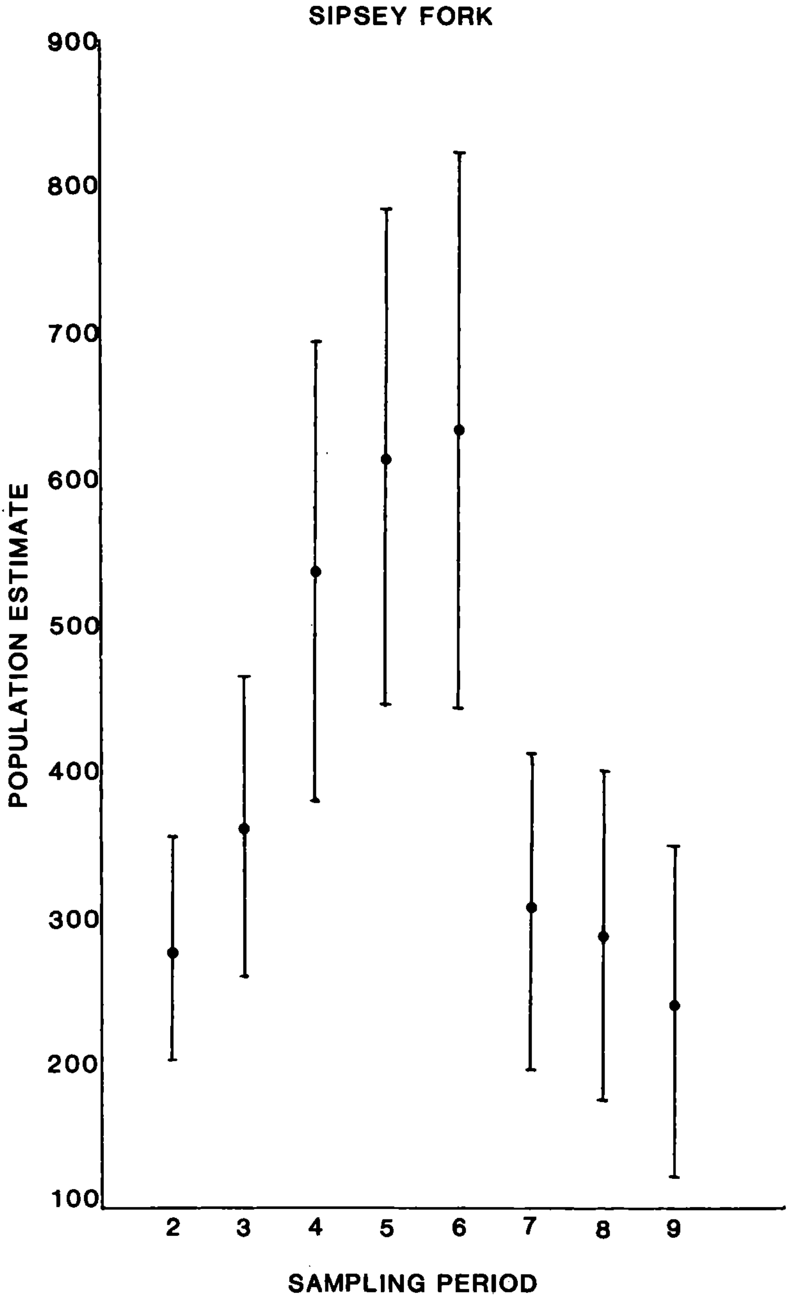

Figure 4. Population estimates of *S. depressus* in Sipsey Fork, with 95% confidence intervals, using the Jolley-Seber method.

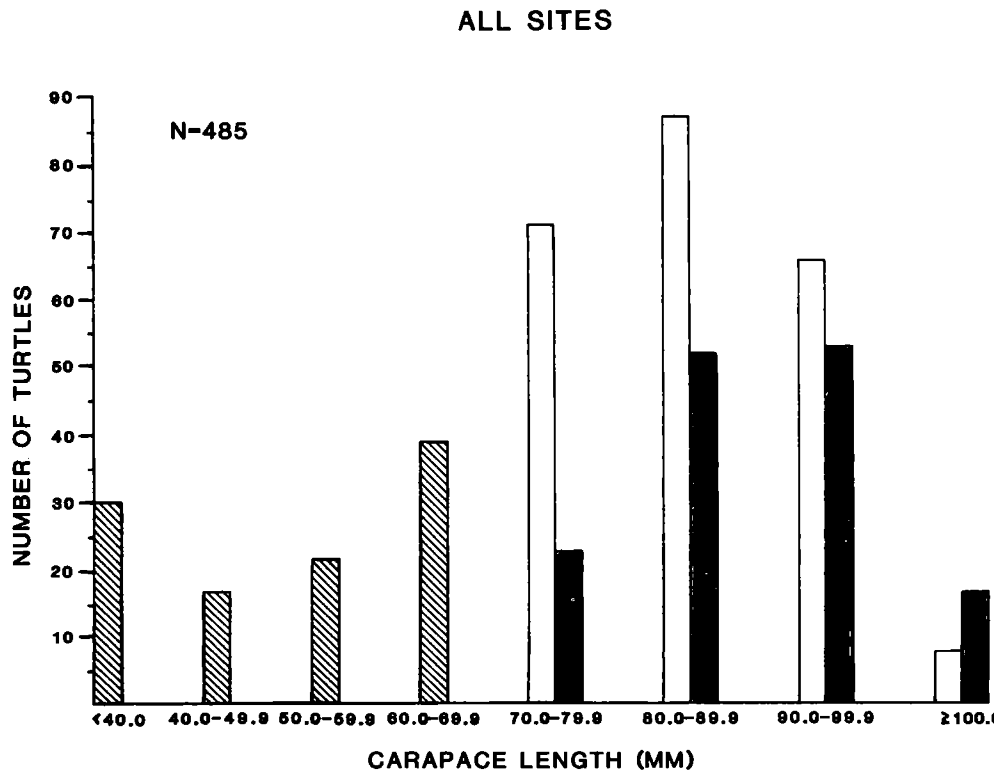

Figure 5. Histogram showing the combined size class frequencies of *S. depressus* caught during the summer of 1985 in northern Alabama. Juveniles = diagonal bars; males = open bars; females = solid bars.

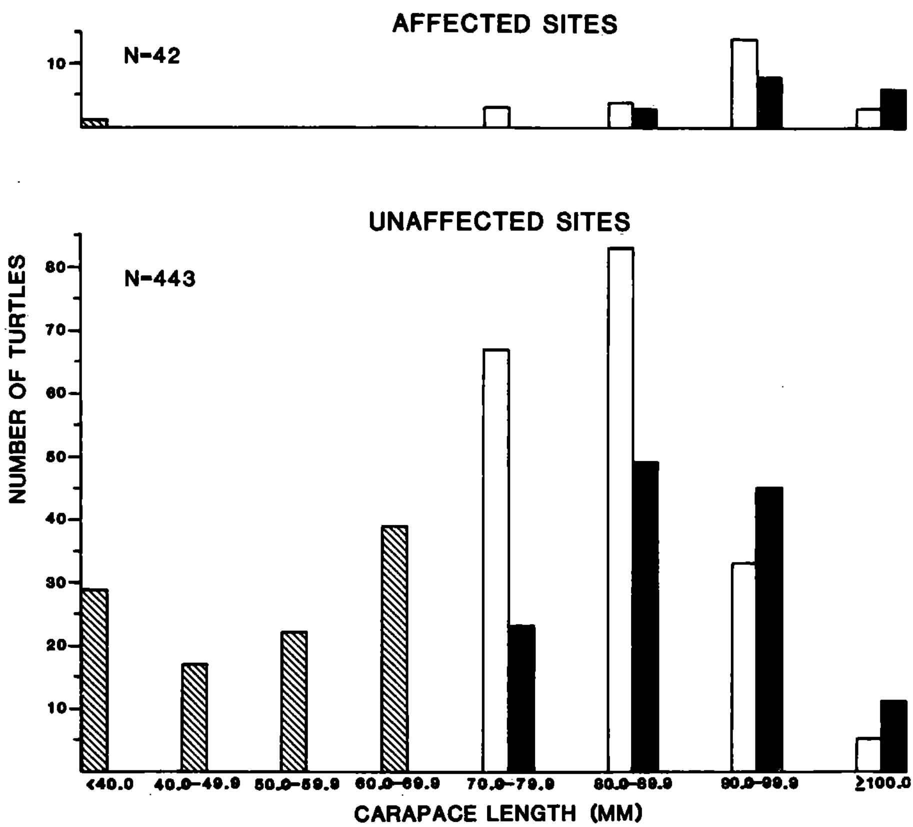

Figure 6. Histograms comparing size class frequencies of *S. depressus* between mine-affected and -unaffected sites in northern Alabama during the summer of 1985. Juveniles = diagonal bars; males = open bars; females = solid bars.

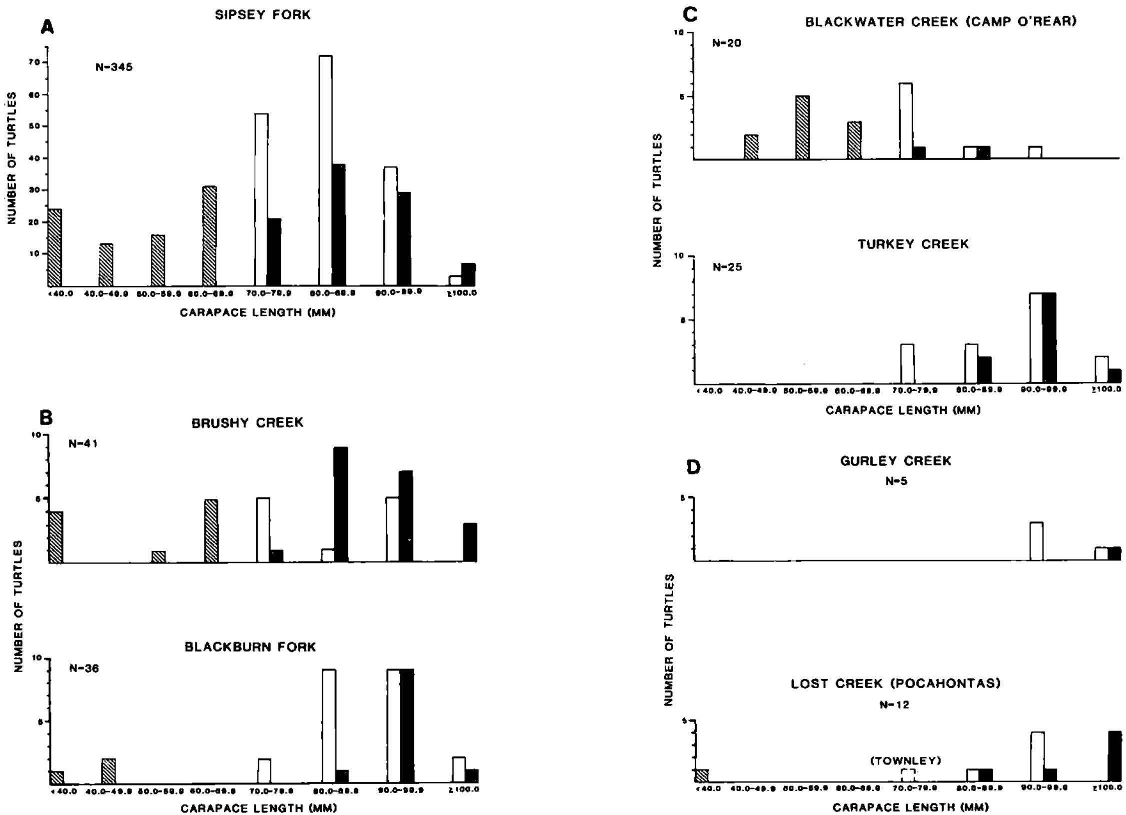

Figure 7A-D. Histograms showing the size class frequencies of *S. depressus* caught at eight study sites during the summer of 1985. Juveniles = diagonal bars; males = open bars; females = solid bars.

Table 5. Biomass of *Sternotherus depressus* at sites in northern Alabama. Weights are in kg; Parentheses indicate the number of observations; and area is in hectares.

Location	Males	Females	Juveniles	Total	Area	kg/ha
Unaffected Sites						
Sipsey Fork	13.68(166)	8.58(98)	1.75(87)	24.01	2.24	10.72
Brushy Creek	0.93(11)	2.11(20)	0.22(10)	3.26	1.99	1.64
Blackburn Fork	2.51(22)	1.42(11)	0.02(3)	3.95	1.98	2.00
Blackwater Creek (Camp O'Rear)	0.56(8)	0.13(2)	0.25(10)	0.94	2.37	0.40
Total	17.67	12.24	2.24	32.16	8.58	3.75
Affected Sites						
Turkey Creek	1.59(15)	1.28(10)	—	2.87	1.98	1.45
Gurley Creek	0.54(4)	0.18(1)	—	0.72	1.17	0.62
Lost Creek (Pocahontas)	0.53(5)	0.89(6)	0.004(1)	1.43	1.65	0.90
Lost Creek (Townley)	—	—	0.05(1)	0.05	6.52	0.80
Total	2.66	2.35	0.054	5.07	6.52	0.80

juvenile turtles at Blackwater Creek-Camp O'Rear was reflected by the low biomass of 0.40 kg/ha. A few large *S. depressus* at Turkey Creek elevated its biomass closer to that of the unaffected sites.

There was a significant difference between unaffected and affected sites ($X^2 = 9.07$; $p < 0.05$) in terms of total turtle biomass (*S. depressus* and all other species), with approximately 70 kg for the unaffected and 43 kg for the affected sites (Table 6). Of this, *S. depressus* constituted 52% of the biomass from unaffected sites and only 12% from the affected sites. There was considerable variation between sites (Table 5).

Growth.— Data on turtles captured during this study previously marked by Ernst et al. (1983) were available for preliminary analysis (K.R. Marion pers. comm.). We considered changes in carapace length ($\bar{X}$ = +2.3 mm; 1.15 mm/yr), plastron length ($\bar{X}$ = +0.65 mm) and weight ($\bar{X}$ = +4.8 g) most reliable for comparison between studies since we took measurements of plastron width, carapace width, and shell depth slightly different.

Turtles increased in carapace length from 0.0 to nearly 0.30 mm/yr with males growing slightly faster than females (Fig. 8). The maximum growth of any turtle was 6.7 mm (3.35 mm/yr) CL. There appeared to be only a slight tendency for animals > 92 mm to decrease growth. Plastron lengths increased very little except for one 77 mm male from Sipsey Fork (Fig. 8B); the large increase is probably due to a measurement error.

Weight Change.— Nearly all data on within-season weight changes were based on turtles from unaffected sites; hence, we could not compare data between unaffected and affected sites. Males showed a slight tendency to gain weight early, then either maintain or lose weight as the season progressed (Fig. 9A). In some instances, substantial weight loss occurred in a rather short period of time. One male lost 16 g in 27 days, while one lost 13 g in 14 days. Weight gains were less dramatic, although one male gained 13 g between 1 June and 27 August. Of 112 weight change observations on males in Sipsey Fork, 46 increased, 66 decreased, and 10 had no change.

The change in female weight within a season is complicated by egg deposition. Although we had fewer observations for females than males, a

Table 6. Comparison of total turtle biomass and *S. depressus* at sites in northern Alabama, summer 1985. Biomass is in kg.

Location	Total Turtle Biomass	*S. depressus* Biomass	Percent *S. depressus*
Unaffected Sites			
Sipsey Fork	27.63	24.01	86.9
Brushy Creek	7.60	3.26	42.9
Clear Creek	6.24	0.0	0.0
Blackburn Fork	13.68	3.95	28.9
Blackwater Creek (Camp O'Rear)	6.84	0.94	13.7
Total	61.99	32.16	51.9
Affected Sites			
Turkey Creek	5.57	2.87	51.5
Gurley Creek	15.62	0.72	4.6
Lost Creek (Pocahontas)	1.61	1.43	88.9
Lost Creek (Townley)	14.77	0.05	0.3
Blackwater Creek (Harris Br.)	5.09	0.0	0.0
Total	42.66	5.07	11.9

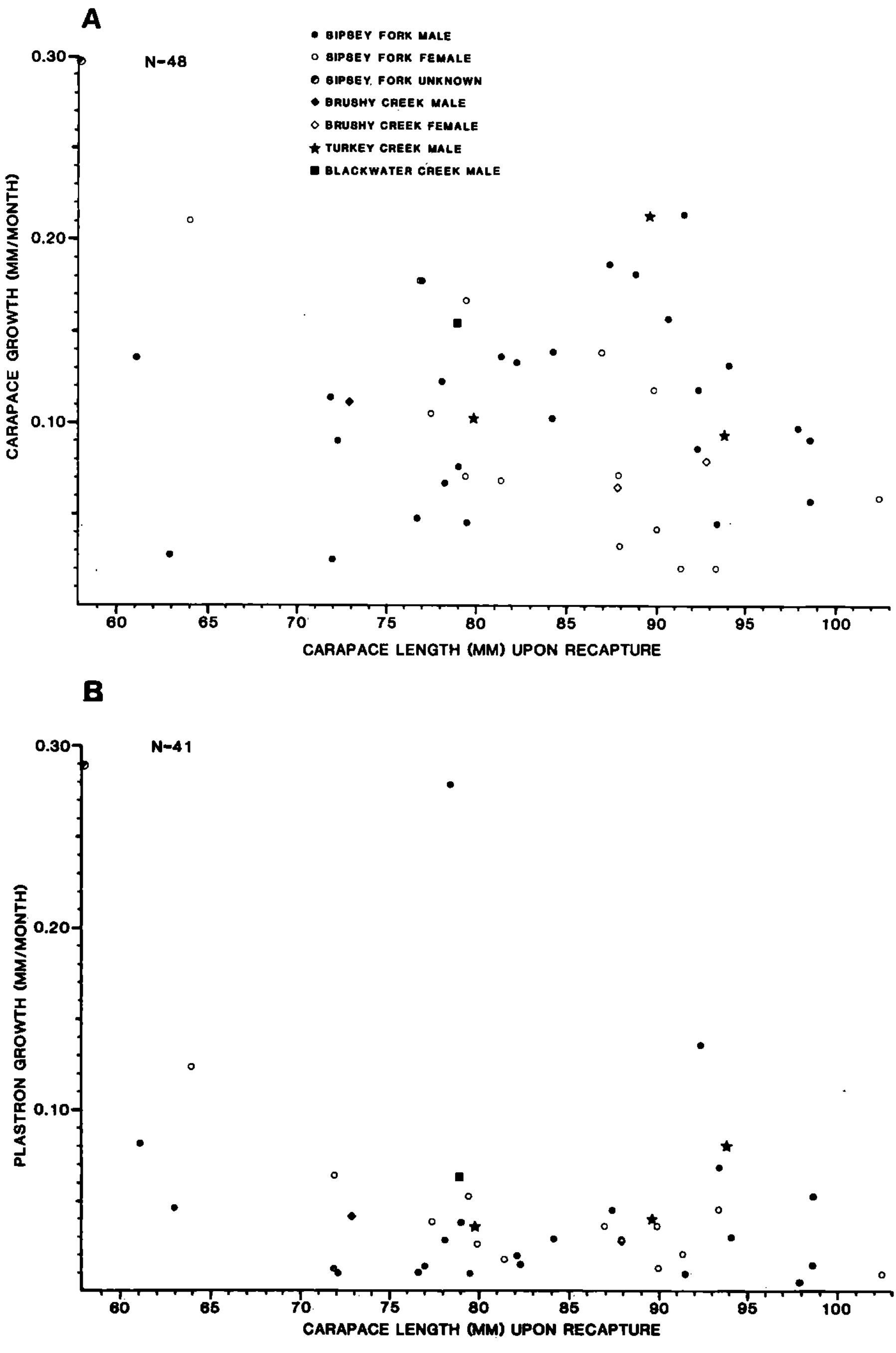

Figure 8. Carapace (A) and plastron (B) growth rates (mm/month) as a function of recapture carapace length for *S. depressus* initially captured in 1983 and recaptured in 1985.

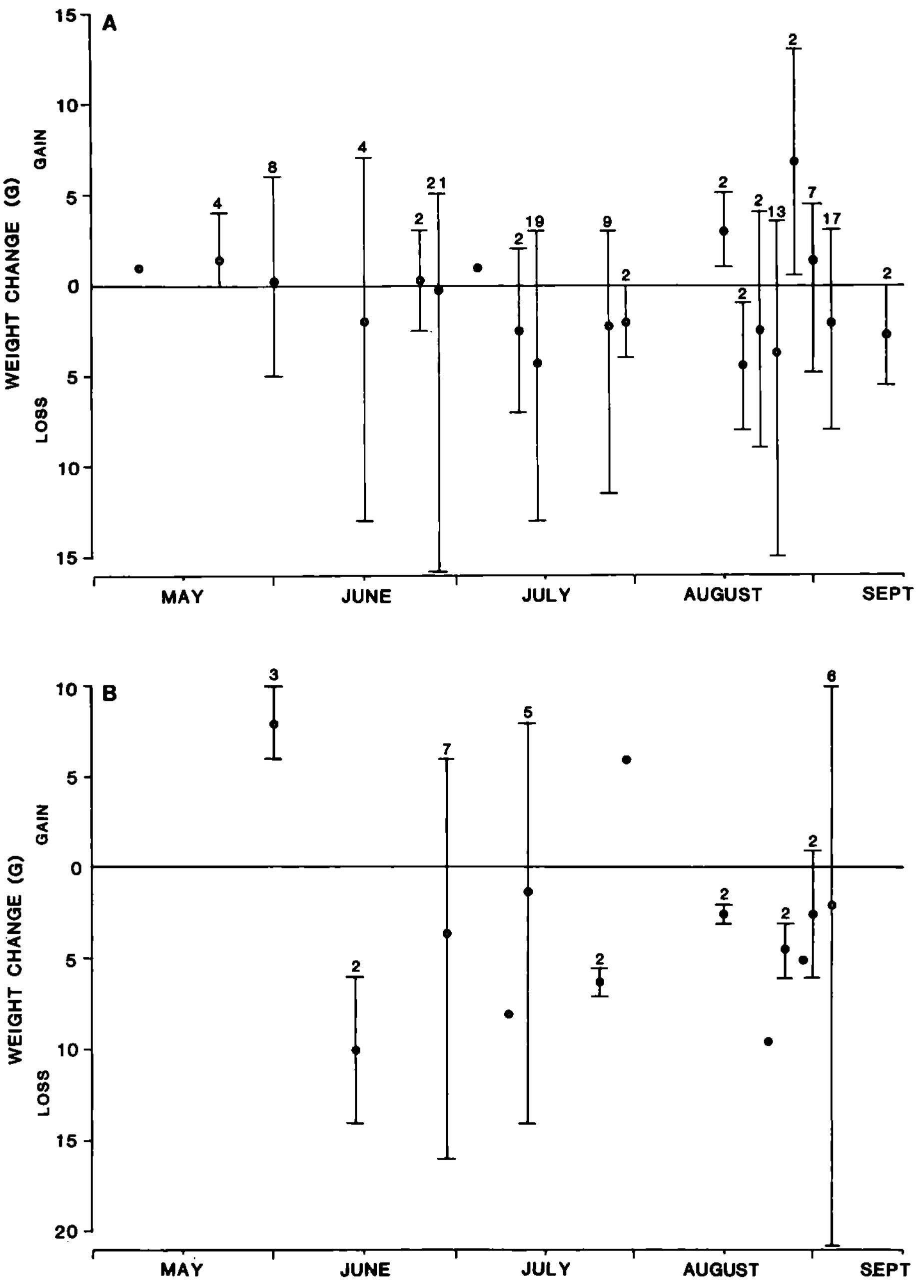

Figure 9. Patterns of seasonal weight changes for male (upper) and female (lower) *S. depressus* recaptured at study sites during the summer of 1985 in northern Alabama.

cumulative diagram (Fig. 9B) showed females tended to lose weight in the middle of the season followed by a gradual gain throughout the remainder. This is illustrated by weight change data for 22 females from all locations (Fig. 10). The greatest weight loss in females (at Sipsey Fork) was 21 g between 25 July and 4 September; the largest gain, 10.5 g (at Brushy Creek), occurred between 22 June and 11 September. Only two females showed no differences in weight.

At all locations, juvenile turtles showed a tendency to lose weight (Fig. 11); we recorded 21 weight losses (0.1 - 6.5 g), 3 no change in weights, and only 4 weight increases (0.5 - 4.0 g) among 23 turtles.

For inter-seasonal weight changes, data were available from 41 *S. depressus* marked by Ernst et al. (1983). These data showed an average increase of 4.8 g between 1983 and 1985, with a maximum gain of 15.7 g in an 86.9 mm female. Several females showed substantial weight gains, but these increases may be associated with egg development prior to oviposition. In general, turtles increased most in the range of 0.10-0.30 g/month regardless of carapace length (Fig. 12).

Nests and Hatchlings.— Prior to this study, natural nests of this species were unknown. On 31 July, CKD found a natural nest on the north shore of Sipsey Fork on a high, sandy bank. This bank had been checked daily since 1 July; attention was drawn to the nest by a fresh crawl. The nest was located 6.5 m from water in such a position that it would receive the afternoon sun. It was shallow and located under slight vegetative cover similar to the nests of *S. minor* (Carr 1952). Hatchlings would have only to go directly downhill to reach the water. Two freshly deposited eggs were uncovered. Dimensions (length, width, mass) were as follows: 33.1 mm, 16.1 mm, 6.0 g; 31.1 mm, 15.7 mm, 5.5 g. These figures are similar to those reported by Estridge (1970) for shell measurements of one hatchling and the average mass of 5.23 g (N = 15) for hatchlings given by Close (1982).

The eggs were incubated at 25°C. Hatching began 14 September (45 days) for one egg and 16 September (47 days) for the other; incubation duration thus was much shorter than reported for other kinosternids (Ewert 1985; Ernst 1986). Both took about two days to complete hatching, and hatching occurred in a sequence similar to that reported by Estridge (1970). There was barely a trace of a yolk scar on both turtles upon release on 18 September.

Shell Erosion

Erosion affecting the carapace has been noted by a number of biologists and commercial collectors working with *S. depressus*. Of 437 *S. depressus* from

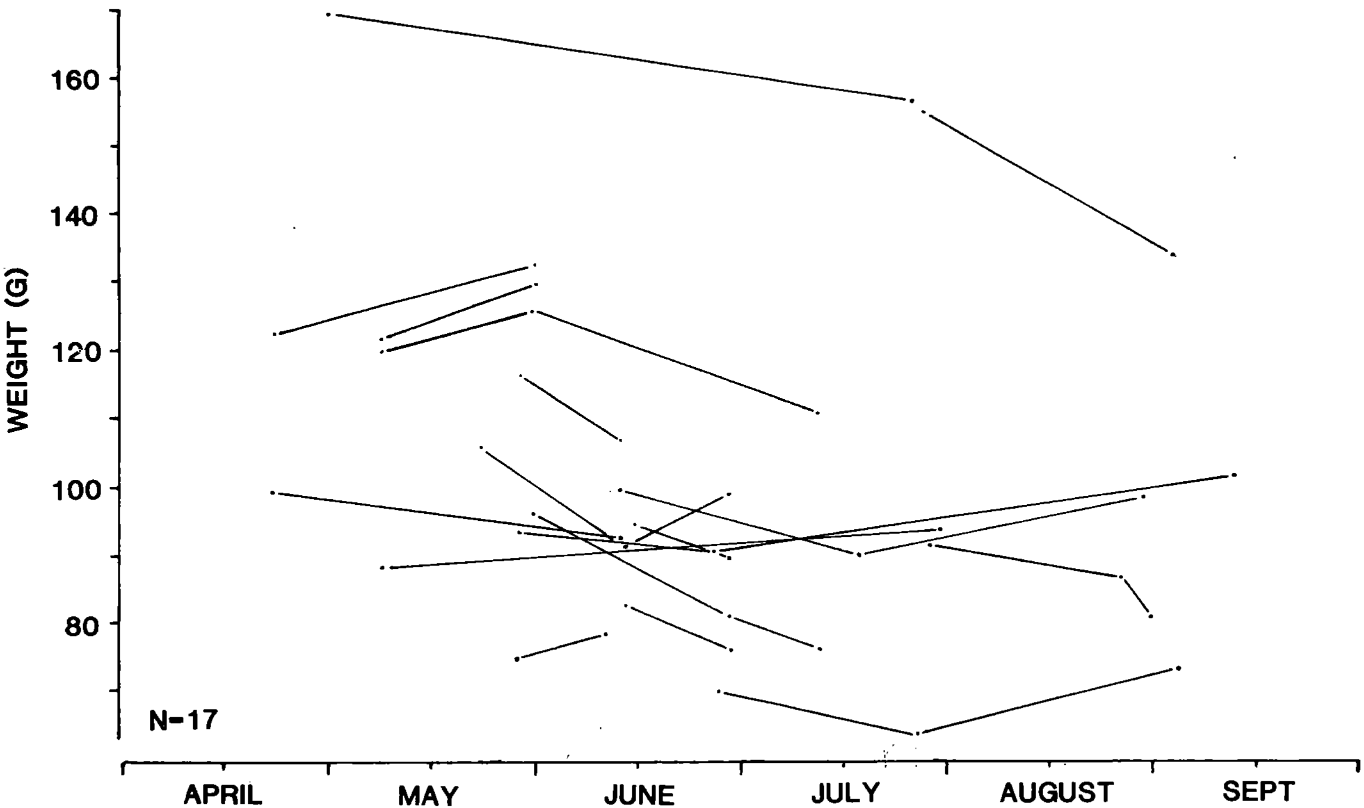

Figure 10. Intraseasonal weight changes of female *S. depressus* recaptured at study sites in northern Alabama during the summer of 1985.

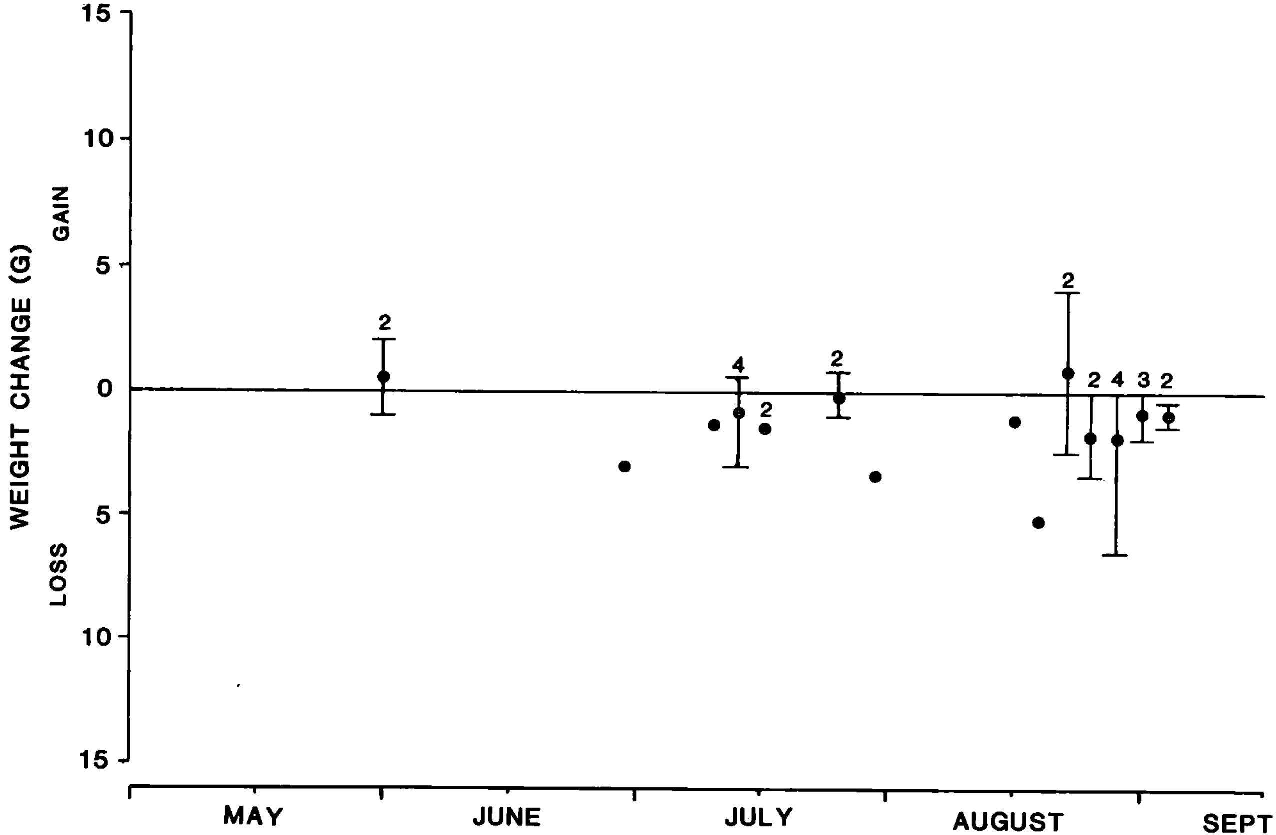

Figure 11. Patterns of seasonal weight changes for juvenile *S. depressus* recaptured at study sites in northern Alabama during the summer of 1985.

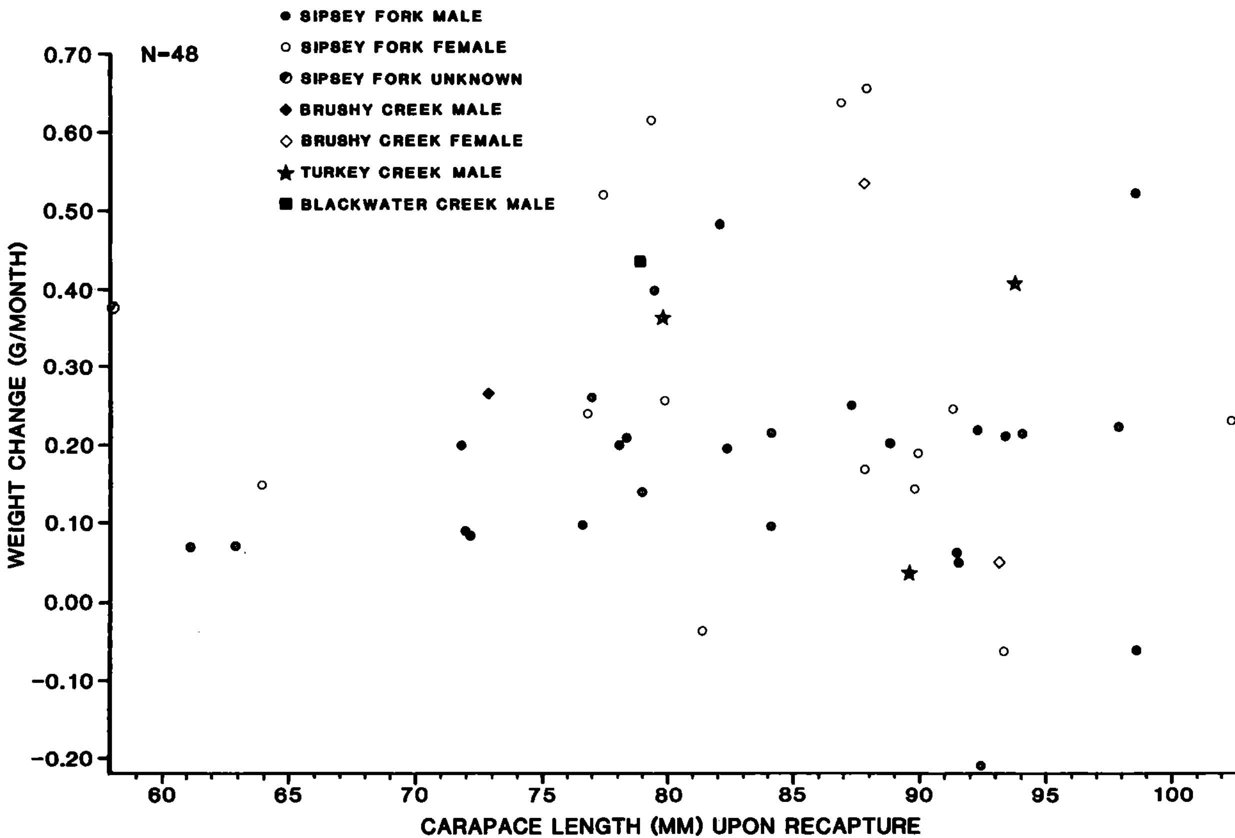

Figure 12. Rates of weight change (g/month) as a function of recapture carapace length for *S. depressus* caught in 1983 and recaptured in 1985.

unaffected sites, 150 (34.3%) were eroded; 58.1% of the mine-affected site turtles (25 of 43) were eroded. These differences were statistically different (X^2 = 11.59; $p < 0.001$). There was considerable variation between populations as to the percentage of eroded turtles, from 0% at Lost Creek-Pocahontas to 91.7% at Blackburn Fork (Table 7). The patterns of erosion, however, seem to vary little between populations, except at Sipsey Fork and Brushy Creek (Fig. 13). Marginals were equally liable to be eroded regardless of location on shell or study site. At Brushy Creek, erosion was concentrated on the front and sides of the carapace; no erosion was found on marginals 10 and 11. At Sipsey Fork, the nuchal and first marginals were most likely (> 65% of the time on eroded turtles) to be eroded.

Table 7. Prevalence of eroded shells in populations of *S. depressus*.

Location	N	N eroded	% eroded
Unaffected Sites			
Sipsey Fork	345	112	32.5
Brushy Creek	36	5	13.9
Blackburn Fork	36	33	91.7
Blackwater Creek (Camp O'Rear)	20	0	0.0
Total	437	150	34.3
Affected Sites			
Turkey Creek	25	20	80.0
Gurley Creek	5	5	100.0
Lost Creek (Pocahontas)	12	0	0.0
Lost Creek (Townley)	1	0	0.0
Total	43	25	58.1
Overall Total	480	175	36.1

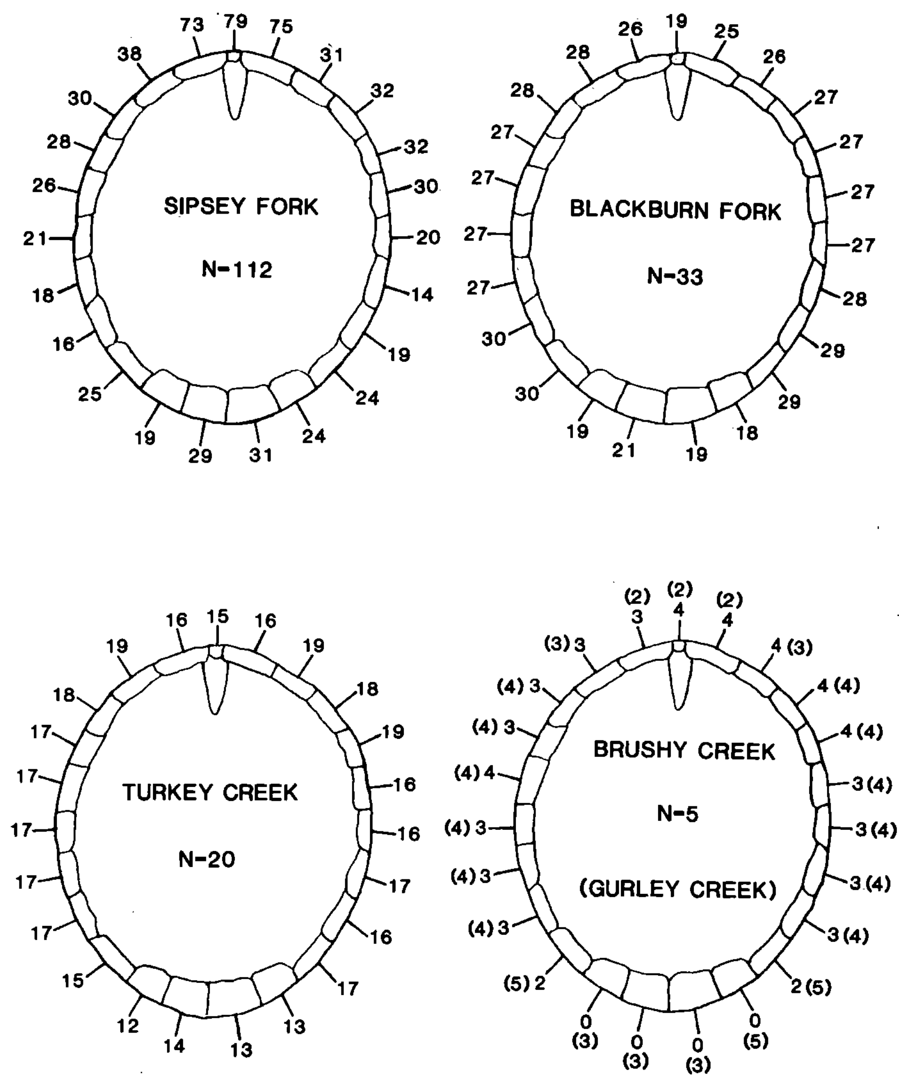

Figure 13. Carapacial erosion patterns of the marginal scutes of *S. depressus*. Numerals outside carapace indicate the number of individuals affected at that site.

Movements and Habitat Use

We followed 13 adult *S. depressus* from 4 to 40 days (Table 8). Males moved 69% of the days and females moved 50%. Movements ranged from 0.5 to 460 m overnight, although movements > 30 m were unusual. Males moved greater distances than females ($\bar{X}$ = 31.2 m, N = 81; $\bar{X}$ = 19.2 m, N = 25), although there were exceptions. Individuals overlapped spacially in terms of movement and cover site selection.

Examination of individual movement patterns (Figs. 14A-G) demonstrated that flattened musk turtles tend to stay in a particular area, and return continously to the same cover sites. An example of this pattern was shown by turtle No. 4600 (Fig. 15) which ventured more than 20 m on five occasions, two of which were to baited traps upstream. Turtle No. 6774 at one point remained under the same ledge for eight days before making an overnight move 43 m upstream; after one night, it returned to its ledge (Fig. 14F).

Table 8. Movement of *S. depressus* based on radio-telemetry data.

Turtle No.	Sex	Length (mm)	Days/0 Movement	Days/ Movement	Range (m)
4330	M	90.5	1	3	1-25
4600	M	97.9	8	32	0.5-24
4612	M	84.4	4	15	0.5-35
4618	M	85.6	2	2	10-135
4335	M	85.6	3	15	0.5-460
6774	M	88.7	8	6	7-103
4280	M	88.6	11	8	6-64
Total Males			37 (31.4%)	81 (68.6%)	
4614	F	86.5	1	3	3.5-160
4616	F	85.5	3	2	2-150
4619	F	83.9	1	3	6-50
4665	F	78.2	10	11	0.5-16
4716	F	93.9	4	4	2-3
4717	F	94.1	6	2	2-4
Total Females			25 (50.0%)	25 (50.0%)	
Total (N=13)	7:6		62 (36.9%)	106 (63.1%)	0.5-460

Table 9. Cover sites used by *S. depressus* in Sipsey Fork based on radio-telemetry data.

Turtle	N	Rock	Crevice	Mud	Root-Debris	Log
Males						
4330	4			2	2	
4600	41	6		6	14	15
4612	16	1	1	10	4	
4618	4	4				
4335	16	3	10		3	10
6774	14	3	10		1	
4280	15	14				1
Total	110	31	11	18	24	26
Females						
4614	4		2			2
4616	5	5				
4619	4	1				3
4665	8				1	7
4716	19	18		1		
4717	8	8				
Total	48	32	2	1	1	12
Overall Total	158	63	13	20	26	38

S. depressus occasionally makes long distance movements for relatively short periods of time. This was shown by turtle No. 4335 which generally remained under a stump and brush pile but made two long movements overnight, the farthest 460 m upstream to a log jam where it remained two nights (Fig. 14G). Long distance movements were always upstream and for short duration, i.e. one to two days. We were unable to correlate these movements either with particular weather or stream conditions, as turtles made such movements independent of one another. Both sexes made long distance movements.

Individual turtles used similar cover sites, i.e. some turtles favored mud, some root debris, and others rocks and crevices (Table 9). Overall summaries give the impression that turtles had no preferences, whereas individual summaries clearly show site preferences. Females tended to prefer rock cover ($X^2 = 27.72; p < 0.001$).

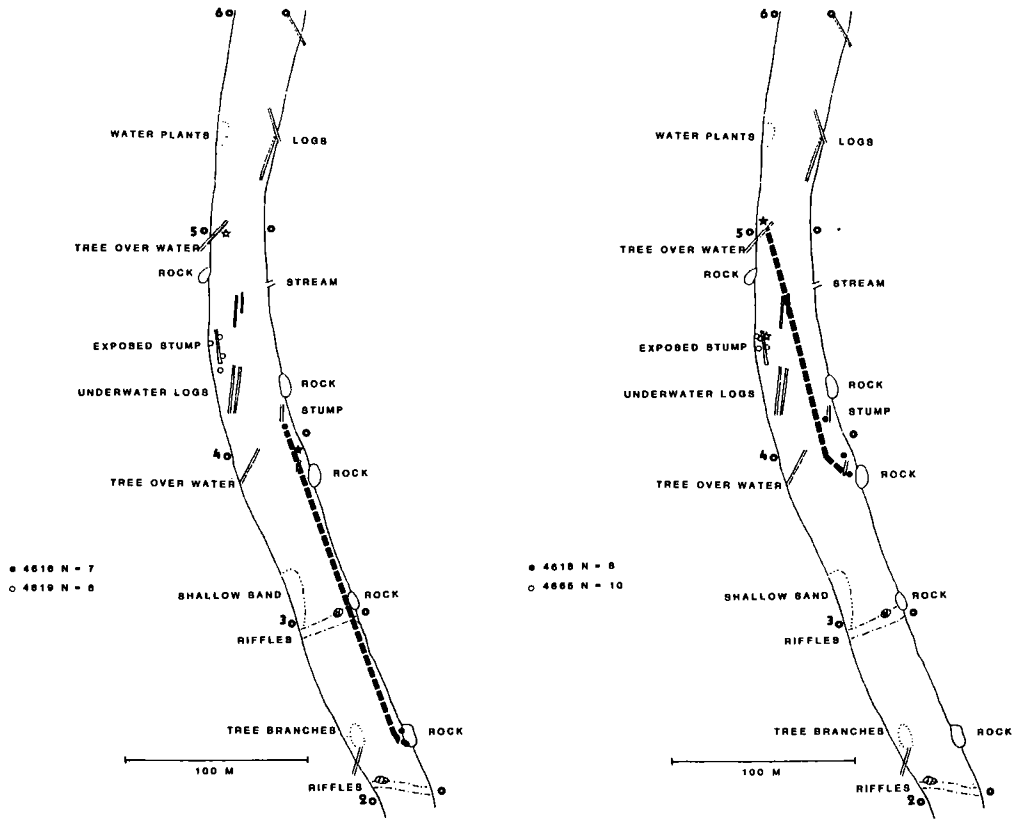

Figure 14 A-G. Locations and movements of radio-telemetered *S. depressus* in Sipsey Fork. A star indicates the initial release point; a large circle indicates that there were many fixes in the same location. The striped line indicates a particularly long overnight movement.

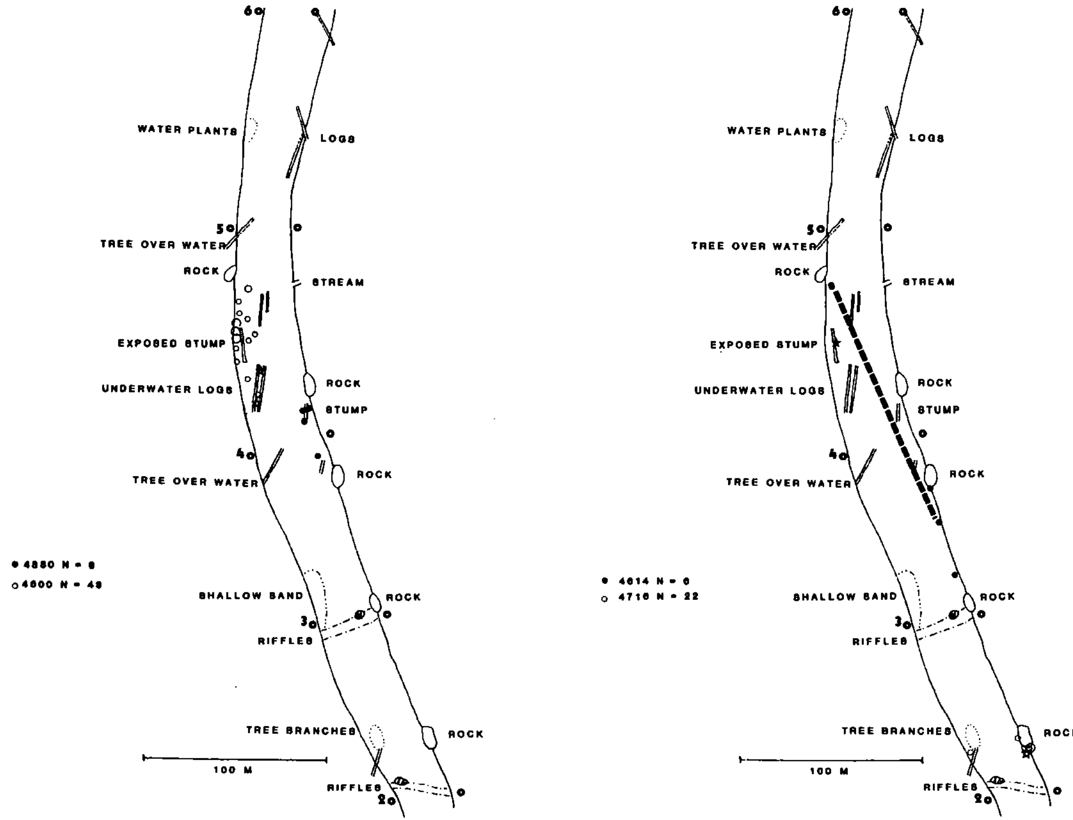

Figure 14 -- Continued.

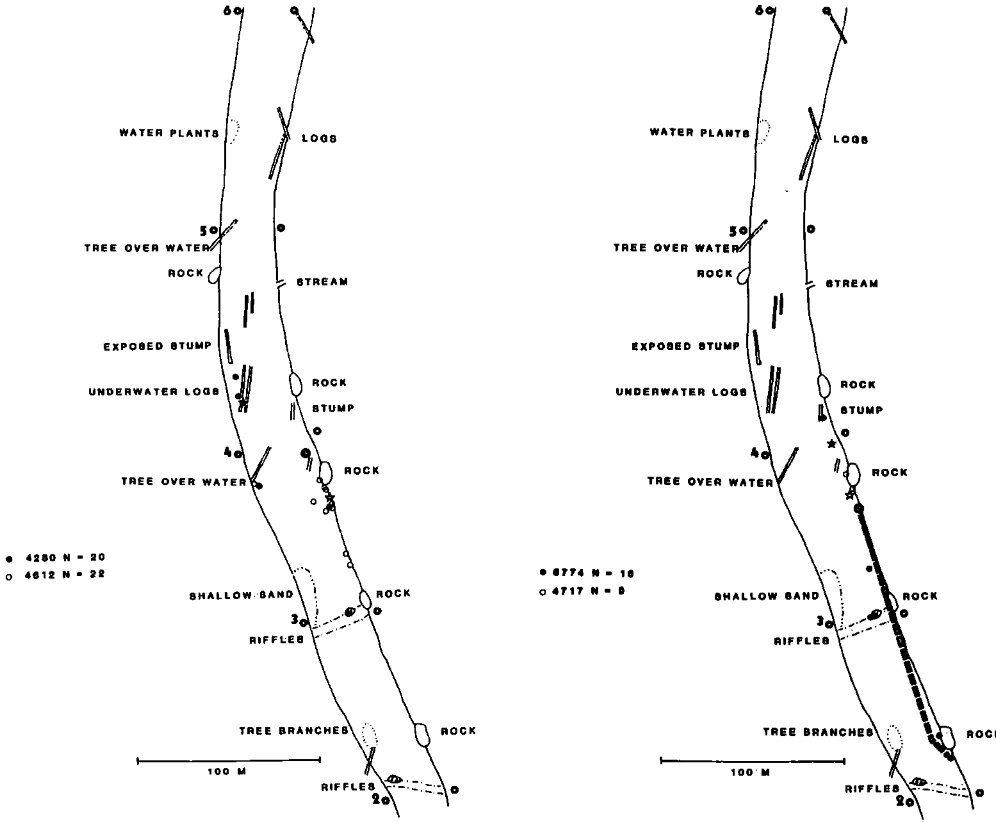

Figure 14 – Continued.

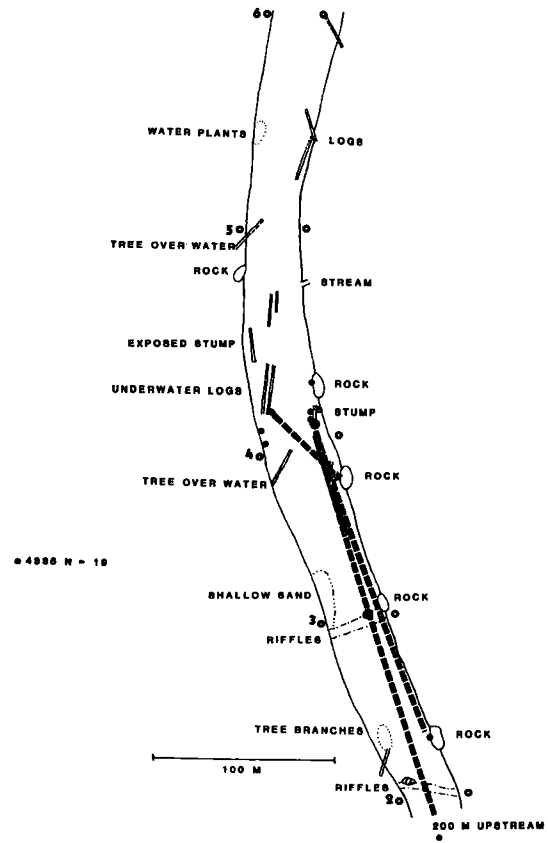

Figure 14 – Continued.

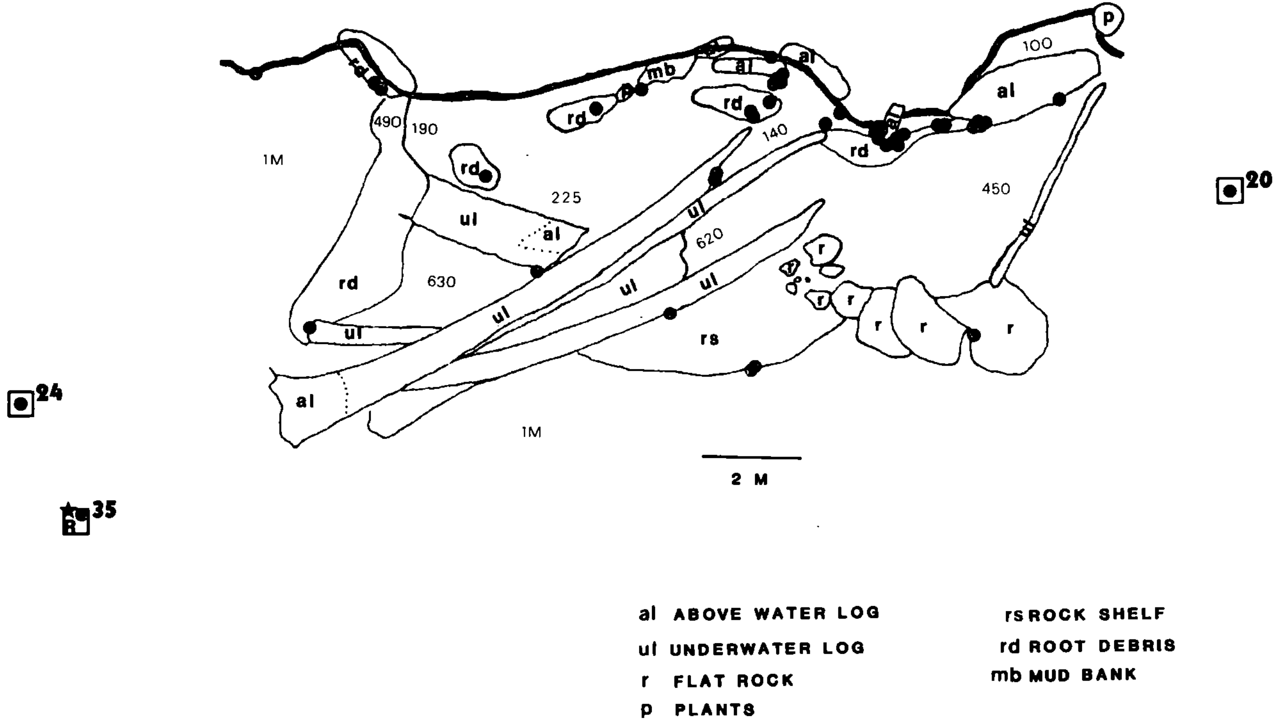

Figure 15. Locations and movements of radio-telemetered turtle 4600. The boxes indicate an overnight movement outside the area normally occupied by the turtle, and the distance traveled. The star is the initial release point; R is the final recapture location. The light numbers indicate water depth in mm, and the shoreline is represented by the thick black line.

Table 10. Cloacal temperatures of individual basking *S. depressus* in Sipsey Fork, 1985. Parentheses indicate the time when the reading was made.

Turtle	Date	Weather	Air Temp	Water Temp. (Time)	Cloacal Temp.	Light	Alert-ness	Notes
4684	08/22	clear, cool		22.0 (0850)	32.6	Sun	No	on log
4757	08/22	clear, cool		22.0 (0850)	30.2	Sun	Yes	
6500	08/23	overcast, cool	23.0	22.2* (0900)	22.2	Overcast	?	turtle wet
4684	08/26	clear, cool	20.0	22.0 (0930)	24.0	Sun	No	on land, died 08/27)
4628	08/28	clear	23.4	22.0 (1000)	25.8	Shade	Yes	on rock
4782	08/28	clear	23.4	22.0 (1000)	26.6	Sun	Yes	
4641	09/01	clear, warm		24.0 (1040)	33.1	Sun	No	on log
4628	09/03	partly cloudy	23.0	22.0*	24.0	Shade	No	

* The maximum water temperature at Sipsey Fork on 08/23 was 25°C; on 09/03 it was 27°C.

For turtle No. 4600, an adult male, 39 data points were available for determining a core area of habitat use (Kaufmann 1962). We excluded several points inasmuch as they were > 20 m from the main center of activity and represented either exploratory movements or movements toward a baited trap. We used a variety of home range estimators, including minimum convex polygon, harmonic mean transformation (Dixon and Chapman 1980), 95% ellipse, and fourier transformation (Anderson 1982) to compute the area of concentrated use. These methods provided varied results, from 77 m^2 (minimum convex polygon), to 88 m^2 (50% value, fourier transformation, Dixon and Chapman 1980) to 123 m^2 (95% ellipse).

Basking

We recorded 67 instances of basking at three locations: 1 at Blackwater Creek-Camp O'Rear, 1 at Blackburn Fork, and the remainder at Sipsey Fork.

The earliest turtles were observed basking was May 16 at Blackwater Creek-Camp O'Rear and the latest was 14 September at Blackburn Fork. The majority of observations occurred betwen 14 August and 4 September at Sipsey Fork. Turtles were most frequently observed during early to mid-morning hours, but this may be a reflection of observer presence rather than a time preference per se. Turtles as small as 33.1 mm CL were observed basking.

The cloacal temperatures of basking turtles (N = 8) were as high as 33.1°C, 9.1°C above the water temperature on that occasion (Table 10). The lowest temperature, 22°C, was recorded in a turtle that was wet, indicating it had just emerged from the water, also 22°C. Even on cloudy days, turtles out of water had body temperatures above that of the water. Turtles with low body temperatures may not have been out of water for a long period.

Most basking turtles were in the direct sun (78.6%), were alert (66.7%), and appeared to be sick (60.6%). Sick turtles (see Dodd 1988b) were less alert than healthy turtles and were more likely to be out of water in shade than their healthy counterparts (Table 11). Also, turtles in the sun appeared more alert than those in shade.

Of the 47 basking platforms used by *S. depressus*, some were used more than once, particularly a rock in the middle of Sipsey Fork that was used by at least six different turtles on different occasions. Branches were the most commonly used platform, followed closely by logs (Table 12). Branches were higher above the water, narrower, and over deeper water than other perch sites. We recorded two instances of the same turtle "basking" on land, although this turtle was very sick and was recovered dead in shallow water the day after the second observation. Basking sites were generally positioned such that they received maximum morning or early afternoon sun (Fig. 16).

S. depressus is an adept climber. The highest we recorded a turtle was 910 mm over water on a 30 mm wide branch. To reach this position, the turtle had to crawl around several branches and move upward at a steep angle. We noted three instances of *S. depressus* perched vertically, once on a branch, once on a rock in the middle of the stream, and once on a vertical cliff face.

Individuals apparently will also move over land to reach a desired basking position; we observed turtles on branches over water that could only have been reached by first crawling on land. Three turtles were perched on branches over land but at the water's edge; when the turtles jumped, they fell on land and were captured.

Morphological Analysis

All power function exponents of body mass regressions on the independent variables of carapace length, carapace width, plastron length, and plastron width

Table 11. Relationship of basking to position in direct sun, whether a turtle was sick, and alertness in the flattened musk turtle, *S. depressus*, in northern Alabama. Number of observations: sun = 42, sick = 33, alert = 57.

	SunY	SickY	AlertY	SunN	SickN	AlertN
SunY	33					
SickY	8	20				
AlertY	26	7	38			
SunN	42	5	6	9		
SickN	9	33	11	2	13	
AlertN	7	12	57	3	2	19
SunY SickY			4			4
SunY SickN			8			1
SunN SickY			3			2
SunN SickN			1			1

Table 12. Basking platforms used by *S. depressus* in northern Alabama. Sipsey Fork, N=45; Blackburn Fork, N=1; Blackwater Creek (Camp O'Rear), N=1. Measurements in mm.

Type	N	Height above water $\bar{X}$ (range)	Width $\bar{X}$ (range)	Depth of water $\bar{X}$ (range)
Branch	20	440 (60-910)	90 (30-180)	541.9 (155-840 N=16*
Log	16	156.6 (70-320)	230.9 (45-400)	405 (210-670)
Rock	8	236.3 (30-570)	315 (75-730)	462.5 (30-870)
Rock Face	1	Carapace touching water	---	185
Land	2	1 turtle with nose in water; the same turtle later observed 500 mm from water		
Total	47	301.7 (30-910)	182.2 (30-730)	464.3 (30-870)

* An additional 3 turtles were basking over land; data not recorded for 1 turtle.

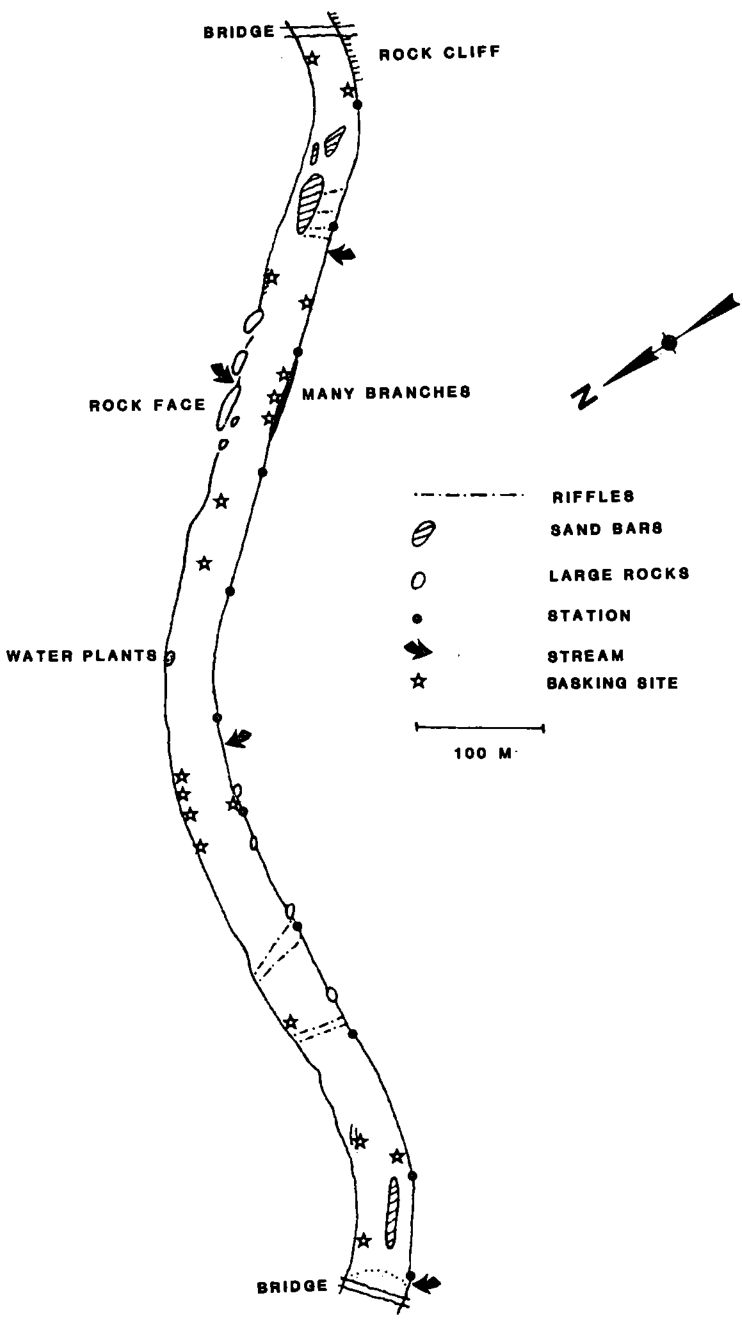

Figure 16. Basking locations used by *S. depressus* at Sipsey Fork.

were highly significant and were near 3.0 (Table 13). According to Iverson (1984), such values are to be expected for regressions of mass on carapace length. There were small differences between the sexes, except for mass x plastron width in juveniles and females; both had power function exponents around 4.0. In addition, the power function of the regression of mass x plastron length was lower for juveniles than the others, being only 2.4.

For other regressions involving morphological comparisons, all power functions again were highly significant, and values for slopes were similar

Table 13. Relationship between body mass (Y) and carapace length (CL), carapace width (CW), plastron length (PL), and plastron width (PW) (X variables) in *Sternotherus depressus*, based on the equation $Y = aX^b$. Units in gm and mm. The statistical significance of correlation coefficients is indicated (**, $p < 0.01$).

Independent Variable	N	b	a	r
Males				
CL	225	3.2797	0.00004	0.952**
CW	224	3.4968	0.00005	0.797**
PL	225	3.0031	0.00047	0.938**
PW	224	3.1529	0.00134	0.900**
Females				
CL	143	3.2622	0.00004	0.960**
CW	143	4.0544	0.000005	0.862**
PL	143	2.9670	0.00043	0.932**
PW	143	3.2468	0.00090	0.917**
Juveniles				
CL	109	2.9237	0.00017	0.992**
CW	109	4.0198	0.000005	0.979**
PL	109	2.4739	0.00303	0.991**
PW	109	2.8087	0.00365	0.985**

regardless of sex (Table 14). However, while statistically significant, the r^2 values for certain comparisons explained only a small part of the variance: gular length x gular width-females (29.7%), males (42.3%), overall (46.3%); shell depth x carapace width-females (40.9%); interhumeral length x plastron length-females (11.7%), males (32.6%), overall (56.2%); shell depth x carapace length- females (49.9%). Thus, predictions for one of these dependent variables based on the size of the correlated independent variable would not be reliable, although a trend might be indicated.

Character proportions of CW/CL, PW/PL, PL2W, PL2L, and GW/GL are provided in Table 15.

Table 14. Relationship of various dependent variables (Y) to independent variables (X) of shell measurements of *Sternotherus depressus*, based on the equation Y = a + bX. Units in mm. Statistical significance of correlation coefficients is indicated (**, $p < 0.01$). C = combined totals.

Sex	Y	X	N	b	a	r
M	CL	CW	251	1.2607	2.1×10^{-4}	0.888**
F	CL	CW	159	1.6314	3.0×10^{-6}	0.869**
J	CL	CW	116	1.6185	1.6×10^{-8}	0.977**
C	CL	CW	539	1.6654	2.0×10^{-7}	0.959**
M	PL	PW	251	1.4925	8.6×10^{2}	0.916**
F	PL	PW	159	1.8679	0.07183	0.938**
J	PL	PW	116	1.7736	0.05355	0.982**
C	PL	PW	539	1.8100	0.06399	0.977**
M	GL	GW	225	0.5046	2.82215	0.654**
F	GL	GW	143	0.5370	4.98832	0.545**
J	GL	GW	110	0.8790	1.23825	0.781**
C	GL	GW	479	0.5494	2.99906	0.681**
M	SD	CL	251	0.2687	5.08452	0.872**
F	SD	CL	159	0.2368	3.1×10^{2}	0.707**
J	SD	CL	116	0.2435	49.40245	0.954**
C	SD	CL	539	0.2589	19.73710	0.950**
M	SD	CW	251	0.3920	3.15598	0.898**
F	SD	CW	159	0.4023	5.38814	0.637**
J	SD	CW	116	0.3941	0.6259	0.932**
C	SD	CW	539	0.4527	0.10215	0.948**
M	IL	PL	251	0.0881	2.31822	0.571**
F	IL	PL	159	0.0566	19.20941	0.342**
J	IL	PL	116	0.1021	1.92803	0.831**
C	IL	PL	539	0.0827	3.40928	0.809**
M	PL2L	PL2W	251	0.6465	0.46580	0.938**
F	PL2L	PL2W	159	0.7663	0.02720	0.879**
J	PL2L	PL2W	116	0.5574	3.27363	0.909**
C	PL2L	PL2W	539	0.6553	0.53504	0.967**

CL = carapace length, CW = carapace width, PL = plastron length, PW = plastron width, GL = gular length, GW = gular width, SD = shell depth, IL = interhumeral length, PL2L = length of 2nd pleural, PL2W = width of 2nd pleural.

Table 15. Character proportions of *Sternotherus depressus*. Mean ratios as percentages are followed by ± one standard deviation. Character range appears below mean.

Sex	N	CW/CL	PW/PL	PL2W/PL2L	GW/GL
Males	248	70.1 ± 5.7 (0.0-79.7)	60.0 ± 4.5 (0.0-68.9)	162.0 ± 10.7* (123.6-218.8)	144.3 ± 48.5 (73.5-436.4)
Females	159	70.3 ± 3.7 (59.9-79.5)	55.6 ± 2.1 (49.5-61.4)	154.2 ± 10.8 (121.7-189.5)	116.9 ± 30.7** (41.2-228.6)
Juveniles	116	84.8 ± 7.7 (70.8-101.5)	62.1 ± 4.2 (47.6-74.1)	160.2 ± 14.6 (86.6-185.4)	108.3 ± 24.7*** (51.7-190.9)
Overall	524	73.4 ± 8.3 (0.0-101.5)	58.7 ± 4.5 (0.0-74.1)	159.3 ± 12.1# (86.6-218.8)	127.6 ± 42.0## (41.2-436.4)

* N=247; ** N=143; *** N=109; # N=523; ## N=471.

Miscellaneous Notes

The following observations were made on individual *S. depressus* during the course of this survey. Physical deformities: deformed vertebrals- 1 (Sipsey Fork); deformed marginals- 5 (Lost Cr., Blackburn Fork); flared carapace- 3 (Sipsey Fork, Turkey Cr., Blackburn Fork); pushed-in snout- 1 (Sipsey Fork); extremely pitted carapace- 6 (Blackburn Fork); extra marginals- 1 (Blackburn Fork); extreme facial algae- 2 (Blackburn Fork); abnormal growth or tumor- 1 (Sipsey Fork); lack of gular scute- 7 (Sipsey Fork, Blackburn Fork). Physical signs of trauma: missing front foot- 1 (Sipsey Fork); missing rear foot- 5 (Sipsey Fork, Brushy Cr.); missing toes- 1 (Sipsey Fork); bite marks- 3 (Sipsey Fork, Brushy Cr., Turkey Cr.); cracked & healed carapace- 2 (Sipsey Fork, Lost Cr.); missing tail- 1 (Sipsey Fork); blind in one eye- 4 (Sipsey Fork, Blackburn Fork). Many similar injuries have been reported for *S. odoratus* (Ernst 1986).

DISCUSSION

Turtle Capture.— While we were able to correlate certain environmental variables with turtle captures, the subtle interaction of these variables and how they might influence turtle behavior is unknown. We measured variables only at 10 sites, and we do not know whether turtle capture and values for pH, conductivity, and O_2 would be similarly correllated at other locations. Turtles tolerate values outside the range we report as optimum, and we urge caution in extrapolating our results to the interpretation of habitat suitability elsewhere in the Basin.

Trapping likely does not adequately sample a turtle population, especially the smaller size classes. Ream and Ream (1966) noted that estimates of population structure varied according to the type of trap used in their study of *Chrysemys picta* in Wisconsin. We agree with Ernst et al. (1983) that juvenile turtles (< 50 mm) are unlikely to be captured by traps and are potentially underrepresented in some samples. However, if large numbers of turtles in the 50-70 mm size class are trapped, juveniles smaller than this should be in the population. This appears to be the case at Blackwater Creek-Camp O'Rear. When water conditions are favorable, such as at Blackburn Fork, Sipsey Fork, Lost Creek-Pocahontas, and Brushy Creek, wading can supplement trapping to estimate population structure and status.

Two problems with trapping have not been adequately addressed by previous studies on *S. depressus*, i.e. how effective are the traps in drawing turtles to them and how effective are they in retaining turtles once inside? Our results indicated that radio-transmittered turtles could move > 30 m overnight to a baited trap. However, on several occasions we attempted to catch a radio-transmittered turtle under a large rock. Traps were baited less than two meters from the turtle for several consecutive nights, yet the turtle was never trapped. On one occasion, the turtle moved three meters directly past the trap. Thus, individual turtles vary in trapability (also see Ream and Ream 1966).

Most researchers assume that once trapped, a turtle remains in the trap. This may not be the case. One evening, we checked our traps in Sipsey Fork after they had been in place 45 minutes. In one trap, we found two marked turtles. After recording the numbers we left the turtles in the trap overnight. The next morning, both were gone, and a different *S. depressus* was in the trap. The probability of initially trapping an individual *S. depressus*, and the probability of escape, are unknown. Repeated trapping may partially overcome this problem.

Differences in trapping success from previous studies (Table 1) are probably due to declines in the resident population of flattened musk turtles. At Blackburn Fork and Blackwater Creek-Camp O'Rear, this most likely resulted from commercial collecting since collectors have worked both streams at least since 1980. We interpret the lack of adults as reflecting collecting pressure on larger animals. Capture variation at Sipsey Fork, Brushy Creek, and Turkey Creek are more difficult to explain, but disease may be partly responsible, especially at Sipsey Fork (Dodd 1988b). Collectors also have been active in these streams (Guthrie 1986).

Differences in trap success between 1983 and 1985 at Lost Creek are easier to explain. Lost Creek at Cedrum (Ernst et al. 1983) is excellent habitat with good cover and food resources. At the Pocahontas site, the stream is much smaller with fewer cover sites and a smaller mollusc population. Cedrum probably has a larger population of *S. depressus* than Pocahontas because of better habitat conditions.

We hypothesize that recruitment to the adult population was not taking place if large juveniles were not captured during trapping. The lack of juveniles in the 50-70 mm size class at Turkey Creek, for instance, probably reflects lack of successful recruitment rather than the failure of trapping to reflect population structure. We found a hatchling at Lost Creek-Pocahontas, but the lack of large juveniles suggests that reproduction may be occurring without recruitment to the adult population.

We caught no turtles in Clear Creek. Clear Creek is marginal *S. depressus* habitat because of its fast current, lack of cover sites, and heavy sand load that clogs available crevices. If there ever was a population of flattened musk turtles, it is likely extirpated. Animals caught by Ernst et al. (1983) were probably vagrants from downstream where habitat conditions are more favorable.

Habitat Use, Activity, and Movements.— The flattened musk turtle frequently used the same cover site or group of cover sites within a home range (*sensu* Brown and Orians 1970) that overlapped those of conspecifics. Both males and females made occasional long-distance movements of several days duration prior to returning to a frequently used cover site. Plummer and Shirer (1975) also found that male and female *Apalone mutica* occasionally made long distance movements of unknown purpose both up- and downstream and noted that females traveled long distances to nesting sites. We have no data for nesting female *S. depressus* because our telemetry study began after the peak of the nesting season.

We made no attempt to calculate home ranges of turtles, except for turtle No. 4600, because of lack of sufficient data points. Mahmoud (1969) calculated home ranges based on as few as five observations, but noted that home range estimates seemed to decrease with more observations. By connecting the points of most distant movement, he may have confused the periodic movements of turtles with home range, and thus greatly overestimated the extent of the home range. Our impression was that linear home ranges are not greatly different for males and females, but more data are needed to confirm this. The area of concentrated cover site use by No. 4600 was probably less than the estimates provided, although its area of activity was probably much greater, because of procedural difficulties in applying and interpreting the various home range techniques (see Samuel et al. 1985, and references within).

Plummer and Shirer (1975) found that *A. mutica* may shift home ranges within a season. We were not able to determine if flattened musk turtles do likewise, although several turtles did move from an often used area to a section of stream 20-30 m distant. We do not know whether this represented a temporary shift of home range or was simply a shift to a distant part of the home range.

Another problem in the determination of home range is that we have few data on movements within a 24-h cycle. Turtles likely foraged at night and returned to the same or a nearby cover site each morning. More than 50% of the turtles were known to shift cover sites from day to day. At least two turtles moved > 30 m upstream from a favored cover site to a baited trap, but we do not know if they normally foraged to this extent or were merely drawn to the bait.

There is some disagreement as to the activity period of S. depressus (Tinkle 1958; Estridge 1970; Mount 1981; Ernst et al. 1983). Early in the season when water temperatures were rather cool, S. depressus normally was diurnal, at least in Sipsey Fork. However, some turtles were active either nocturnally or crepuscularly, and were caught in traps. As the season progressed and the water became warmer, diurnal activity became less obvious and capture success decreased while wading. At the same time, nocturnal trapping success increased. S. depressus is not strictly nocturnal, even during mid-summer. On 17 July, Dodd watched a flattened musk turtle for 15 min at 1000 h from a large rock along the shore of Sipsey Fork as the turtle moved upstream from rock to rock along the bottom as if looking for food items.

Juvenile *S. depressus* (< 40 mm CL), which frequent shallow riffles and weed beds, were diurnal as they crawled along the bottom. We cannot rule out nocturnal activity, because we only waded once at night at Sipsey Fork; during 3 man-hours of wading, we captured three adults. Diurnal activity in inaccessible areas might protect juveniles from large, aquatic, night-foraging piscine or chelonian predators.

Diurnal activity included basking, the primary function of which is assumed to be to raise body temperature to assist digestion, with secondary benefits to the skin and shell (Boyer 1965; Moll and Legler 1971; Hutchinson 1979). Kluger (1979) noted that elevated body temperatures assist in suppressing certain bacteria, and this may account for the basking seen in Sipsey Fork *S. depressus*, many of which were diseased (Dodd 1988b). Both *S. minor* and *S. carinatus* are adept climbers and baskers (Cagle and Chaney 1950; Carr 1952; Cox and Marion 1978). The other member of the genus, *S. odoratus*, also has been reported to bask aerially in the wild, albeit uncommonly (Risley 1933;

Cahn 1937). It is not surprising, therefore, that *S. depressus*, a member of the *Carinatus* group, also basks on occasion.

S. depressus selected basking positions over deeper water, often on precarious perches. Such locations allow the turtle to drop into the water to crevices under the perches, and thus readily escape. The narrowness of many of these perches made them sensitive to the slightest disturbance which would alert the turtle to the approach of a predator. Location of basking positions to facilitate escape is not uncommon in turtles (Bury 1972; Waters 1974). Of more interest were the perches located over land or in close proximity to the shore. Turtles selecting such locations would be at a distinct disadvantage should quick escape become necessary, and we easily captured two turtles after they fell off a branch over land. Diseased basking turtles seemed less alert than non-diseased baskers, and these turtles would be particularly vulnerable to predation.

Population Estimates, Biomass, and Sex Ratio.— There has been little work on population estimation of stream and river dwelling turtles. Mahmoud (1969) gave estimates of 149.9 *S. odoratus*/ha in an Oklahoma creek, 228.7 *S. carinatus*/ha in a river, and 159.3 and 258.4 *K. subrubrum*/ha in two creek populations. Cox and Marion (1979a) estimated 288 *S. minor*/ha in a north Florida spring pool. Bury (1972 *in* Bury 1979) reported 419.9 *Clemmys marmorata*/ha in a California stream. Plummer (1977) estimated 1900 *A. mutica* per 1.5 km of river but cautioned that estimates could be biased by temporary emigration and immigration. E. Moll (1980) used a known number of nesting females combined with a sex ratio from trapping to construct a crude estimate of 1200-3600 *Batagur baska* in the Perak population, Malaysia. Other workers (*in* Bury 1979; Congdon et al. 1986; Ernst 1986) have provided estimates for pond and lake species.

The population estimate for Sipsey Fork during mid-summer (prior to decline) translated to 28.75 *S. depressus* per hectare (range 19.7-36.8) assuming even distribution and habitat suitability. There were probably more *S. depressus* per hectare where appropriate cover sites were available. At Brushy Creek, we estimated only 4.4 *S. depressus* per hectare (range 3.4-6.4). These figures are considerably less than those reported for other river-dwelling turtles (see references above), but similar to *S. odoratus* in a Pennsylvania lake (Ernst 1986). We consider both populations stable and representative of good populations for this species in similar-sized streams in the mid-1980s.

Beginning in mid-July, a decline in the size of the population of *S. depressus* occurred in Sipsey Fork that was not seen in sympatric turtle species or in other flattened musk turtle populations. One explanation is that females congregated in this area to nest on an extensive sand bank and then dispersed after the nesting season. Gibbons (1986) noted that excursions by females to suitable nesting sites was one of the four categories of long-range movement of turtles. However, this explanation is not supported by trapping results, and sex ratios did not change appreciably among trapping periods. In addition, there are sand banks all along Sipsey Fork, so it seems unlikely that nesting areas represent a limiting resource.

Environmental factors may cause some species of turtles to move less often, aestivate, or leave streams (Gibbons 1970b; Ernst 1986; R. Bury pers. comm.). However, the radio-telemetry data in the latter half of the season showed that flattened musk turtles moved > 50% of the time. We think it unlikely that flattened musk turtles left our study site for any of these reasons.

A third hypothesis is that a population decline occurred. In this regard, we started picking up dead and sick turtles with necrotic shells (discussed by Dodd 1988b). While disease may have contributed to the decline of the Sipsey fork *S. depressus* population, it may be only partially responsible. Guthrie (1987) reported that 200 *S. depressus* were removed from Sipsey Fork by commercial collectors about the time we noticed the decline. Although this report cannot be verified, collecting could partially account for the decrease in population size.

Literature reports of unbalanced sex ratios may result from biased technique or inadequate sampling (Ream and Ream 1966; Gibbons 1970a; Bury 1979). Tinkle (1958) reported a ratio of one male to three females for *S. depressus*, but the sample was small. Our results for localities other than Sipsey Fork also may be biased by small sample size, but most of these populations have few turtles. The data from Sipsey Fork constitute a larger sample size and we did not rely as heavily on trapping as we did elsewhere.

While we recognize that the sex ratio of freshwater turtle populations may vary seasonally (Morreale et al. 1984; Dodd 1988a; Mitchell 1988; K. Marion pers. comm.), we believe our results mirror population size and structure and note that male-biased sex ratios have been reported in other studies on *Sternotherus* (Bancroft et al. 1983). We have no indication that trapping tends to catch one sex more often than the other. However, males tend to move more often than females, and we realize this may influence results especially during certain times of the year (Morreale et al. 1984; Parker 1984; Gibbons 1986; Ernst 1986).

The literature on turtle biomass shows ranges from 1.83 to 3341 kg/ha for kinosternid populations (Iverson 1982; Congdon et al. 1986). Values for *S. minor* were 45.7 kg/ha (Cox and Marion 1979a); *S. carinatus* 14.35 kg/ha (Mahmoud 1969); and *S. odoratus* from 7.5-41.7 (Mahmoud 1969; Wade and Gifford 1965; Iverson 1982; Congdon et al. 1986; Mitchell 1988). Our streams were less productive with only 10.72 kg/ha in Sipsey Fork, the densest population, where *S. depressus* comprised 87% of the total turtle biomass.

The maximum total turtle biomass of 27.63 kg in one 100-m study area of Sipsey Fork was considerably less than the value for most species in Iverson's (1982) review. Biomass estimates should increase with precise data on population size, but we suspect that the high values reported in the literature on aquatic turtles reflects inadequate data on population size and structure. Even when precise information is available (Congdon et al. 1986), biomass tends to be higher than we observed in northern Alabama streams.

We suggest that some studies may have biased results by their choice of study sites. If sites are chosen because large amounts of data can be gathered within a reasonable time period, population and biomass estimates might reflect the biology of turtles in unusual habitats rather than general estimates for the species. Low-density populations, although more difficult to study, may provide a different picture of population dynamics of aquatic turtles. Comparative studies are necessary to ascertain the significance, if any, of the low biomass estimates that we observed.

Growth and Weight Changes.— Except for sea turtles and certain tortoise populations, there are few data on chelonian growth rates based on measurements between or within seasons rather than estimates based on annuli counts (see reviews by Gibbons 1976; Andrews 1982; Galbraith and Brooks 1987). Growth might be expected to slow with maturity, or even to stop (Gibbons 1967; Wilbur 1975; Moll 1976; Andrews 1982; Bancroft et al. 1983), and may vary considerably between individuals (Cox and Marion 1979b) and populations (Iverson 1985). Plummer (1977) and Vogt (1980) reported rates from zero to very small values (unspecified) per year. Cox and Marion (1979b) noted that *S. minor* in Florida had a slow absolute growth rate and hence considered only data collected > 9 months apart to determine growth rates in this species.

We collected 50 *S. depressus* marked by Ernst et al. (1983). Growth and weight change analysis showed that, on the average, turtles grew < 1.15 mm/yr during the two years between capture; weight changes also were minor. These data are in accordance with studies on sexually mature turtles (Andrews 1982). The data further showed that growth does not slow uniformly with sexual maturity, and that individual variation in growth rate is not correlated with carapace length. Some large turtles grew at the same rate as turtles barely sexually mature. These results are different than expected (Wilbur 1975; Andrews 1982), although *S. odoratus* also continues to grow at larger sizes (Ernst 1986).

There are two difficulties with interpreting these data. The first is that the sample only includes turtles sexually mature or nearly so. Our smallest turtle had the fastest growth rate, and we suspect that small *S. depressus* grow considerably faster than 1-2 mm per year. The second is that different groups of observers took the measurements, thus allowing for error due to measurement technique. We have no way to assess the magnitude of these factors, and we urge caution in the interpretation of these growth data.

Few studies have measured biomass changes within a season. Iverson (1982) recorded only two estimates of annual biomass production in turtles, 1.4-14.9 kg/ha/yr for *Geochelone elephantina* (Coe et al. 1979) and 6 kg/ha/yr for *Chrysemys picta*. While we have not estimated annual production, our measurements suggested reductions in biomass during the course of the year. For females, this was not surprising since they lose a significant portion of their biomass during oviposition. We observed weight increases during the latter part of the summer which would indicate that females were regaining weight lost during reproduction.

Males and juveniles also lost weight as the season progressed, but the data could be biased by significant biomass decreases in a few individuals. Slight differences in biomass could be accounted for by recent ingestion or defecation of a large quantity of food before capture. D. Jackson (pers. comm.) has suggested that males stop feeding late in the season and rely on lipid reserves while courting females. However, Close (1982) found lipid levels increased until October, which suggests that stored lipid is not used during autumn courtship. Close (1982) concluded that lipid levels were not important to males for reproduction in this species. We have no explanation for the weight changes in males and juveniles unless these animals were diseased (Dodd 1988b).

Carapace Erosion.— There have been a few casual observations of carapace erosion in turtles of the genus *Sternotherus* (Carr 1952; Tinkle 1958; Jackson 1964). Carapace erosion primarily affected the posterior margin of the shell. Jackson (1964) observed erosion more often on old animals and suspected that individual and social behavior, and possibly algae, were causal factors. We also observed extensive erosion on the edges of the marginals in *S. depressus*, but unlike earlier observations, erosion occurred in equal probability around the margins. We assume this reflects the tendency of *S. depressus* to wedge into crevices at different angles, thus causing abrasion.

Pitting on the carapace of some turtles, particularly at Blackburn Fork, was occasionally observed. One individual at Gurley Creek was so pitted that the carapace was worn completely through leaving a depression with only a light membrane between the outside of the body and the internal body cavity. Pitting in terrestrial species is associated with tick infestation (Ernst and Ernst 1977), but we have no reason to believe ectoparasites were responsible for pitting these aquatic turtles.

We observed three individuals at Blackburn Fork with what might be described as scalloped shells. Instead of being smooth, the carapaces were furrowed like those of captive turtles raised on a calcium deficient diet. We suspect this could be a developmental abnormality, whereas the pitting is likely due to unknown environmental conditions or disease (Dodd 1988b).

Morphology.— The body mass versus carapace length regression of *S. depressus* was similar to that of other species of turtles (Gibbons 1983; reviewed by Iverson 1984; Dodd 1988a; Wilbur and Morin 1988). Turtles have lower power function exponents than other vertebrates although direct comparisons are difficult because the head is not included in the overall length (Iverson 1984). He speculated that an exponent less than three indicated that body length increased more with size than in groups with cubic exponents, or that body mass decreases more with size than in other groups.

The length of the gular and interhumeral scutes were poor predictors of gular width and plastron length, respectively, because of the great degree of variation in shape and size of these scutes. This variation was more pronounced in older individuals, indicating that growth was not uniform relative to surrounding scutes. The size and shape of these scutes, or even the absence of the gular, would not be useful systematic characters.

Carapace length and width were poor predictors of shell depth for female *S. depressus*. This is due perhaps to reproductive constraints on the volume of the female's body cavity for egg production (Iverson 1985). Values were similar between males and juveniles.

Habitat.— We concur with Mount's (1981) assessment of optimum habitat of the flattened musk turtle although we note that *S. depressus* can survive in streams of less than a 130 km^2 drainage area, such as Gurley Creek. We observed *S. depressus* in streams with a sand bottom and concur that flattened musk turtles can live in such habitats as long as food and cover are nearby. Too much sand, even of natural origin as at Clear Creek, can be detrimental to *S. depressus* and limit its distribution and abundance by clogging crevices and covering potential cover sites along the stream margin. The telemetry data show that while turtles may move across sandy areas, they do not choose locations in sand for cover sites.

Trapping also showed that flattened musk turtles can live in heavily silted streams, such as Turkey Creek, if suitable microhabitat and food are available. In such cases, a strong current and good stream gradient are necessary to provide available habitat. Lacking these, *S. depressus* disappears, such as at Lost Creek-Townley and in sluggish portions of Gurley and Turkey Creeks.

In the late 1940s, a survey of water quality within the Warrior Drainage provided a measure to assess changes that have occurred during the last 30+ years (Anon. 1949). Oxygen, pH, total dissolved solids, hardness, and alkalinity are essentially identical to current values in Sipsey Fork, Clear Creek, Lost Creek, and Blackwater Creek, with the exception of alkalinity in Lost Creek. There has been a three- to four-fold increase in alkalinity in Lost Creek. Our values also were similar to those obtained by Ernst et al. (1983) and Anon. (undated).

We found no indication that adverse modification of streams has affected the parameters we measured, but we caution that we did not measure many other variables in either the water or sediments that might affect either the flattened musk turtle or its prey. Such variables include heavy metals, particularly mercury and manganese, polychlorinated biphenyls, pesticides, and sewage effluents. We observed high conductivity values in certain mine-affected sites and at Blackburn Fork, but it is unknown what this means to turtles. It is difficult to assess the effects of many chemicals that might be in the habitat of *S. depressus* because very little is known concerning toxic side effects of stream pollution on turtle populations.

Status.— In one of the few studies on the effects of habitat degradation on river dwelling turtles, D. Moll (1980) demonstrated that three species, *Kinosternon flavescens*, *Apalone mutica*, and *Emydoidea blandingi*, had declined or disappeared from the Illinois River as a result of heavy pollution. He attributed municipal and agricultural pollution, especially from siltation, and direct habitat degradation as responsible for these declines. Additional species that once were widespread, such as *Graptemys*, were confined only to areas with their specialized prey.

D. Moll (1980) was fortunate in having baseline data on turtle populations to compare with current information. Even then, he had difficulty in ascribing individual sources of environmental degradation to their effects on turtles. Because we have no baseline data on *S. depressus* populations, heavy metal and other sources of pollution, and silt loads, it is difficult to assess individual threats. However, it is possible to make a biologically reasonable hypothesis that populations of this species are not as viable now as they were prior to the influx of heavy siltation and that the species has disappeared in formerly occupied habitat.

Previous studies of the distribution of the flattened musk turtle (Mount 1981; Ernst et al. 1983) drew conclusions about its status based on spot sampling and examination of certain physical and chemical variables. Both were valuable in providing a foundation on which to build future research and management. However, the status of a species should be based on repeated samples throughout at least one activity season and at a variety of locations. Otherwise, estimates of population size and abundance may be in error. Assessments based on spot sampling should be used with caution unless there are clear and immediate threats to the species.

It is difficult to determine habitat characteristics and their effects on a species through sampling physical parameters once during the course of a single season or even at weekly intervals. Critical low values of oxygen, for instance, may affect the flattened musk turtle or its food sources during hibernation rather than during summer activity, and while average values of certain parameters may seem normal for a stream during spot sampling, fluctuations of critical importance may be undetected.

Siltation has impacted the flattened musk turtle. This is evident at sites such as Blackwater Creek-Harris Bridge and Lost Creek-Townley. While we cannot attribute mining as the sole source of siltation even at these severely degraded sites, mining, agriculture, and improper stream bank management have contributed to the silt load.

There is little direct impact from mining at Blackwater Creek-Harris Bridge, although it probably was severe when the numerous unregulated mines in the vicinity were operating 20 or more years ago. Erosion continues at this site where the bank is undercut resulting in numerous tree falls. There seems little likelihood that *S. depressus* could exist in this section of stream nor in any section above the Musgrove Country Club Dam. Ernst et al. (1983) also failed to find *S. depressus* above the dam and noted the unsuitability of the habitat.

Blackwater Creek-Camp O'Rear, located 18 km downstream from Harris Bridge, is suitable habitat for the turtle. Both Mount (pers. comm.) and Ernst et al. (1983) considered this site optimal with a good *S. depressus* population. The site is free of siltation because a dam is located 6.5 km upstream. The Musgrove Country Club Dam creates a sluggish backwater to Harris Bridge and beyond, but allows silt and debris to settle out in its backwater. Anon. (undated) stated that mining was compatible with healthy *S. depressus* populations because good populations were found in Blackwater Creek only 1.6 km downstream from a strip-mine discharge stream. However, this report did not mention the intervening dam. Whereas properly regulated mining may have reduced impacts, the presence of *S. depressus* downstream in Blackwater Creek is probably more the result of the Musgrove Dam than reclamation laws.

There is reason for concern about the status of the population below the dam since adults are known to have been removed by commercial collectors (R. Guthrie pers. comm. to Peter Meylan; specimens in Florida State Museum). *S. depressus* from Blackwater Creek are attractive with non-eroded shells and a striking carapace pattern, and the site is easily accessible. We collected fewer turtles than Mount (1981) and Ernst et al. (1983) although our size classes indicated successful recruitment.

At Lost Creek, active mining is occurring immediately adjacent to the creek. Mining occurred in the past as well, but not in the immediate headwaters. The Pocahontas site contains a small population of flattened musk turtles consisting mostly of old adults. Successful reproduction is occurring, but we have no idea of recruitment to the adult population. We found no adult turtles in Lost Creek-Pocahontas below Mill Creek, although suitable habitat is present. Lost Creek-Pocahontas has a small but stable population that is probably isolated from populations downstream.

At Townley, 14 km downstream from the Pocahontas site and only about 2.5 km downstream from Cedrum, Lost Creek was extremely impacted by mining and contained deep silt deposits. In some places, whole sandbars were composed of coal fragments (Fig. 17), and the streambank was severely eroded and contained many downed trees. We found one small adult male on one occasion. This turtle likely moved downstream from Cedrum where suitable habitat extends several hundred meters downstream from the base of the dam of the old mill at Cedrum. A short distance thereafter, there are extensive abandoned mines on the south bank that have not been reclaimed and from which silt enters the creek. By the time Townley is reached, Lost Creek is clogged by silt. Thus, *S. depressus* in Lost Creek does not constitute a continous population. Instead, the site has two remnant populations, a small one near the headwaters where mining has not encroached, and another protected below the dam at Cedrum.

Gurley Creek was, as previous studies have commented (Mount 1981; Ernst et al. 1983), an enigma. While the water was not deep and the creek was small in the section studied, mollusks were extremely abundant, cover sites were available, and no adverse environmental variables were measured. We consider this population a remnant and likely to disappear in the near future.

Factors causing the skewed older population at Gurley Creek could be related to the unregulated mining nearly 20 years ago. Siltation is substantial in certain sections where it settles out in pools. We were told by local residents that catfish (*Ictalurus* sp.) had declined dramatically and that "stinking jims," a local name for both *S. odoratus* and *S. depressus*, had become scarce. Blue water was noted in an adjacent strip pit which receives water from the creek, but we do not know what causes the coloration. We found dead and dying muskrats (*Ondatra zibethica*) at Gurley Creek on several occasions.

It is difficult to assess the impacts resulting solely from mining at Turkey Creek. Unlike other impacted sites, this location appears to have a good turtle population, although weighted toward older adults. The stream not only has been affected by mining but also by municipal sewage from the town of Morris and by siltation from the construction of Interstate Highway 65 which cut through an abandoned mine immediately west of the creek. Runoff from this construction had high conductivity indicating mine contamination.

Selective habitat use by *S. depressus* at Turkey Creek was striking. The turtle was found only in areas with good current and rock slabs. When weed beds restricted the water to chutes or when the water pooled with a bottom composed of deep muck, *S. depressus* was absent. Mining activities have impacted the flattened musk turtle at this site, but they are certainly not the only impacts. Recruitment does not appear to be occurring.

For mine-unaffected sites, the Brushy Creek population is relatively small but stable, with good size-class distribution and reproduction although Ernst et al. (1983) characterized the population as "dense." Ernst et al. (1983) stated

Figure 17. Excessive erosion of an adjacent coal strip mine may result in sedimentation which clogs streams and eliminates *S. depressus*. Lost Creek near the former town of Holly Grove.

that this location was atypical of *S. depressus* localities, but we do not think this is the case.

Sipsey Fork may contain the only large viable population of *S. depressus* throughout its range. The population was dense with good size-class representation and vigorous reproduction. The headwaters of this river rise in the Sipsey Wilderness and exhibit virtually no human-related adverse impacts. At least from the Sipsey Recreation Area to the headwaters of Smith Lake, population structure likely mirrors that in our study area.

We were surprised to find so few turtles at Blackburn Fork. Both Mount (1981) and Ernst et al. (1983) considered this location as the best habitat for *S. depressus* in the eastern part of its range. We concur that the habitat appears excellent in terms of both cover and potential food items. Blackburn Fork is a site for commercial collecting of *S. depressus* (Mount pers. comm.; J. Pulliam, U.S. Fish and Wildlife Service, pers. comm.). Commercial collectors have been known to return between 10% and 20% of the *S. depressus* collected here because of the degree of erosion of the shells (J. Pulliam pers. comm.).

A student at the University of Alabama-Birmingham, A. R. Johnson, studied food habits of *S. depressus* using animals from this population in 1983 and 1984. She noted a decline between these years (K. Marion pers. comm.), a decline that continued during our study. The size-class data indicated that no recruitment had taken place for several years, which would affect animals that should be in subadult stage.

Clear Creek also presents something of an enigma. Mount (1981) found what he considered a good population of *S. depressus* at Camp McDowell downstream from our sampling locality. Ernst et al. (1983) collected *S. depressus* at several other locations on Clear Creek including the site we chose for study. Clear Creek is a biologically depauperate creek with few species or individuals of turtles, crayfish, fish, clams, snails, and insects. There is no mining activity in the area, nor does the stream appear to receive much human use. The reasons for a depauperate fauna remain unknown.

Habitat Fragmentation.— The importance of habitat fragmentation has been recognized in terms of local extinction (see review by Wilcox and Murphy 1985). Wilcox and Murphy (1985) point out that fragmentation has three main effects: populations (demographic units) may be destroyed; future sources of immigration are lost; and immigration from remaining populations is impeded by intervening unfavorable habitat. Each of these factors may be operating on remaining flattened musk turtle populations and affect future conservation efforts for this species.

It seems reasonable to assume that this turtle inhabited all major streams and rivers of the Warrior Basin. Today, however, the rivers and streams of northern Alabama are vastly different from what they were several hundred years ago. Mount (pers. comm.) estimated that the flattened musk turtle had been extirpated from 350 km of favorable habitat; that it inhabited 163 km of severely impacted streams, presumably at reduced population sizes; and that it inhabited 540 km of seriously impacted streams. Only 229 stream km were considered reasonably healthy, and he included both Blackburn Fork and Blackwater Creek downstream from the Musgrove Country Club Dam, both areas disturbed by commercial collecting, within this latter category. If these estimates are even reasonably close, this species has already undergone extensive habitat fragmentation.

The implications of habitat fragmentation, especially on small populations or those depleted by collecting, should be obvious. Assuming that such populations can recover naturally, protection from additional perturbation becomes critical to their future survival. At the same time, the inability of *S. depressus* to colonize seemingly favorable habitats, such as Gurley Creek, indicates that immigration from viable source populations is a slow process, or that some populations are already so isolated that such cannot occur. The low reproductive potential of *S. depressus* (Close 1982) also indicates that recovery will be a slow process. We agree with Wilcox and Murphy (1985) that "habitat fragmentation is the most serious threat to biological diversity and is the primary cause of the present extinction crisis." The degradation of the aquatic biota of the Warrior Basin, from whatever sources, is a reminder of man's slow and painful progress of recognizing the obvious.

LITERATURE CITED

Anderson, D.J. 1982. The home range: a new nonparametric estimation technique. Ecology 63:103-112.

Andrews, R. M. 1982. Patterns of growth in reptiles. Pp. 273-320 *in* C. Gans and F. H. Pough (eds.), Biology of the Reptilia, Vol. 13. Academic Press, New York.

Anonymous. undated. The flattened musk turtle (*Sternotherus minor depressus*). Report to Drummond Coal Co., Jasper, Alabama.

Anonymous. 1949. Studies of Pollution in Streams of Alabama. State of Alabama Water Improvement Advisory Commission, Montgomery, AL.

Atchley, W. R., C. T. Gaskins, and D. Anderson. 1976. Statistical properties of ratios. I. Empirical results. Syst. Zool. 25:137-148.

_____, and D. Anderson. 1978. Ratios and the statistical analysis of biological data. Syst. Zool. 27:71-78.

Bancroft, G. T., J. S. Godley, D. T. Gross, N. N. Rojas, D. A. Sutphen, and R. W. McDiarmid. 1983. The herpetofauna of Lake Conway: Species accounts. Misc. Pap. A-83-5, U.S. Army Engineer Waterways Experimental Station, CE, Vicksburg, Mississippi.

BMDP. 1979. Biomedical Computer Programs. P-Series. Univ. California Press, Berkeley.

Boyer, D. R. 1965. Ecology of the basking habit in turtles. Ecology 46:99-118.

Brown, J. L., and G. H. Orians. 1970. Spacing patterns in mobile animals. Ann. Rev. Ecol. Syst. 1:239-262.

Bury, R. B. 1972. Habits and home range of the Pacific pond turtle, *Clemmys marmorata*, in a stream community. Ph.D. dissertation, Univ. California, Berkeley.

____. 1979. Population ecology of freshwater turtles. Pp. 571-602 *in* M. Harless and H. Morlock (eds.), Turtles, Perspectives and Research. John Wiley & Sons, New York.

Cagle, F. R. 1939. A system for marking turtles for future identification. Copeia 1939: 170-172.

____, and A. H. Chaney. 1950. Turtle populations in Louisiana. Am. Midl. Nat. 43:383-388.

Cahn, A. R. 1937. The turtles of Illinois. Univ. Illinois Bull., Biol. Monog. 16:1-218.

Carr, A. F. 1952. Handbook of Turtles. Cornell Univ. Press, Ithaca, New York.

Caughley, G. 1977. Analysis of Vertebrate Populations. John Wiley & Sons, N.Y.

Close, D. K. 1982. The reproductive cycle of *Sternotherus minor depressus*. M.S. thesis, Univ. Alabama-Birmingham, Birmingham, Alabama, 101 pp.

Coe, M. J., D. Bourn, and I. R. Swingland. 1979. The biomass, production and carrying capacity of giant tortoises on Aldabra. Phil. Trans. Royal Soc. London B 286:163-176.

Congdon, J. D., J. L. Greene, and J. W. Gibbons. 1986. Biomass of freshwater turtles: a geographic comparison. Am. Midl. Nat. 115:165-173.

Cox, W. A., and K. R. Marion. 1978. Observations on the female reproductive cycle and associated phenomena in spring-dwelling populations of *Sternotherus minor* in North Florida (Reptilia, Testudines). Herpetologica 34:20-33.

____, and ____. 1979a. Population structure and survivorship in the musk turtle, *Sternotherus minor* in North Florida spring (Reptilia: Chelonia). ASB Bull. 26:84.

____, and ____. 1979b. Growth in the musk turtle, *Sternotherus minor* in a North Florida spring (Reptilia: Chelonia). ASB Bull. 26:84.

Dixon, K. R., and J. A. Chapman. 1980. Harmonic mean measure of animal activity areas. Ecology 61:1040-1044.

Dodd, C. K., Jr. 1988a. Population structure and biomass of *Sternotherus odoratus* (Testudines: Kinosternidae) in a northern Alabama lake. Brimleyana, in press.

____. 1988b. Disease and population declines in the flattened musk turtle *Sternotherus depressus*. Am. Midl. Nat. 119:394-401.

____, K. M. Enge, and J. N. Stuart. 1986. The effects of mining siltation on the distribution and abundance of the flattened musk turtle, *Sternotherus depressus*, in northern Alabama. Report to Office of Surface Mining, U.S. Dept. Interior, Washington, D.C.

Ernst, C. H., and E. M. Ernst. 1977. Ectoparasites associated with neotropical turtles of the genus *Callopsis* (Testudines, Emydidae, Batagurinae). Biotropica 9:139-142.

____. 1986. Ecology of the turtle, *Sternotherus odoratus*, in southeastern Pennsylvania. J. Herp. 20:341-352.

____, W. A. Cox, and K. R. Marion. 1983. The distribution and status of the flattened musk turtle in the Warrior Basin of Alabama. Report to the Alabama Coal Association, Birmingham, Alabama.

Estridge, R. E. 1970. The taxonomic status of *Sternotherus depressus* (Testudinata, Kinosternidae) with observation on its ecology. M.S. thesis, Auburn Univ., Auburn, Alabama, 49 pp.

Ewert, M. A. 1985. Embryology of turtles. Pp. 75-267 *in* C. Gans, F. Billett, and P. F. A. Maderson (eds.), Biology of the Reptilia, Vol. 14 (Development A). John Wiley & Sons, New York.

Galbraith, D. A., and R. J. Brooks. 1987. Addition of annual growth lines in adult snapping turtles *Chelydra serpentina*. J. Herp. 21:359-363.

Gibbons, J. W. 1967. Variation in growth rates in three populations of the painted turtle, *Chrysemys picta*. Herpetologica 23:296-303.

____. 1970a. Sex ratios in turtles. Res. Popul. Ecol. 12:252-254.

____. 1970b. Terrestrial activity and the population dynamics of aquatic turtles. Am. Midl. Nat. 83:404-414.

____. 1976. Aging phenomena in reptiles. Pp. 453-476 *in* M. F. Elias, B. E. Eleftherious, and P. K. Elias (eds.), Special Review of Experimental Aging Research. Experimental Aging Research, Inc., Bar Harbor, Maine.

____. 1982. Reproductive patterns in freshwater turtles. Herpetologica 38:222-227.

____. 1983. Reproductive characteristics and ecology of the mud turtle *Kinosternon subrubrum* (Lacepede). Herpetologica 38:254-271.

____. 1986. Movement patterns among turtle populations: Applicability to management of the desert tortoise. Herpetologica 42:104-113.

Guthrie, R. W. 1986. Derivation of a habitat quality predicting function for the flattened musk turtle. Report to U.S. Fish and Wildl. Serv., Jackson, MS.

Hayes, E. C. 1978. 7-day low flow duration of Alabama streams through 1973. Geol. Surv. of Alabama Bull. No. 113.

Hutchinson, V. H. 1979. Thermoregulation. Pp. 207-228 *in* M. Harless and H. Morlock (eds.), Turtles, Perspectives and Research. John Wiley & Sons, New York.

Iverson, J. B. 1977a. Geographic variation in the musk turtle *Sternotherus minor*. Copeia 1977:502-517.

____. 1977b. *Sternotherus depressus* Tinkle and Webb. Cat. Amer. Amphib. Rept. 194.1-2.

____. 1979. Another inexpensive turtle trap. Herp. Rev. 10:55.

____. 1982. Biomass in turtle populations: A neglected subject. Oecologia (Berl) 55:69-76.

____. 1984. Proportional skeletal mass in turtles. Florida Sci. 47:1-11.

____. 1985. Geographic variation in sexual dimorphism in the mud turtle *Kinosternon hirtipes*. Copeia 1985:388-393.

Jackson, C. G., Jr. 1964. Carapace erosion in the loggerhead musk turtle, *Sternothaerus minor minor* Agassiz. Herpetologica 20:279-281.

Kaufmann, J. H. 1962. Ecology and social behavior of the coati, *Nasua narica* on Barro Colorado Island Panama. Univ. California Publ. Zool. 60:95-222.

Kluger, M.J. 1979. Fever in ectotherms: evolutionary implications. Am. Zool. 19:295-304.

Mahmoud, I. Y. 1969. Comparative ecology of the kinosternid turtles of Oklahoma. Southwest. Nat. 14:31-66.

Milliken, G. A., and D. E. Johnson. 1984. Analysis of Messy Data. Vol. 1: Designed Experiments. Lifetime Learning Publ., Belmont, California.

Mitchell, J.C. 1988. Population ecology and life histories of the freshwater turtles *Chrysemys picta* and *Sternotherus odoratus* in an urban lake. Herp. Monog. 2:40-61.

Moll, D. 1976. Environmental influence on growth rate in the Ouachita map turtle, *Graptemys pseudogeographica ouachiensis*. Herpetologica 32:439-443.

____. 1980. Dirty river turtles. Nat. Hist. Mag. 89(5):42-49.

Moll, E. O. 1980. Natural history of the river terrapin, *Batagur baska* (Gray) in Malaysia (Testudines: Emydidae). Malaysia J. Sci. 6(A):23-62.

____, and J. M. Legler. 1971. The life history of a neotropical slider turtle, *Pseudemys scripta* (Schoepff), in Panama. Bull. Los Angeles Co. Mus. Nat. Hist. No. 11.

Morreale, S. J., J. W. Gibbons, and J. D. Congdon. 1984. Significance of activity and movement in the yellow-bellied slider turtle (*Pseudemys scripta*). Can. J. Zool. 62:1038-1042.

Mount, R. H. 1975. The Reptiles & Amphibians of Alabama. Agric. Exper. Sta., Auburn Univ., Auburn, AL.

____. 1981. The status of the flattened musk turtle, *Sternotherus minor depressus* Tinkle and Webb. Report to the U.S. Fish and Wildlife Service, Jackson, Mississippi.

Parker, W. S. 1984. Immigration and dispersal of slider turtles *Pseudemys scripta* in Mississippi farm ponds. Am. Midl. Nat. 112:280-293.

Plummer, M. V. 1977. Reproduction and growth in the turtle *Trionyx muticus*. Copeia 1977:440-447.

____, and H. W. Shirer. 1975. Movement patterns in a river population of the softshell turtle, *Trionyx muticus*. Occ. Pap. Mus. Nat. Hist. Univ. Kansas 43:1-26.

Ream, C., and R. Ream. 1966. The influence of sampling methods on the estimation of population structure in painted turtles. Am. Midl. Nat. 75:325-338.

Risley, P. L. 1933. Observations on the natural history of the common musk turtle, *Sternotherus odoratus* (Latreille). Pap. Michigan Acad. Sci. Letters 17:685-711.

Samuel, M. D., D. J. Pierce, and E. O. Garton. 1985. Identifying areas of concentrated use within the home range. J. Anim. Ecol. 54:711-719.

SAS Institute, Inc. 1985. SAS User's Guide: Basics, Version 5 Edition. SAS Institute, Inc., Cary, North Carolina.

Scott, J. C. 1978. Drainage areas for the Upper Black Warrior River Basin, Alabama. Geol. Surv. of Ala. Atlas Ser. No. 12, University, Alabama.

Seidel, M. E., and R. V. Lucchino. 1981. Allozymic and morphological variation among the musk turtles *Sternotherus carinatus*, *S. depressus*, and *S. minor* (Kinosternidae). Copeia 1981:119-128.

_____, S. L. Reynolds, and R. V. Lucchino. 1981. Phylogenetic relationships among musk turtles (genus *Sternotherus*) and genic variation in *Sternotherus odoratus*. Herpetologica 37:161-165.

Tinkle, D. W. 1958. The systematics and ecology of the *Sternothaerus carinatus* complex (Chelonia, Kinosternidae). Tulane Stud. Zool. 3:53-67.

_____. 1959. The relation of the Fall Line to the distribution and abundance of turtles. Copeia 1959:167-170.

_____, and R. G. Webb. 1955. A new species of *Sternotherus* with a discussion of the *Sternotherus carinatus* complex (Chelonia, Kinosternidae). Tulane Stud. Zool. 3:53-67.

Tolson, J. S. 1984. Alabama coal data for 1983. Geol. Surv. of Alabama, Information Ser. No. 58E, Tuscaloosa, Alabama.

U.S. Fish and Wildlife Service. 1987. Determination of threatened status for the flattened musk turtle (*Sternotherus depressus*). Federal Register 50(212):45638-45643.

Vogt, R. C. 1980. Natural history of the map turtles *Graptemys pseudogeographica* and *G. ouachitensis* in Wisconsin. Tulane Stud. Zool. Bot. 22:17-48.

Wade, S. E., and C. E. Gifford. 1965. A preliminary study of the turtle population of a northern Indiana lake. Proc. Indiana Acad. Sci. 74:371-374.

Wahl, K. D., W. F. Harris, and P. O. Jefferson. 1971. Water resources and geology of Winston County, Alabama. Geol. Surv. Alabama Bull. No. 97.

Waters, J. C. 1974. The biological significance of the basking habit in the black-knobbed sawback, *Graptemys nigrinoda* Cagle. M.S. thesis, Auburn Univ., Auburn, Alabama, 81 pp.

Wilbur, H.M. 1975. A growth model for the turtle *Chrysemys picta*. Copeia 1975:337-343.

_____ and P. J. Morin. 1988. Life history evolution in turtles. Pp. 387-439 *in* C. Gans and R. B. Huey (eds.), Biology of the Reptilia, Vol. 16 (Ecology B), Defense and Life History. Alan R. Liss, Inc., New York.

Wilcox, B. A., and D. D. Murphy. 1985. Conservation strategy: The effects of fragmentation on extinction. Am. Nat. 125:879-887.

[Copies of unpublished reports are deposited in the Division of Reptiles and Amphibians, National Museum of Natural History, Washington, D.C. 20560.]

Contributions to the BULLETIN OF THE FLORIDA STATE MUSEUM, BIOLOGICAL SCIENCES SERIES, may be in any field of biology. Manuscripts dealing with natural history or systematic problems involving the southeastern United States or the New World tropics are solicited especially. Manuscripts should be of medium length--circa 35 to 200 pages (10,500-60,000 words). Examination for suitability is made by an Editorial Board.

The BULLETIN is distributed worldwide through institutional subscriptions and exchanges. It is considered the responsibility of the author to distribute his paper to all interested individuals. To aid in this the author(s) receive(s) 50 copies free, and he(they) may purchase additional separates at cost if ordered when page proof is returned. The author is also responsible for any charges incurred for alterations made by him on galley or page proofs. The Museum will send an invoice to the author for this amount upon completion of publication.

PREPARATION OF MANUSCRIPT

Contributors should consult recent numbers of the BULLETIN for preferred style and format. Highly recommended as a guide is the CBE Style Manual, 3rd Edition, 1972 (American Institute of Biological Sciences, Washington, D.C.).

Manuscripts must be submitted in duplicate and satisfy the following minimal requirements. Please submit duplicate copies of manuscripts. They must be double-spaced throughout, including tables, figure captions, and literature citations. Figure legends and tables should be typed on separate sheets. Also, please submit a copy of the complete text and tables on one or more 5¼" flexible diskettes.

All illustrations are referred to as figures. They must comply with the following standards: Photographs should be sharp, with good contrast, and printed on glossy paper. If the background of photographs (especially those of specimens) is not desired, amberlith should be cut out and used to cover the background. Drawings should be made with dense black waterproof ink on quality paper or illustration board. All illustrations should have a cover sheet. All lettering will be medium weight, sans-serif type (e.g. Futura Medium, News Gothic) in cutout, dry transfer, or lettering guide letters. Make allowance so that after reduction no lower case letter will be less than 1 mm high (2 mm is preferred) nor any capital letter greater than 5 mm high. The maximum size for illustrations is 9" x 14" (twice BULLETIN typepage size); illustrations should not be less than typepage width (4½"). With soft lead pencil on the back of each illustration, designate the top and identify each by author's name, manuscript title, and figure number.

All manuscripts not submitted in BULLETIN format will be returned to the author for retyping.

Manuscripts and all editorial matters should be addressed to:

Managing Editor of the BULLETIN
Florida State Museum
University of Florida
Gainesville FL 32611