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A Study of Population Density, Seasonal Movements and Weight Changes, and Winter Behavior of the Eastern Box Turtle, *Terrapene c. carolina* L., in Eastern Tennessee

Richard Albert Dolbeer
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To the Graduate Council:

I am submitting herewith a thesis written by Richard Albert Dolbeer entitled "A Study of Population Density, Seasonal Movements and Weight Changes, and Winter Behavior of the Eastern Box Turtle, *Terrapene c. carolina* L., in Eastern Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

James T. Tanner, Major Professor

We have read this thesis and recommend its acceptance:

David A. Etnier, H. R. DeSelm

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

February 11, 1969

To the Graduate Council:

I am submitting herewith a thesis written by Richard Albert Dolbeer entitled "A Study of Population Density, Seasonal Movements and Weight Changes, and Winter Behavior of the Eastern Box Turtle, <u>Terrapene c. carolina</u> L., in Eastern Tennessee." I recommend that it be accepted for twelve quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Zoology.

James T. Tanner

Major Professor

We have read this thesis and recommend its acceptance:

David A. Etnier

H. R. DeSelm

Accepted for the Council:

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Vice Chancellor for Graduate Studies and Research

A STUDY OF POPULATION DENSITY, SEASONAL MOVEMENTS AND WEIGHT CHANGES, AND WINTER BEHAVIOR OF THE EASTERN BOX TURTLE, *TERRAPENE C. CAROLINA* L., IN EASTERN TENNESSEE

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Richard Albert Dolbeer

March 1969

ABSTRACT

During 1968, a quantitative and descriptive field study was made in a 23 acre woodland on a population of the eastern box turtle. The area was systematically searched and turtles were repeatedly collected, marked, weighed, and released. Trees were marked at 256 foot intervals so that the exact location of captured turtles could be recorded. A trailing device was used to study movements of some turtles.

Smaller turtles were found to be more active in the fall as 37.3 percent of the turtles captured during September and October weighed less than 300 grams as compared to 23.3 percent during July and August and 16.6 percent during April through June. Individual turtles generally had a peak in weight in the latter part of the summer. The average home range diameter was estimated to be 248 feet for 76 turtles captured three or more times. The adult population density was estimated to be between 7.6 and 9.2 turtles per acre.

Five turtles were trailed from 21 October to 31 January. These turtles remained somewhat active until 13 December from which time there was no movement until 24 January. The average depth of the hibernacula during January was about 6.0 inches below the surface of the leaf litter.

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CHAPTER I

INTRODUCTION

A quantitative and descriptive field study was made on a population of the eastern box turtle, *Terrapene c. carolina* L., in eastern Tennessee during the year of 1968. The study was made at an undisturbed wooded area near Knoxville, Knox County, Tennessee, on The University of Tennessee's Cherokee Farm.

The main goals of this study were to study the home range of the turtles in relation to population size; to investigate the seasonal differences in movements and activities of the sexes and different weight classes; and to study the seasonal weight changes of the turtles. The winter movements and hibernation of the eastern box turtle were also investigated. Since most studies on the eastern box turtle have been in the northern part of its range, it was also felt that a study near the southern edge of its range would be useful.

Terrapene c. carolina is an abundant, long-lived animal of the woodlands of the eastern United States ranging from southern Maine into Georgia and Alabama. Due to its size and easiness to catch and mark, it makes an ideal animal for population and behavioral studies. Handling and marking of the turtles has little or no effect on them, and since they have a restricted home range, most of the turtles in an area can be marked within a year, many being recaptured a number of times.

Literature Review

Due to the suitability of the box turtle for field study, much previous work has been done with this animal. Many observations are recorded in the literature from 1900 to 1930 regarding the behavior and life history of the eastern box turtle, but the first major study done on the population biology was by Nichols (1939). In this study turtles were marked near his home at Long Island, New York, and a number of these turtles were recaptured several years later within a few hundred yards of their release point.

Stickel (1950) did an extensive three-year study on the population and home range relationship of the eastern box turtle. Her work showed that the box turtle does have a defined home range within which it spends a majority of its time. She also obtained a good estimate of the population density, and with the use of trailing devices investigated the summer movements of individual turtles. Williams (1961) also studied the home ranges and estimated the density of a population of eastern box turtles in Indiana.

Gould (1957) did a study in Maryland on the directional orientation and homing tendencies of the eastern box turtle in which he demonstrated that the turtles utilize the sun in order to orient themselves.

The literature on hibernation studies of the eastern box turtle is much less complete than for other phases of its life history, and what is present is generally superficial. Very little is reported, especially in the southern end of its range. Cahn (1933) reports on the hibernation activities of 24 adult and six juvenile eastern box turtles which were kept in an enclosed pen in Illinois. Allard (1948) also used an enclosed pen near Washington, D. C., to observe the behavior of the eastern box turtle, and he reports some information on hibernation. Information as to dates of hibernation are given by Stickel (1950), and Minton (1944) gives information on the depth of a hibernaculum of one individual.

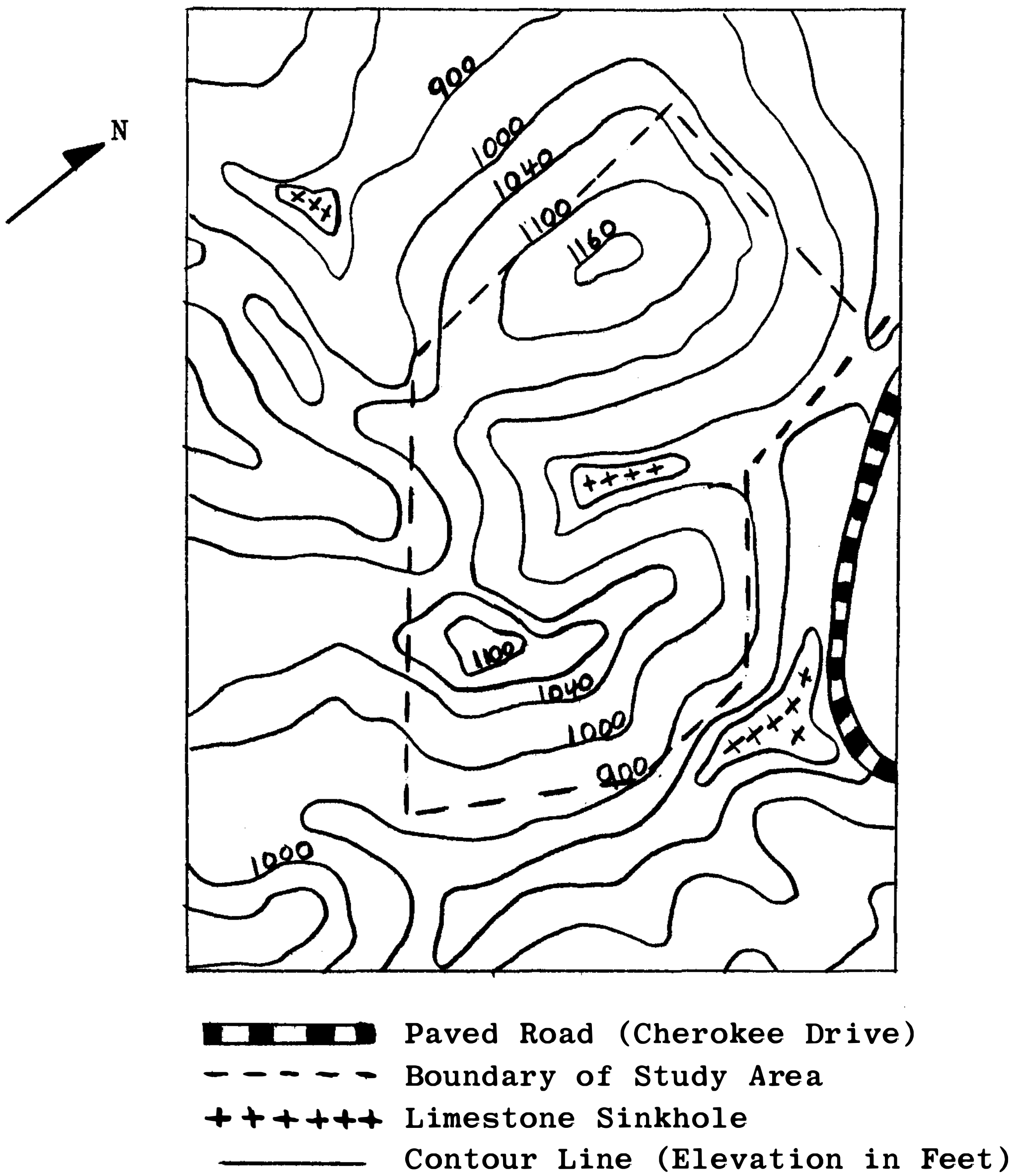
Carpenter (1957) has done the most intensive field study on the hibernation of box turtles. He did a three-year study on hibernation of the three-toed box turtle, *Terrapene c. triangus* L. in Oklahoma. From the first of October to the thirty-first of March during the three years, 344 individuals were observed with information gathered as to types of hibernacula, depth of burrowing, and winter movements.

The Study Area

This study was done within the 130 acre Cherokee woodlot which is a part of The University of Tennessee farm. This area is located one mile south of Knoxville. The specific study area consisted of 23 acres of densely wooded hills in which a remnant of the original forest still remains (Shanks and Norris, 1950). The elevation of the study area ranges from approximately 920 to 1150 feet with a limestone sinkhole in the center of the area being the lowest point. Figure 1 is a map of the area showing the elevation and general topography. The broken line outlines the specific study area that was used.

The study area is completely wooded except for a small grassy area of approximately 1/2 acre around the limestone sinkhole. The land surrounding the study area is quite diverse, however, with a swampy area on the eastern edge, pasture on the northeastern border, and continuing woodland bordering the rest. The trees are primarily deciduous except for the southeastern corner of the area which is mixed deciduous and pine forest.

Oaks dominate the area with *Quercus alba* L., being the most common species. Other trees present in decreasing order of abundance include hickory (*Carya* spp.), pine (*Pinus* spp.), tulip poplar (*Liriodendron tulipifera* L.), dogwood



Scale: 1 inch = 500 feet

Figure 1. Map of study area on The University of Tennessee's Cherokee Farm.

(*Cornus florida* L.), elm (*Ulmus* spp.), maple (*Acer* spp.), and beech (*Fagus grandifolia* Ehrh) (Wallace, 1964).

Shrub, sapling, and vine density is high in certain areas of the hillsides. The two east to northeast facing slopes had particularly well developed and sometimes tangled understory. The density and height of the undergrowth plus the steepness of the hills made the observer's movement and censusing difficult in some places.

Materials and Methods

The major method used in securing population, movement, and weight information on the eastern box turtle was by repeated and systematic collecting, marking, and weighing of turtles in the study area. For more detailed studies of summer movements and for following the turtles into hibernation, a trailing device described below was used.

The collection data, which were obtained from early April through October of 1968, were used to estimate the size of the population, to estimate the size of home ranges of individual turtles, and to obtain information on the weights and weight changes of turtles in the population. Also, during this time much general information was obtained on various aspects of box turtle behavior, such as feeding, mating, and the effects of weather on activity.

A grid system was set up in the study area with trees marked at 256 feet intervals over the entire study plot. This allowed the location of collections to be recorded quite easily by pacing the distance to the nearest marker, using a compass reading to obtain the direction to the marker.

Each turtle was marked in two ways to assure positive identification on recapture. A number was marked on the posterior end of the carapace with red fingernail polish, and notches were filed in the marginal scutes according to a code system set up by Cagle (1939). Marginal scutes four through seven were not used for filing as these scutes form part of the bridge joining the carapace and plastron. The notches were filed with an eight inch triangular file. The notches are more or less permanent, whereas the fingernail polish begins to wear off after about a year.

For each turtle found, in addition to the location and marking, the date, time of day, behavior, habitat, and sex were also recorded. Each turtle was weighed in grams with an Ohaus hand scale, the turtle being placed in a small net which was suspended from the hook of the scale. At each recapture of a turtle, the same information was recorded again so that a history of movements, weight changes, and other behavioral information could be kept on the individual. The sex of each adult was determined by several characteristics. The plastron depression ordinarily present in males and absent in females was the major characteristic, with eye color, size of rear claws, and shape of carapace also helping in identification.

Collections were made in a somewhat systematic method, with four to five acres usually covered in a one to three-hour census trip. The area was covered as carefully as possible during census trips with care taken not to disturb the habitat more than was absolutely necessary. Since the study area was 23 acres, the entire area was covered in four to five collecting days. There were 105 collection trips made by the author during the year, usually in the afternoons between one and six o'clock. Two additional collecting trips were made in the fall by two animal ecology classes from The University of Tennessee. Data gathered on these ecology class trips were used for a population estimate of the turtles. In all, 270 turtles were collected a total of 566 times.

A second method which was used in the study of movements, and also in hibernation studies, was the use of trailing devices. Each consisted of a spool of thread in a metal housing attached to the carapace of the turtle with waterproof tape, as developed and described by Stickel (1950) in her study of turtle populations. The device is set up so that when the turtle moves the spool of thread unwinds and the path of movement is marked by the trail of thread. This is an ideal method of trailing for it not only tells how far the turtle has traveled, but it also shows the exact route taken. New spools of thread could easily be changed in the field in about five minutes time. Using this device, the movements of turtles in the summer months were followed, turtles were trailed into hibernation, and winter movements were recorded.

Additional information was collected on the hibernation and winter behavior of the turtles. The depths of hibernacula were recorded for those turtles that were trailed and could be located. Also, maximum and minimum daily soil and air temperatures, and daily precipitation were recorded. The soil temperatures were recorded at the study area with a soil thermometer (Science Associates, Inc., Princeton, N. J.), and the air temperatures and precipitation data were obtained from the United States Weather Bureau which is located seven miles from the study area. This information was used to examine the relationships between hibernation and weather conditions from 21 October to 31 January.

CHAPTER II

MOVEMENTS AND GENERAL BEHAVIOR

Most of the information gathered on the general behavior of the box turtle in relation to the environment during its active part of the year agrees with the findings of the extensive studies of Stickel (1950).

General Behavior in Relation to Environment

Turtles were found in almost all parts of the study area with the most favorable habitat being the sloping hillsides which offered extensive cover in the form of tangles of vines, fallen logs, and a thick canopy of trees. The least favorable habitat was the open, grassy region of a low area near the center of the study area and an extremely steep, rocky hillside close by. The turtles appeared to have no difficulties in movements up and down the rather steep hillsides, and on the basis of the numbers collected, the turtles seemed to prefer the wooded hillsides to the more level parts of the wooded areas.

The weather conditions influence turtle activities to a great extent. The most favorable conditions for turtle activity were found to be warm or hot days after showers, especially on sunny days. The least favorable conditions seemed to be hot, dry periods or cool periods (below 60° F.). But even on the most favorable days, some turtles were found to be inactive. Inactive turtles were usually found in shallow forms or cavities made from litter.

Three turtles were trailed for a total of 42 days during the month of July, and these turtles demonstrated the extent and behavior of movements quite well. The movements were found to be much like those described by Stickel (1950). Table I contains the record of the movements. The distances recorded are for total distances covered each day and not for straight distances between each day's stopping point as this could be deceiving. On three occasions turtle 51 traveled between 50 and 150 feet but was found in late afternoon within five feet of its departing point that same morning. Movements such as this lend support to the work of Gould (1957) in which he demonstrated that box turtles could orient themselves in their habitat by observing the sun. The sun was shining on all three days in which turtle 51 returned to its original departing point.

Home Range

The turtles that were marked and recaptured in the study area showed a definite home range behavior. All of the turtles that were captured three or more times in 1968 appeared to occupy specific home ranges. No territorial

TABLE I

DISTANCES (IN FEET) TRAVELED BY THREE BOX TURTLES DURING JULY

Date	Turtles 51	129	40
4 July	-[a]	15	-
5	-	0	-
6	120	50	-
7	380	0	-
8	245	0	-
9	25	30	-
10	65	50	50
11	30	0	75
12	15	0	35
13	170	10	200
14	65	0	70
15	80	110	20
16	20	10	210
17	30	0	
18	60	0	
19	0	250	
20	75		
21	60		
22	25		
23	15		
24	70		

[a]The dash (-) indicates turtle was not trailed on that date.

behavior was demonstrated as home ranges overlapped grossly for both male and female turtles of all sizes. In fact, the turtles appeared to have complete tolerance for one another, as groups of four to six turtles were sometimes found together, and on three instances two male turtles were found sharing the same form or resting site.

The home range for each adult turtle was estimated by the smallest circle which included all the known positions of that turtle from recapture data. The diameter of this circle was the estimated diameter of the home range. Using all turtles recaptured three times or more, an estimated diameter of 244 feet was obtained as the mean value of the home range for 76 turtles. Male turtles had a home range of 252 feet and females 224 feet, but an analysis of variance of the two groups showed that this difference was insignificant so the two groups could therefore be combined. The largest home range was found to be between 550 and 600 feet with the smallest less than 50 feet. Table II gives a record of the home ranges of the turtles.

The size of the home range is somewhat smaller than that found for the eastern box turtle by Stickel (1950) and Williams (1961). Using similar methods Stickel reported an average home range of 330 feet for males and 370 feet for females, and Williams reported an average value of 375 feet for both sexes. More will be discussed on the size of the

TABLE II

SIZE OF HOME RANGE FOR TURTLES CAPTURED THREE OR MORE TIMES

Maximum Diameter of Known Range[a]	Number of Captures								Total
	3	4	5	6	7	8	9	10	
0-50	1	-	-	2	-	-	-	-	3
51-100	3	1	-	-	-	-	-	-	4
101-150	7	2	-	1	-	-	1	-	11
151-200	6	5	-	2	1	-	-	1	15
201-250	7	1	1	2	1	-	-	-	12
251-300	8	5	2	-	1	-	-	-	16
301-350	1	-	-	-	2	-	-	-	3
351-400	1	1	-	1	1	-	-	-	4
401-450	-	1	-	-	-	1	-	-	2
451-500	1	1	1	1	-	-	-	-	4
501-550	-	-	-	-	-	-	-	-	-
551-600	2	-	-	-	1	-	-	-	3

[a]Measured in feet.

home range after an estimate of population density is discussed in a later part of this paper.

Fluctuations in Sex Ratio

The overall sex ratio for 247 adults captured in 1968 was 1.61 males to 1.00 females. Stickel (1950) had a sex ratio of about 1:1 in her collection of 238 turtles in 1945. The reason for such a large percentage of males found in the study presented in this paper is not clear. There may have been some misidentification of sexes, but this should not have been very significant as several characteristics were examined carefully to determine the sex of each turtle. Also, the males may have been more active and aggressive, thus more subject to notice and capture. Another alternative may be that this population just has a high ratio of males to females for some unknown reason.

A comparison of the sex ratios from month to month was also undertaken to determine if there were any significant changes in the activity of the sexes throughout the year. Although the sex ratio did fluctuate somewhat from month to month, the extremes being 2.29 males to 1.00 females in June, and 1.41 males to 1.00 females in August, a chi-square test showed that the fluctuations were nonsignificant.

Mating Activity

During 1968 twelve turtles were observed while mating. Eight of these observations occurred in September, with one each in May, June, August, and October, and none in April or July. Since there were at least twice as many collections made in September as in any other month, the number of matings observed in September is not intended to indicate that there is an eight fold increase in mating at this time of the year. It is a good indication, however, that mating does increase in the fall, and that many turtles are fertilized at this time.

Ewing (1933, 1935) demonstrated that female box turtles may retain viable sperm for over a year, so it is probable that many females retain the sperm during hibernation, and are able to lay fertilized eggs in the late spring or early summer without mating again. Ewing (1933) also reports that turtles have a tendency to mate more often immediately following hibernation or before going into hibernation. Allard (1949) states that the box turtle mates throughout its active part of the year, and that there is no peak in mating activity. While not enough observations were made in this study to make definite conclusions, there does appear to be evidence of more mating in the fall. Whether this is true in general remains unknown.

Feeding Observations

Studies on the feeding habits of the box turtle have been done previously by Klimstra and Newsome (1960), and observations were recorded by Allard (1948), Stickel (1950), and other investigators. Klimstra and Newsome, noting that the box turtle is an omnivore, found over 130 specific types of food in their examination of the stomachs of 117 box turtles.

During the work of 1968, field notes were kept on all feeding observations. During June, July, and August, there were twelve observations of box turtles' feeding on mushrooms. Eight of these were in the latter half of June and the first half of July. Several turtles were captured feeding in blackberry patches during the last half of July, and 35 turtles were found feeding on muscadine grapes (*Vitis rotundifolia* Michx.) in September. On 12 and 13 September, six turtles were found each day within an approximate radius of six feet of one another feeding on ripe muscadines that had fallen to the forest floor. Only one turtle was present both days, the other five being different turtles on the second day. At other times, groups of two to five turtles were found close together feeding on muscadines.

These observations are indications of some of the staple foods, but are not intended to represent the major foods of the eastern box turtle. Field observation of turtles' feeding on insects and other small prey is difficult, and this was probably overlooked frequently. Only three observations were made of the turtles' feeding on small prey, two on earthworms and one on a beetle.

CHAPTER III

ANALYSIS OF WEIGHT CHANGES

Since each turtle was weighed at each capture, information as to weight changes in individual turtles and activity of different weight classes was obtained for the entire year.

Seasonal Weight Changes of Individual Turtles

Figure 2 shows the weight changes of the seven male turtles which were captured at least six times over a five month period or longer. An examination of the graph shows that most of the males had a peak in weight sometime in the latter half of the summer. This seems quite reasonable since there is abundant food such as mushrooms, ripe fruits and berries, and insects available at this time. Weight fluctuations were not extreme, but were of some significance, indicating that the turtles probably gorge themselves when desirable foods are present and go for extended periods at other times without eating. Turtle 87, which had an average weight of 300 grams, lost 32 grams in 16 days at the end of August which is about a 10 percent loss of body weight. This was during an extremely dry period. Turtle 66 gained 32 grams during 21 days of July, a period with

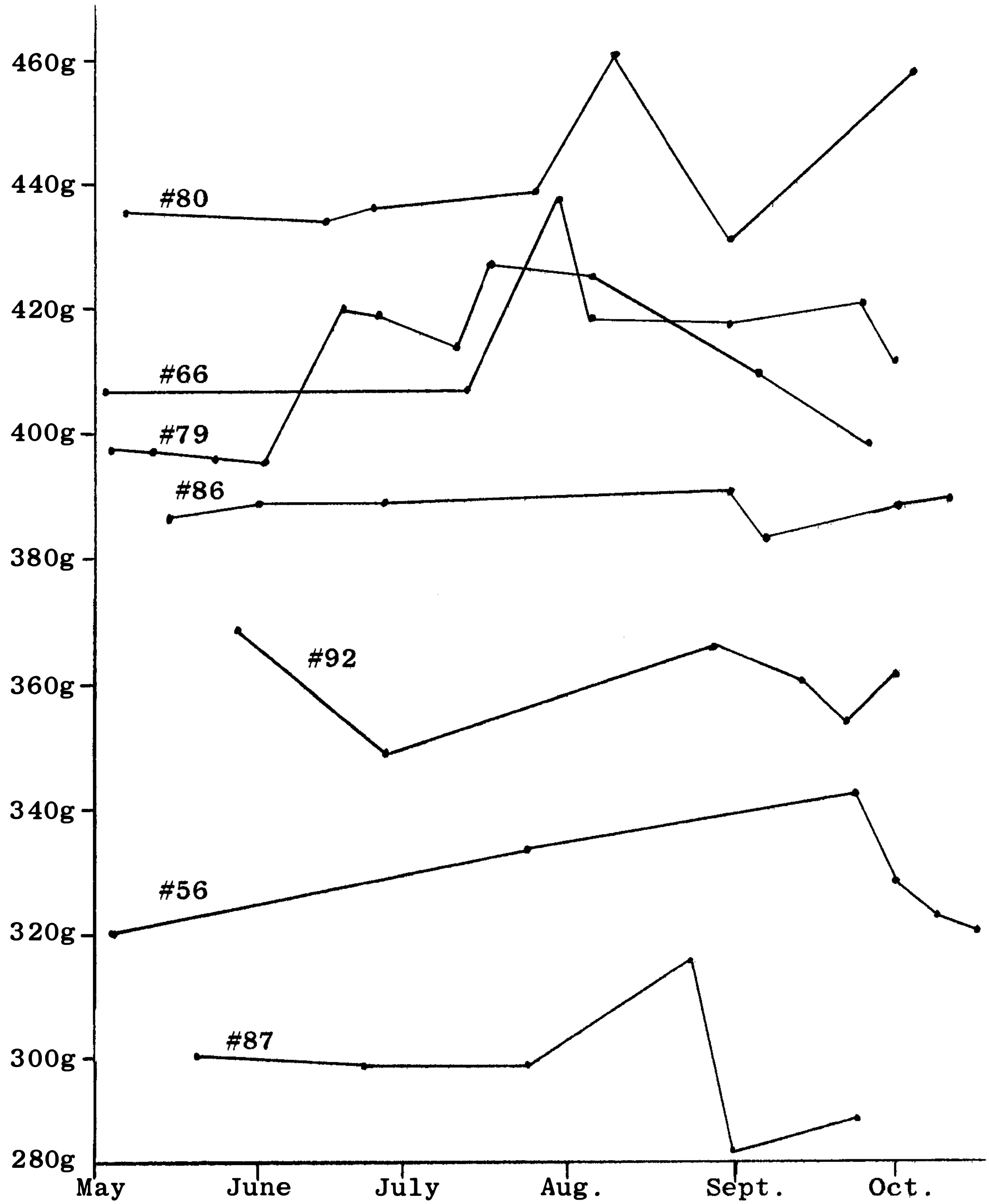


Figure 2. Weight fluctuations of male turtles during 1968.

several showers and an abundant supply of mushrooms and other food.

Figure 3 shows the weight changes of the five females that were captured at least five times over a five month period. The trend is much the same as with the males with the weight peaking sometime in the latter half of the summer. The fluctuations seem to be more extreme than in the males, which may be due partly to egg development and laying. Turtle 108 was believed to have layed her eggs sometime in the period between 19 June and 8 July because there was a loss of 40 grams during this period when most other turtles were gaining weight. Turtle 82, with an average weight of 400 grams, gained 39 grams from 17 July to 17 August which was about a 10 percent gain in body weight.

Allard (1948) did some work on annual weight gain in juvenile turtles. The average weight of 24 juveniles at hatching was estimated to be 6.5 grams. One year later the weight had increased to 20.6 grams and the next year to 39.6 grams. After the third year the average weight was 53.9 grams at which time weighing was discontinued. This information indicates to some extent that annual weight gain in the box turtle is not rapid, and that it must take at least several years before juveniles approach adult weight.

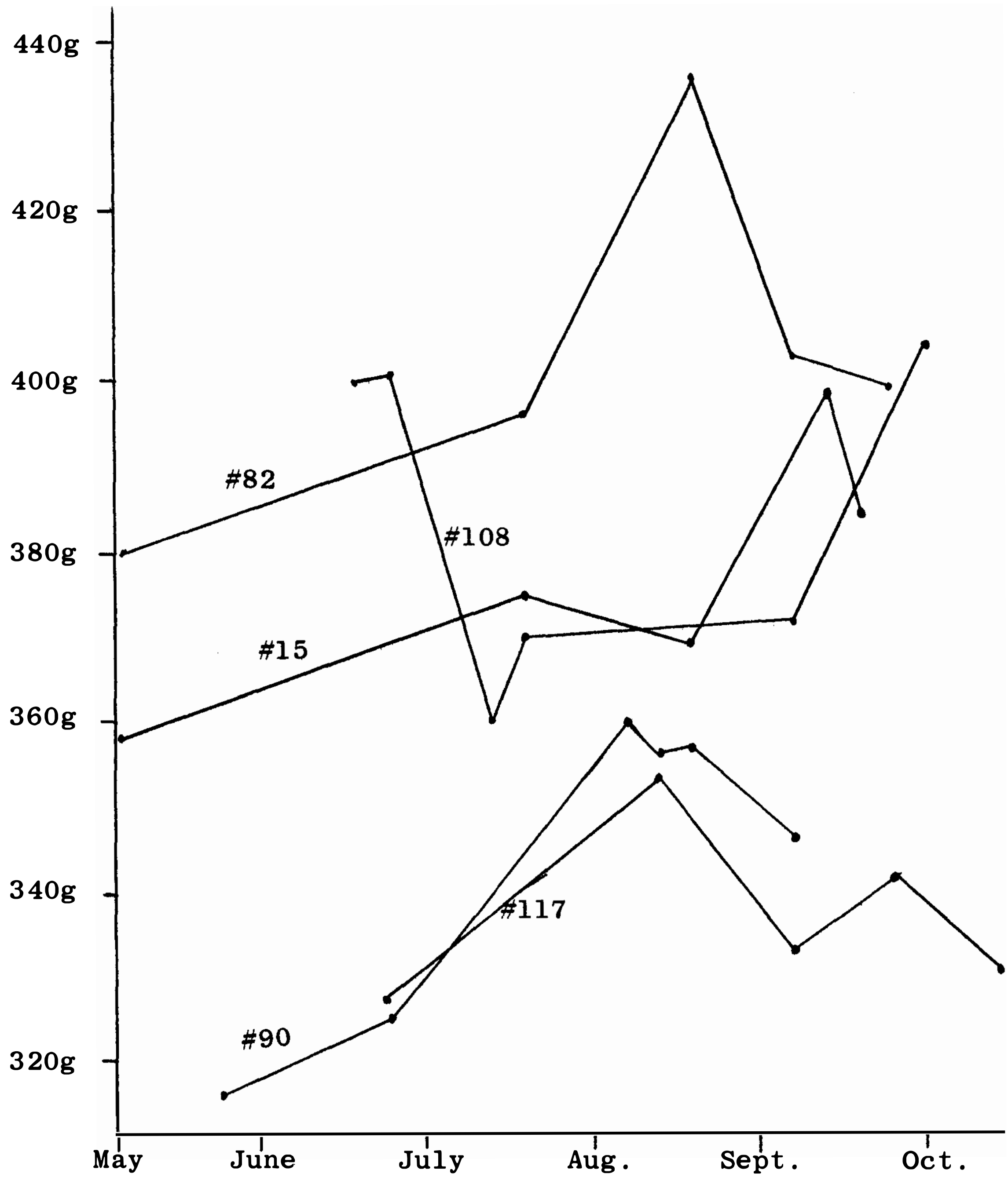


Figure 3. Weight fluctuations of female turtles during 1968.

Seasonal Changes in the Activity of Different Weight Classes

An analysis of changes of the percentage of turtles found in the different weight classes in each season was undertaken to determine if certain sized turtles were more active during certain times of the year. Since active or exposed turtles were more subject to capture, any changes in the percentage of turtles captured in each weight class should indicate changes in activity of the turtles in that weight class.

Fifty gram weight classes were used with the smallest being 0-50 grams and the largest 451-500 grams. The periods, or seasons, compared were April-June, July-August, and September-October. The total number of turtles captured in each weight category was recorded for each season. For any turtle captured twice or more during a season, the average weight was used and recorded only once. The percentage of turtles found in each weight class for the different periods was calculated and is shown in Table III. Figure 4 also shows the percentage of turtles in each weight class for the different periods.

As can be seen from the table and graph, there is an increase in the percentage of turtles captured in the lighter weight classes during the last two periods,

TABLE III

PERCENTAGE OF TURTLES CAPTURED IN EACH WEIGHT CLASS FOR EACH SEASON

Weight Classes in Grams	Seasons		
	April-June (79)[a]	July-August (146)[a]	September-October (169)[a]
0-50	-	0.68%	1.18%
51-100	-	-	2.37
101-150	-	1.37	2.96
151-200	3.33%	4.79	2.96
201-250	1.66	4.11	10.06
251-300	11.59	12.32	17.75
301-350	42.02	31.50	33.14
351-400	34.78	30.82	18.93
401-450	7.25	13.01	8.88
451-500	-	1.37	1.78

[a]Number of turtles captured in that season.

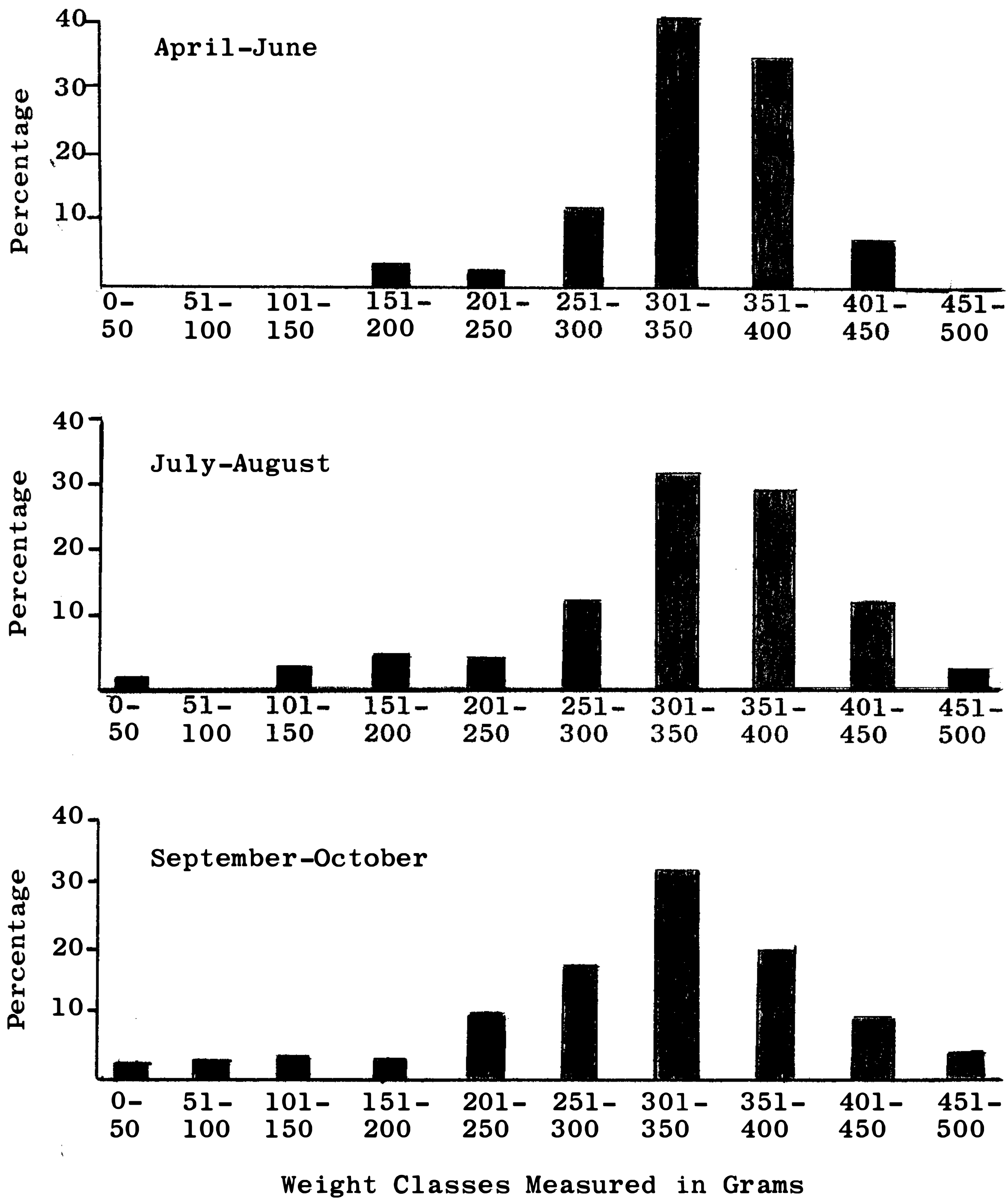


Figure 4. Percentage of turtles found in each weight class for different seasons.

especially in the months of September and October. In September and October, 37.3 percent of the turtles found weighed below 300 grams as compared to 23.3 percent for July and August and 16.6 percent for April through June. The reasons for this increase in the activity of the younger turtles in September and October are unknown but one plausible explanation may be that these turtles are foraging for food in preparation for winter and hibernation.

As was shown in the preceding section, the weights of individual turtles did fluctuate throughout the year. These fluctuations may have had some effect on the shifts in the percentage of turtles found in each weight class, but this is not felt to be of significance. For one thing, the weights of individual turtles tended to increase at the end of the summer while the percentage of turtles found in the heavier classes decreased. Also, since the range of weights in each class was quite large, most turtles' weights did not change enough to shift from one weight class to another during the year. From general observations in the field and from the data presented here, it appears that the smaller turtles were more active, or at least exposed, and subject to capture during the latter part of the summer and in the fall.

CHAPTER IV

POPULATION ESTIMATES

General Considerations

During the entire year of collecting, 236 adult turtles were marked in the study area. Adult turtles were considered as those whose weights averaged over 170 grams. There are two reasons for using this weight as the cut-off point between adults and juveniles. There was a significant weight gap from 133 to 170 grams in which no turtles were found, and those turtles weighing less than 133 grams did not have distinguishing secondary sex characteristics which those above 170 grams did. Also, the marked turtles that weighed 133 grams and less were recaptured so infrequently that no accurate population estimate could be made using these smaller turtles.

When considering the population estimate of the study area, the problem of the ranges of the border residents overlapping the boundaries of the study area must be taken into account. The eastern edge of the area and approximately one-half of the northern edge of the area are bordered by a five to ten foot drop off in most places to a swamp and pasture. Periodic checks were made in these areas, and only three turtles were found. These were all first captures and were never recaptured. Therefore, it was felt that most turtles found along these borders did not extend their range outside the study area.

On the western, southern, and northwestern edge of the study area there were no natural boundaries, there being wooded areas of suitable habitat for most of the length. Therefore, many of the turtles marked along these borders had ranges which extended outside the study area, and more turtles were marked in the study area than actually lived entirely within the study area. Dice (1938) stated that on the average it is statistically correct to assume that when all the animals using a plot of ground are collected, they will represent the population of the area plus the population of an area around its borders equal to approximately one half of the average home range. Since the home range diameter averaged almost 250 feet, an added strip of 125 feet around these borders increases the area from 22.7 acres to 30.2 acres. The population estimate should now include the residents and border residents of the study area.

One other factor that should be assessed is that of the transient turtles which may move through the study area but not include this area in their home range. In this study there was no real way of estimating the number of captured turtles that might be of this type, and the assumption made is that their number is small. The reasons for this assumption are that of all the turtles marked and recaptured in the study area, only two were found to have traveled over 1000 feet. Also, about ten turtles were marked at distances ranging from 200 to 500 feet outside the study area, and none of these were ever recaptured within the area. From this evidence it appears that the turtles do not have a major tendency to move over large areas and that the number of transients would be small.

Methods and Results of Population Estimations

The methods used in marking the turtles were ideal for multiple capture-recapture population estimates since each turtle was individually marked and a complete capture-recapture record could be obtained. A multiple mark-recapture method developed by Jolly (1965) was used as one method of estimating the population in the study area. His approach is stochastic, and is intended to give maximum likelihood estimations for the population size. It takes into account emigration and immigration between collecting dates, and does not require that the collecting be done on a regular basis. His method is designed to estimate the population density at each collecting trip, and, therefore, show the changes in population size between sampling dates. Using Jolly's method, population estimates cannot be made for the first or the last sampling period, but an estimate can be made for all periods in between.

In using this method, the data obtained for each five consecutive collecting days were combined as one sample. This was done for two reasons: (1) the entire area was usually covered during a five day collecting period, and (2) by combining the data for each five days, larger samples were obtained.

Equations used in the population estimate were as follows:

$$\alpha_i = \frac{m_{.i}}{n_i}$$

$$\hat{M}_i = \frac{s_i Z_i}{R_{.i}} + m_{.i} \qquad i = 2.....(L-1)$$

$$\hat{N}_i = \frac{\hat{M}_i}{\alpha_i}$$

The symbols mean the following:

M_i: total number of marked animals in population at time i

$m_{.i}$: all marked animals in the ith sample

n_i: number of marked plus unmarked caught in the ith sample

s_i: number of marked animals released from the ith sample

Z_i: marked animals not caught in the ith sample but subsequently caught, and therefore known to be alive at time i

$R_{.i}$: individuals of s_i caught subsequently, and therefore known to be alive at time (i + 1)

N_i: estimate of the population at time i

The population estimate for each of eighteen collection periods of the year 1968 is shown in Table IV. The estimates ranged from 99 to 386 with a mean of 228. Since the box turtle is a long-lived animal with a restricted home range, the population does not in all probability fluctuate as much as these estimations indicate. On some trips turtles were aggregated due to concentrated food supplies or favorable habitat sites, and thus sampling was not as random as at other times. Also, as reported earlier in this study, the turtles belonging to different weight classes were not equally active during the entire year. Thus, at any census trip, collection of certain groups of turtles might be favored over others, and this could account for some of the fluctuations. Another important factor is that all sample sizes were not the same, ranging from 10 to 47, and this would also tend to give fluctuations in the estimates. The mean of the estimates, 228, is probably the most reliable estimate of the stable adult population. This estimate gives a density of 7.6 turtles per acre.

TABLE IV

POPULATION ESTIMATES USING JOLLY'S 1965 STOCHASTIC METHOD

Date	Population Estimate
22 May - 31 May	133
1 June - 13 June	256
14 June - 18 June	99
19 June - 28 June	142
29 June - 6 July	215
7 July - 12 July	257
13 July - 18 July	200
19 July - 24 July	302
25 July - 31 July	379
1 Aug. - 7 Aug.	210
8 Aug. - 15 Aug.	333
16 Aug. - 24 Aug.	228
25 Aug. - 1 Sept.	111
2 Sept. - 6 Sept.	262
7 Sept. - 12 Sept.	194
13 Sept. - 20 Sept.	386
21 Sept. - 27 Sept.	259
28 Sept. - 5 Oct.	144

An estimate of the population was made by another method using capture-recapture data for comparison. On 8 and 10 October, 1968, members of an ecology class at The University of Tennessee searched the entire study area for a period of two and one-half hours each day. The search was made by two entirely different groups, except for instructors, and at the same time of day. The results are as follows:

<u>October 8</u>

total captures (C_1) :15

recaptures (R_1) :13

new captures : 2

total marked at the beginning of census (M_1) :236

<u>October 10</u>

total captures (C_2) :18

recaptures (R_2) :15

new captures : 3

total marked at the beginning of census (M_2) :238

Using a repeated mark-recapture method developed by Schnabel (1938), an estimate was obtained by the following formula:

$$\hat{N} = \frac{\Sigma M_i C_i}{\Sigma R_i}$$

The estimate ($\hat{N}$) equals 276 turtles with 95 percent confidence levels of 204-444, or 9.2 turtles per acre with 95 percent confidence levels of 6.8-14.7. Thus the two independent estimates are quite close.

Since a total of 236 adult turtles had been marked in the area and only five unmarked ones were found out of 33 captures made during the ecology class field trips, this indicates that most of the adult turtles in the area were marked and that the total number marked also gives a fairly accurate population estimate. With these three independent estimates, it appears safe to assume that the population estimate lies somewhere around 7.6 to 9.2 turtles per acre.

The population density estimates for this study area are considerably higher than those made by Stickel (1950) for a wooded lowland habitat in Maryland in which she estimated four to five turtles per acre. Stickel considered turtles with a carapace length of less than 107 mm. as juveniles, and this corresponds closely with those turtles weighing less than 170 grams in this study. Williams (1961) also estimated a turtle density of four to five turtles per acre for a wooded habitat in Indiana. It is not stated whether or not juveniles were included in this study.

Relationship Between Home Range Size and Population Density

As was shown earlier in this paper, the average size of the home range was estimated to be 244 feet. It was also stated that this was somewhat smaller than the home range estimates for the same species given by Stickel (1950) and Williams (1961), which ranged from 330 to 375 feet.

The size of the home range is thought by most population ecologists to express the area of the habitat which an animal requires to obtain all of its needs for survival and reproduction, and the size gives an indication of the suitability of the habitat. The smaller home range in this study might possibly be accounted for if the population density is also taken into consideration. Since the population estimate per acre was between 7.6 and 9.2 turtles per acre, or almost double the estimates of Stickel (1950) and Williams (1961), it would appear that the habitat in this area is more suitable for the box turtle and can support a higher population. Therefore, the smaller home range also indicates that the habitat is more suitable for the box turtles in that they can obtain all their requirements for survival and reproduction in a smaller area.

Legler (1960) estimated that the ornate box turtle, *Terrapene ornata* Agassiz, had an average home range diameter of 586 feet with densities ranging from 2.6 to 6.3 turtles per acre. This species is characteristic of the open grassland areas of the midwestern United States, and it may be that a larger area is required in this habitat for this species to obtain its needs.

CHAPTER V

HIBERNATION AND WINTER BEHAVIOR

From 10 to 21 October, trailing devices were attached to eleven turtles. Six of these turtles were subsequently lost, so only five turtles were trailed throughout the complete period until 31 January when the study was discontinued.

Winter Movements

From 10 to 21 October, there was daily movement of at least two, and usually all, of the turtles that were being trailed. The first day in which there was no movement was 22 October and from this date until the middle of December, the daily movements of the turtles varied extremely. Table V shows the record of movements for the five turtles that were trailed from 21 October through 31 January. The dates are recorded for only those days in which at least one turtle moved. As Table V shows, winter movements were quite common until 13 December, from which time no further movements were recorded until 24 January.

Table VI gives a record of maximum and minimum daily air temperatures, maximum and minimum soil temperatures at a depth of four inches (1.5 inches of leaf litter and 2.5

TABLE V

DISTANCES (IN FEET) OF TURTLE MOVEMENTS FOR FALL AND WINTER 1968

Date	Turtles				
	8	16	54	56	169
21 Oct.	5	-	-	-	-
23	-	-	-	12	5
25	5	-	-	-	-
28	-[a]	-	-	5	-
1 Nov.	-	-	20	-	25
2	-	-	10	75	-
3	-	-	-	-	25
4	-	25	5	200	40
5	-	-	-	-	5
8	-	-	2	-	-
10	-	-	2	-	20
16	-	90	30	-	140
17	-	110	-	80	150
22	100	20	-	-	-
23	400	50	-	-	35
25	60	80	-	50	15
1 Dec.	100	10	140	120	-
3	50	-	-	-	-
6	40	-	-	-	-
13	40	-	15	-	-
24 Jan.	-	-	-	90[b]	40

[a]Lost on 28 October and found on 21 November.

[b]Lost after trailing 90 feet.

TABLE VI

SOIL TEMPERATURE, AIR TEMPERATURE, AND PRECIPITATION IN RELATION TO TURTLE ACTIVITY

Date	Temperature (^{o}F)		Pptn. (in.)[a]	No. of Active Turtles/Av. Feet Moved
	Air Max./ Air Min.[a]	Soil Max./ Soil Min.[b]		
21 Oct.	73/43	-	-	1/5
22	73/46	-	-	-
23	70/49	-	-	2/8
24	63/41	-	-	-
25	46/39	-	-	1/5
26	57/30	56/49	-	-
27	70/33	56/50	.03	-
28	57/43	56/52	Trace	1/5
29	50/35	56/49	-	-
30	61/29	56/48	-	-
31	71/35	56/48	-	-
1 Nov.	77/45	57/51	-	2/23
2	76/51	60/52	-	2/42
3	74/49	60/55	-	1/25
4	70/55	60/55	.22	4/70
5	70/48	59/56	-	1/5
6	63/54	60/56	.18	-
7	60/46	58/56	.02	-
8	47/41	58/54	Trace	1/2
9	42/34	50/55	.37	-
10	44/33	50/46	-	2/11
11	40/32	48/44	.15	-
12	37/33	44/42	.05	-
13	46/28	47/42	-	-
14	51/26	-	-	-
15	69/35	51/44[c]	-	-
16	70/53	55/48	.04	3/103
17	62/46	53/48	.27	3/110
18	62/40	54/50	.31	-
19	40/32	52/46	.04	-
20	39/27	-	-	-
21	50/22	45/41[c]	-	-
22	61/32	48/43	-	2/60
23	65/33	50/44	-	3/165
24	50/38	-	.32	-
25	56/31	49/42[c]	-	-
26	62/27	49/43	-	4/50

TABLE VI (continued)

Date	Temperature (^{o}F) Air Max./Air Min.[a]	Soil Max./Soil Min.[b]	Pptn. (in.)[a]	No. of Active Turtles/Av. Feet Moved
27 Nov.	64/37	-	-	-
28	70/55	-	.03	-
29	55/39	-	-	-
30	53/38	53/43[c]	-	-
1 Dec.	46/39	-	.32	4/92
2	58/42	-	-	-
3	48/39	52/43[c]	.47	1/50
4	48/31	-	.09	-
5	48/29	-	-	-
6	48/23	49/40[c]	-	1/40
7	46/29	-	-	-
8	35/21	-	Trace	-
9	37/16	-	-	-
10	38/20	-	-	-
11	51/25	49/36[c]	-	-
12	50/22	44/36	-	-
13	60/39	42/36	.25	1/27
14	42/19	-	Trace	-
15	31/17	-	Trace	-
16	38/14	-	-	-
17	47/17	-	-	-
18	58/33	-	-	-
19	62/35	41/35[c]	Trace	-
20	51/32	-	-	-
21	46/27	-	.14	-
22	50/41	-	.93	-
23	50/28	-	Trace	-
24	35/21	-	-	-
25	36/22	-	-	-
26	38/20	-	-	-
27	62/30	-	Trace	-
28	64/37	-	.81	-
29	42/29	-	-	-
30	45/25	-	Trace	-
31	42/22	-	.21	-
1 Jan.	27/11	45/34[c]	-	-
2	36/13	-	-	-
3	37/26	-	-	-
4	24/12	-	-	-
5	32/7	-	.13	-
6	38/16	43/33[c]	-	-

TABLE VI (continued)

Date	Temperature (°F) Air Max./ Air Min.[a]	Soil Max./ Soil Min.[b]	Pptn. (in.)[a]	No. of Active Turtles/Av. Feet Moved
7 Jan.	37/23	-	-	-
8	33/21	-	.04	-
9	58/25	-	Trace	-
10	33/17	-	Trace	-
11	37/18	-	.10	-
12	38/16	-	-	-
13	43/26	-	-	-
14	44/20	-	-	-
15	48/25	44/33[c]	-	-
16	51/27	-	-	-
17	57/35	43/34[c]	Trace	-
18	54/47	-	.40	-
19	51/49	-	1.50	-
20	50/45	-	.41	-
21	48/42	-	Trace	-
22	53/43	-	Trace	-
23	57/45	-	.39	-
24	60/33	-	.03	2/65
25	37/25	49/33[c]	-	-
26	36/20	-	-	-
27	37/32	-	.03	-
28	47/33	-	.25	-
29	47/40	-	.01	-
30	69/42	-	.30	-
31	59/48	50/39[c]	.39	-

[a]Obtained from United States Weather Bureau.

[b]Measured at depth of four inches (1.5 leaf litter, 2.5 soil).

[c]Includes maximum and minimum soil temperatures for entire period from last reported temperature.

inches of soil), and the daily precipitation from 21 October to 31 January. The soil temperatures were recorded on an east facing slope in the general area of two of the turtles under observation. The turtles were found to burrow to a depth of approximately four to five inches, and the soil measurements were used to obtain temperature estimates of their hibernacula. The other weather records were used to get some idea of the effects of temperature and rainfall on winter movements and hibernation. Movements were found to be more common on warmer days, but there were exceptions such as the turtle activities on 10 November and 1 December, when the maximum temperatures were 44°F. and 46°F. respectively. Also movements appeared to be more common on days after a period of rain, but again there were exceptions.

All of the turtles stayed well within their previously estimated home ranges during these winter movements with the exception of turtle 8. On 23 November, this turtle moved 200 feet west of its estimated home range and remained in this area through 31 January. The general winter movements of the turtles were quite similar to the summer movements in that there was usually much doubling back and crisscrossing, with the turtles often being found in the afternoon near the morning's departing point.

Carpenter (1957) studied the hibernation of the three-toed box turtle, *Terrapene c. triangus*, in Oklahoma by searching for and locating turtles in their hibernacula. He found that the turtles often moved from one hibernaculum to another during the fall and winter seasons, especially in the late fall and early winter. Cahn (1933) reported that 24 eastern box turtles which he kept in an enclosed pen in Illinois went into hibernation in the latter part of November after going through about a three-week period of alternate burrowing and active movement. He also reported that two of the turtles came out of hibernation and moved about the pen during one day in January. Allard (1948) observed the eastern box turtle for over twenty years and reported finding turtles active during all months of the winter. Thus, it appears that while the eastern box turtle does hibernate during the colder parts of the winter, it also maintains some winter activity.

Depths and Types of Hibernacula

Whenever the turtles were not active during the late fall and winter months, they were found burrowed under the leaf litter. Measurements were made on the depths to which these turtles burrowed and are recorded in Table VII. For each turtle, both the distance from the surface of the leaf litter to the top of the turtle's carapace and the distance from the surface of the soil to the base of its hibernaculum are recorded. None of the turtles burrowed very deeply into

TABLE VII

DEPTHS OF HIBERNACULA FOR FIVE TURTLES DURING FALL AND WINTER MONTHS[a]

Date	Turtles 08	16	54	56	169	Average
21 Oct.	0.0/0.0	0.5/0.0	0.0/0.5	2.0/0.0	1.0/0.5	0.7/0.2
4 Nov.	-	3.5/1.5	2.0/0.5	3.0/1.0	1.5/0.0	2.5/0.8
18 Nov.	-	2.0/2.0	2.5/2.5	4.0/2.0	2.5/2.0	2.8/2.1
3 Dec.	2.5/2.0	3.0/2.0	2.0/1.5	3.0/1.0	2.0/2.0	2.5/1.7
20 Dec.	4.0/2.5	3.5/2.5	4.0/2.5	4.0/2.0	2.5/2.5	3.6/2.4
1 Jan.	4.0/2.5	3.5/2.5	4.5/2.5	4.0/2.0	3.5/2.5	3.9/2.5
14 Jan.	3.5/2.5	3.5/2.5	5.0/2.5	4.0/2.0	3.5/3.0	3.9/2.0
25 Jan.	3.5/2.5	3.5/2.5	5.0/2.5	-	2.5/2.0	3.6/2.4

[a]Distance from leaf litter surface to carapace top/distance from soil surface to base of hibernaculum. Distances measured in inches.

the mineral soil--the maximum depth being 3.0 inches and the average 2.5 inches during January. During colder periods the turtles usually shaped out a cavity to a depth in the soil so that the top of the carapace was just even with the soil surface. This soil depth, coupled with the covering of 2.5 to 5.0 inches of leaf litter, appeared to be enough to insulate the turtles from the coldest weather through 31 January. Table VII shows that the minimum soil temperature at four inches (1.5 leaf litter, 2.5 soil) was 34^{o}F., and this was when the air temperature was 11^{o}F. The maximum depth burrowed by any turtle was 7.5 inches (5.0 leaf litter, 2.5 soil), and this was during the latter half of January.

The types of hibernacula used by the turtles varied somewhat with the season. In late fall and early winter when the turtles were still somewhat active, various sites were used by the turtles. The turtles sometimes burrowed under the leaf litter in open sites on the forest floor, but more often chose places where the leaf litter had been built up more than usual such as next to fallen logs, stumps, or large rocks. When the weather became colder, the turtles seemed to prefer stump holes for their hibernacula. Four of the five turtles spent 13 December to 24 January in or next to stump holes. These depressions usually contained a thick mat of leaf litter with the soil being mixed with rotting wood and litter. Burrowing was probably much easier in this type of hibernacula, and may have provided better insulation against the temperature.

Carpenter (1957) reported that the average depth of the hibernacula of the three-toed box turtle was 5.3 inches (2.8 leaf litter, 2.5 soil) during the winter months. He also reported that stump holes were the favorite type of hibernacula with 39 percent of the turtles found in this type of site. Minton (1944) reported that a female eastern box turtle hibernated at a maximum depth of 5 inches during one winter season in Illinois. In conclusion it appears that the eastern box turtle follows the same pattern of hibernation as the three-toed subspecies, *Terrapene c. triangus*.

CHAPTER VI

SUMMARY

A quantitative and descriptive field study was made on a population of the eastern box turtle, *Terrapene c. carolina*, in eastern Tennessee during 1968. A hilly, 23 acre woodland used as the study area was systematically searched throughout the spring, summer, and fall, and turtles were repeatedly collected, marked, weighed, and released. In all, 270 turtles were collected 566 times.

A grid system, with trees marked at 256 foot intervals, was used in the study area so that the location of the captured turtles could be recorded.

A trailing device was used to study movements of the turtles both in summer and winter and to follow five turtles into hibernation.

Turtles were found to be most active on warm summer days, especially following showers, and least active in cold or dry weather. On the basis of collections, smaller turtles were found to be more active during the fall as compared to the spring or summer months. In September and October, 37.3 percent of the turtles captured weighed less than 300 grams as compared to 23.3 percent during July and August and 16.6 percent during April through June.

The weights of individual turtles fluctuated throughout the collecting period with most turtles having a peak in weight in the latter part of the summer. These fluctuations were not extreme. The greatest change in one month was about 10 percent of the turtle's body weight. The major foods observed being consumed by the turtles were mushrooms in the summer months and muscadines in the fall.

Mating was most frequently observed in the fall as nine out of twelve observations were during September and early October. The sex ratio of all turtles collected was 1.61 males to 1.00 females.

The home range diameter was estimated by taking the diameter of the smallest circle that included all of the locations at which a turtle had been found. The average home range diameter was estimated to be 248 feet for 76 turtles collected three or more times. The maximum home range was 550-600 feet and the minimum was less than 50 feet.

The adult population density was estimated by two methods using capture-recapture data and also by the total number of turtles marked in the area. Adults were considered to be those turtles that weighed over 170 grams. The three population estimates ranged between 7.6 and 9.2 turtles per acre. These population estimates were higher and the average home range diameter was smaller than similar estimates given by other investigators in populations of eastern box turtles in Indiana and Maryland. It was felt, therefore, that the area used in this study offered a more suitable habitat for the box turtle in that it could support a higher population with individual turtles requiring a smaller home range to obtain their needs.

For the last part of the study, five turtles were trailed from 21 October to 31 January, in order to learn more about winter movements and hibernation. These turtles remained somewhat active until the middle of December from which time there was no movement until 24 January, when two turtles emerged from their hibernacula for a few hours. The turtles were usually active on warmer days, especially after periods of rain, but there were some exceptions. Whenever the turtles were not active they were found burrowed under the leaf litter. The average depth burrowed during the coldest month (January) was about 6.0 inches (3.8 leaf litter, 2.3 soil). This was below the frost line and probably provided adequate insulation.

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VITA

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He is married to the former Saundra Anne Parish of Jackson, Tennessee, and has one daughter, Jennie Laura.