

This is to certify that the

thesis entitled

**ECOLOGICAL IMPORTANCE OF NEST CONSTRUCTION IN
THE HISPID COTTON RAT (SIGMODON HISPIDUS)**

presented by

Karl August Shump, Jr.

has been accepted towards fulfillment
of the requirements for

Doctoral degree in **Zoology**

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ABSTRACT

ECOLOGICAL IMPORTANCE OF NEST CONSTRUCTION IN THE HISPID COTTON RAT (SIGMODON HISPIDUS)

By

Karl August Shump, Jr.

Nest construction by the hispid cotton rat (Sigmodon hispidus) was examined from two different climatic regions. A field and laboratory phase were designed to determine factors which might affect nest construction. The field phase was used to determine if nests in fact differed between localities having strikingly contrasting climates. Thirty field-constructed nests of the hispid cotton rat from each of two areas, northeastern Kansas and southern Florida, were found to differ significantly in several specific parameters (i.e., thickness of the base, lengths and widths of clippings incorporated into the outer construction, and conductance). The entire set of nest parameters was simultaneously compared between Florida and Kansas using multivariate analysis and was found to be significantly different. In other words, nests differ between Florida and Kansas.

The laboratory phase of this study was designed to determine if nests were constructed differently as a result of the cotton rats' place of origin, sex, nesting material used, experience, and/or climate. Vegetation characteristic of field nests and live-trapped cotton rats from both field localities were sent back to Michigan for these determinations. Wild-captured and laboratory-born (F_1) cotton rats (equal numbers and sexes) from both areas were allowed to construct nests in environmental chambers adjusted to simulate winter conditions characteristic of each locality. Each rodent was allowed to construct

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four nests, two with vegetation brought from their home locality plus two with vegetation from the other locality. Under the influence of a given climate these animals constructed nests similar to those found in the field at that climatic locality. Nests were constructed similarly under the stimulus of a particular climate regardless of population differences, sex, type of vegetation utilized, or experience. However, nests were found to differ in several parameters between the simulated climates. These experiments indicate, among other things, that hispid cotton rats from Kansas and Florida are capable of modifying their nest construction to cope with different climatic conditions.

Body size, tail length in proportion to body length, fur thickness, hair length, follicle count, and pelt insulation were compared between Kansas and Florida Sigmodon. No differences were found to exist between these two populations in any of the above morphological characteristics.

A technique was developed to measure the conductance of nests, and it was equally appropriate for the determination of pelt insulation.

ECOLOGICAL IMPORTANCE OF NEST CONSTRUCTION IN
THE HISPID COTTON RAT (SIGMODON HISPIDUS)

By

Karl August Shump, Jr.

A DISSERTATION

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for the degree

DOCTOR OF PHILOSOPHY

Department of Zoology

1976

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INTRODUCTION

Many thermoregulatory responses by mammals to various environmental vicissitudes have been identified; however, few have been adequately studied. More complete studies of species which must cope with different latitudinal or altitudinal climatic conditions are necessary. Comparative data on the responses of such species from different parts of their ranges could provide worthwhile information on the adaptations acquired by these animals to help them survive in diverse climatic regions.

Most rodents that construct nests forage outside of these during the day or night. The nest-building response of rodents is considered to be, in part, a thermoregulatory reaction which helps to mitigate climatic variability and has major ecological significance (Cory, 1912; Johnson, 1926; Hamilton, 1940; Nicholson, 1941; Thomsen, 1945; Burt, 1946; Howard, 1951; Sealander, 1952; Pearson, 1960; Stark, 1963; Brown, 1968; Muul, 1968; Dawson and Lang, 1973; Shump, 1974; Bryant and Hails, 1975; Glaser and Lustick, 1975). Some rodents have been observed to use more nesting material (cotton, paper, or wood-wool) in cold laboratory environments as opposed to warm ones (Kinder, 1927; Richter, 1937; Thorne, 1958; Lee and Wong, 1970; Lynch, 1973; Stiemie and Nel, 1973). Progressively enhanced nest-building capability in mice living many generations at -3°C has been described by Barnett (1956, 1965). Species and geographical variations in nest size have been examined in Peromyscus (King et al., 1964; Layne, 1969; Wolfe, 1970). Although much insight has been obtained by the above studies, the following information is lacking for all species:

1) Comparative field studies quantifying differences in nests; 2) effects of different nesting materials (natural vegetation from different areas) on nest construction; and 3) similarities and/or differences between nests constructed in the laboratory and those made in the field which affect the validity of conclusions drawn from laboratory experiments. Other problems, partly explored in a few species, need further investigation to determine: 1) The capability of rodents to modify their nests to cope with different climates; 2) the effect of experience in rodents on nest-building; and 3) the variability of nest-construction with sex of the builder.

Many small mammals excavate and/or use burrows as well as surface nests. The amount of use each receives is not known; however, both may be important refuges from climatic stresses. Burrow microclimates are often favorable to rodent survival, due to depth or snow cover. Humidity seems to be relatively high (Pruitt, 1959; Stark, 1963; Daniel, 1964), and temperatures in burrows (and under the snow near the ground) during winter weather usually stay above freezing (Geiger, 1950; Johnson, 1951; Pruitt, 1959; Getz, 1961; Coulianos and Johnels, 1963; Hayward, 1965). Rodents, especially in the desert, also avoid unfavorable heat by remaining in their cooler burrows (Vorhies, 1945; Robinson, 1959; Kirmiz, 1962; Carpenter, 1966; McNab, 1966; MacMillen and Lee, 1970; Hooper and Hilali, 1972). Burrows even aid mammals to survive longer on dry foods by reducing water loss from the animal therein (Schmidt-Nielsen et al., 1948). Although burrow systems appear to be of value to the survival of certain mammals, few data exist concerning their actual climates and construction. Consequently, any information, especially compared from different regions, should be most enlightening.

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Once the mammal has ventured out of its burrow or nest, it is not devoid of protection from environmental conditions. Many mammals have undergone certain morphological adaptations which help to conserve heat during winter. The well-known rules of Bergmann and Allen may partly explain how certain animals have adapted to cold environments but are not above debate (Rensch, 1936; Reinig, 1939; Scholander, 1955) and need further exploration. The pelage of mammals is important and changes seasonally in small mammals, though not to the extent observed in large mammals (Hart, 1956, 1964, 1971). In addition, mammals living in the north seem to have thicker, more insulative fur than tropical species (Scholander et al., 1950). However, analyses on a single species occupying both a mild and cold climate are lacking. An increase in fur may not be acquired by northern animals if they can modify their environment behaviorally (e.g., by constructing nests and/or burrows). Nevertheless, the possibility of increased insulation of the pelage of a species living in cold regions compared with its conspecifics in milder areas has not been explored and needs investigation.

The hispid cotton rat, Sigmodon hispidus, should provide much information which will help to solve many of the previously mentioned problems. This cotton rat is a diurnal, cricetine rodent which is strictly New World and ranges from 40° N latitude at the Kansas-Nebraska border to about 8° S latitude in coastal Peru (Baker, 1969). This herbivorous rodent is relegated to grasslands and brushlands throughout its range (Hill and Hibbard, 1943; Erickson, 1949; Davis and Russell, 1954; Baker, 1956; Baker and Greer, 1962; Goertz, 1964) and is subjected to a wide variety of climatic regimes.

Both surface and burrow nests are built by cotton rats (Strecker,

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1929; Schendel, 1940; Halloran, 1942; Lewis, 1944; Goodpaster and Hoffmeister, 1952; Hastings, 1956; Dawson and Lang, 1973; Baar et al., 1974); however, those from different climatic regions have not been studied in a comparative fashion nor have any from a single area been studied in detail.

Sigmodon is presumed to be primarily a tropical American form that has lately, in the Pliocene to Recent, moved into both North and South America (Hooper, 1949). The geological evidence indicates the genus extended into Kansas in the Upper Pliocene and Lower Pleistocene (Hibbard, 1960; Hibbard, et al., 1965). Cotton rats were presumably displaced southward during the Wisconsin glaciation into two refugia, peninsular Florida and southwestern America (Blair, 1958). After the last glacial retreat, the southern plains sector of the United States became suitable again for cotton rat inhabitation. A northward spread of cotton rats into Kansas and extreme southern Nebraska within the past century was documented by Cockrum (1948), Jones (1964), and Genoways and Schlitter (1966).

Consequently, the hispid cotton rat has the potential necessary to answer pertinent questions concerning methods of survival in a variety of climates. It is the purpose of this research to examine the following questions:

1. Are nests constructed differently in diverse climatic regions?
2. Do burrows differ in their construction in diverse climatic regions?
3. Are existing differences in nest construction primarily responses to genetic or environmental factors?
4. Are nests constructed differently by lab-born, inexperienced animals, as opposed to wild-caught, experienced individuals?

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5. Does nest construction vary with sex?
6. Does vegetation from different regions affect nest construction?
7. Do cotton rats in colder habitats exhibit insulating morphological characteristics differing from those of their conspecifics in warmer habitats?

MATERIALS AND METHODS

Field Investigations

The field phase of this study was designed to determine whether nests and/or burrows differed in their construction in different climatic regions. This was conducted during the winter of 1973-1974 at two different localities; 1) The Nelson Environmental Complex, Jefferson County, Kansas, situated about 5.9 km north and 3.2 km east of the University of Kansas campus at Lawrence, and 2) the Archbold Biological Station, Highlands County, Florida, located approximately 22 km south of Lake Placid (Figure 1). Table 1 gives aspects of the climates of these areas, indicating the extent to which Kansas is colder. The site of study in Kansas consisted of slightly rolling open land, on a compact humus soil, with a vegetative cover consisting of mixed brome grass (Bromus inermis), bluegrass (Poa pratensis), and foxtail (Sertia viridis); see Figure 2. The site in Florida was fairly level mixed grass-low shrub habitat, on a sandy loam substrate, dominated by broomsedge (Andropogon virginicus) interspersed with dwarf palmettos (Sabal minor), a few slash pine trees (Pinus ellotin) and two small stands (each about 30 m²) of wiregrass (Aristida stricata); see Figure 3.

Sherman live-traps were used to capture cotton rats (Sigmodon hispidus) at both study sites. Some of these rodents (36 from Florida and 29 from Kansas) were transported back to the Museum at Michigan State University, East Lansing, Michigan. Other individuals were fitted with leather harnesses attached to a spool of string (Figure 4), then released and followed through their runways. Every Sigmodon so released scurried to a refuge site, which was usually its nest (Figure 5). All nests were

Figure 1. Location of study sites: 1) Nelson Environmental Complex, Jefferson County, Kansas, and 2) the Archbold Biological Station, Highlands County, Florida. The range of Sigmodon hispidus is shown by cross hatching.

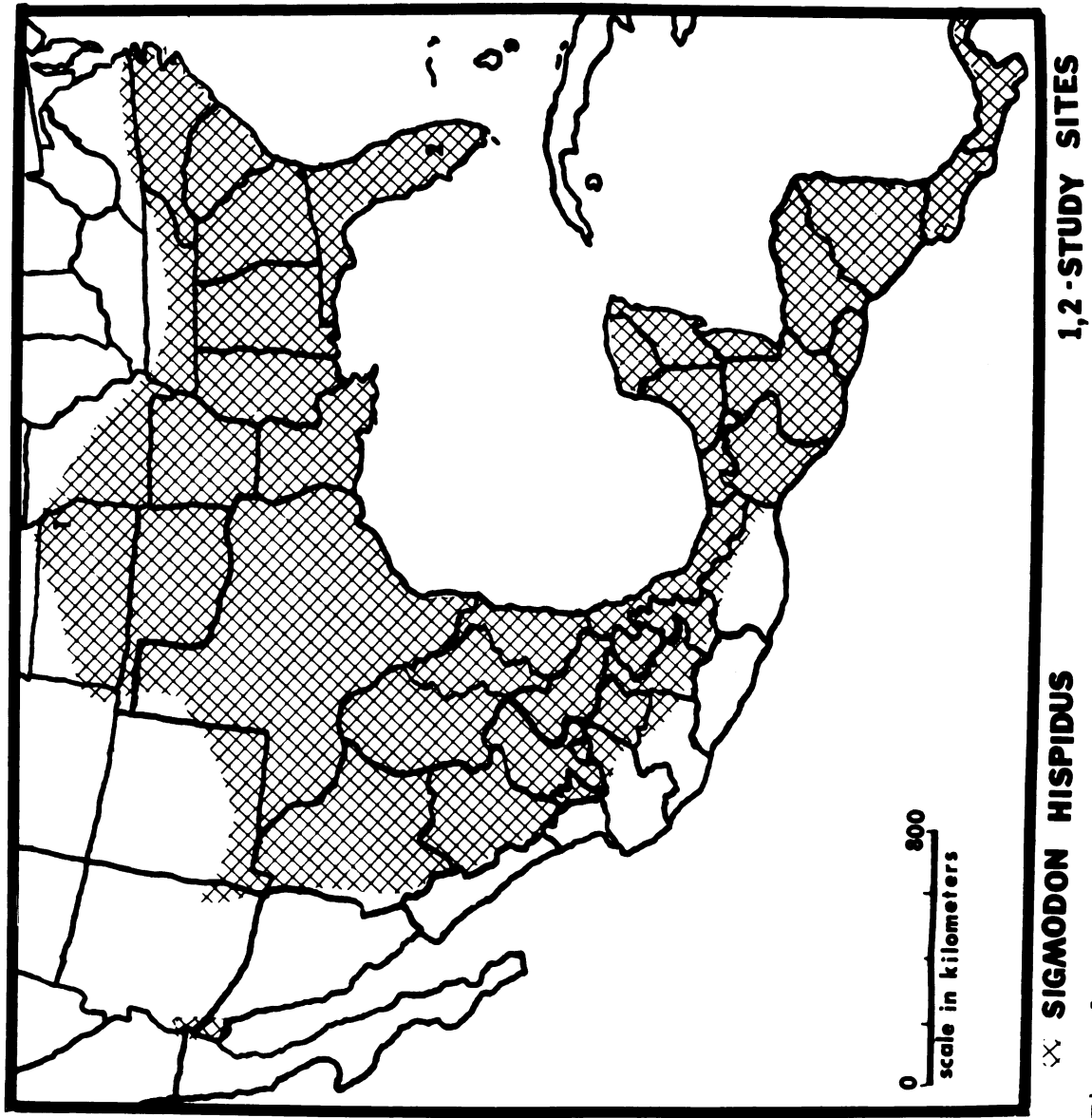


Figure 1.

Table 1. Comparative macroclimatological data between study sites.

		Florida			Kansas		
		Average			Average		
		Max	Min	$\bar{x}$	Max	Min	$\bar{x}$
Temperature ($^{\circ}\text{C}$)	Year	31.5	13.4	22.9	17.7	4.9	11.3
	Summer	37.6	17.3	27.2	28.6	14.5	21.9
	Winter	24.4	9.9	17.2	5.4	- 6.6	- 0.6
Relative Humidity (%)	Year	83.9	35.4	59.8	88.7	46.6	67.6
	Summer	91.9	43.6	67.8	89.7	45.6	67.8
	Winter	83.7	33.6	58.7	85.7	49.9	67.9
Precipitation (cm)	Year			129.3			103.1
	Summer			61.7			34.8
	Winter			15.8			10.9

Note: Temperatures are based on the recorded daily temperatures averaged over 11 years. Humidities are based on the recorded daily humidities averaged for 7 years (Florida) and 8 years (Kansas), respectively. Precipitation was determined by yearly and seasonal averages for 11 years.

Figure 2. Oldfield habitat in which the nests from Kansas were found.

Figure 3. Mixed grass and shrub habitat in which the nests from Florida were found.



Figure 2.



Figure 3.

Figure 4. Hispid cotton rat wearing harness with string attached.

Figure 5. Picture of a typical Sigmodon nest with overlying grasses removed.

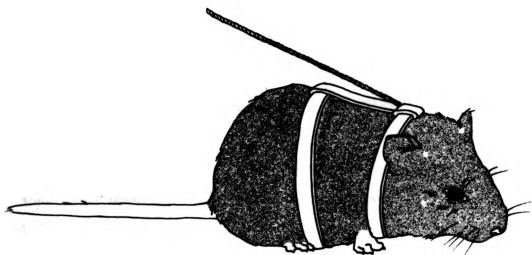


Figure 4.



Figure 5.

located in February and March. Thirty nests, all of the surface type (and determined to be in use) were analyzed (see below) at each locale (Figures 6 and 7). Burrow systems were found by searching, as well as by the method used for locating nests.

Temperatures inside nests in situ, on the surface of the ground beneath nests, under the grass 20 cm from the nests and 3 cm above the substrate, of the air 1.5 m above the ground, and of burrows were recorded with thermistor probes (Yellow Springs Instruments model 401 for air temperatures and model 409 for the ground) attached to a Yellow Springs Instruments Telethermometer (model 43TZ). Burrows with no branches (the simple type) were amenable to placing the probe to the farthest end of the tunnel by attaching it to a long flexible rod; however, complex systems (those burrows with branches) required an alternate method. The technique employed was similar to that of Hayward (1965) except that the metal clip was attached to a small piece of wire hooked on a leather harness around the animal rather than to a wire embedded in the skin. All burrows were dug out to determine whether the probe reached the end of the burrow, and it had in all cases. Subsequent to this, a millimeter ruler was used to measure the entrance diameters, maximum lengths, and maximum depths below the ground surface of 20 burrows in Florida and 5 at Kansas. In Florida, an additional 16 burrows were located and explored for the sole purpose of finding nests.

Ten nests at each locality were observed after moderate showers (20-23 mm) to determine if any moisture had accumulated in their cavities. Depressions adjacent to and under nests were noted and measured. The orientation of nest entrances was determined by compass readings in order to identify a possible preference.

Figure 6. Close-up view of a typical Sigmodon nest found at the Kansas study site.

Figure 7. Close-up view of a typical Sigmodon nest found at the Florida study site.



Figure 6.



Figure 7.

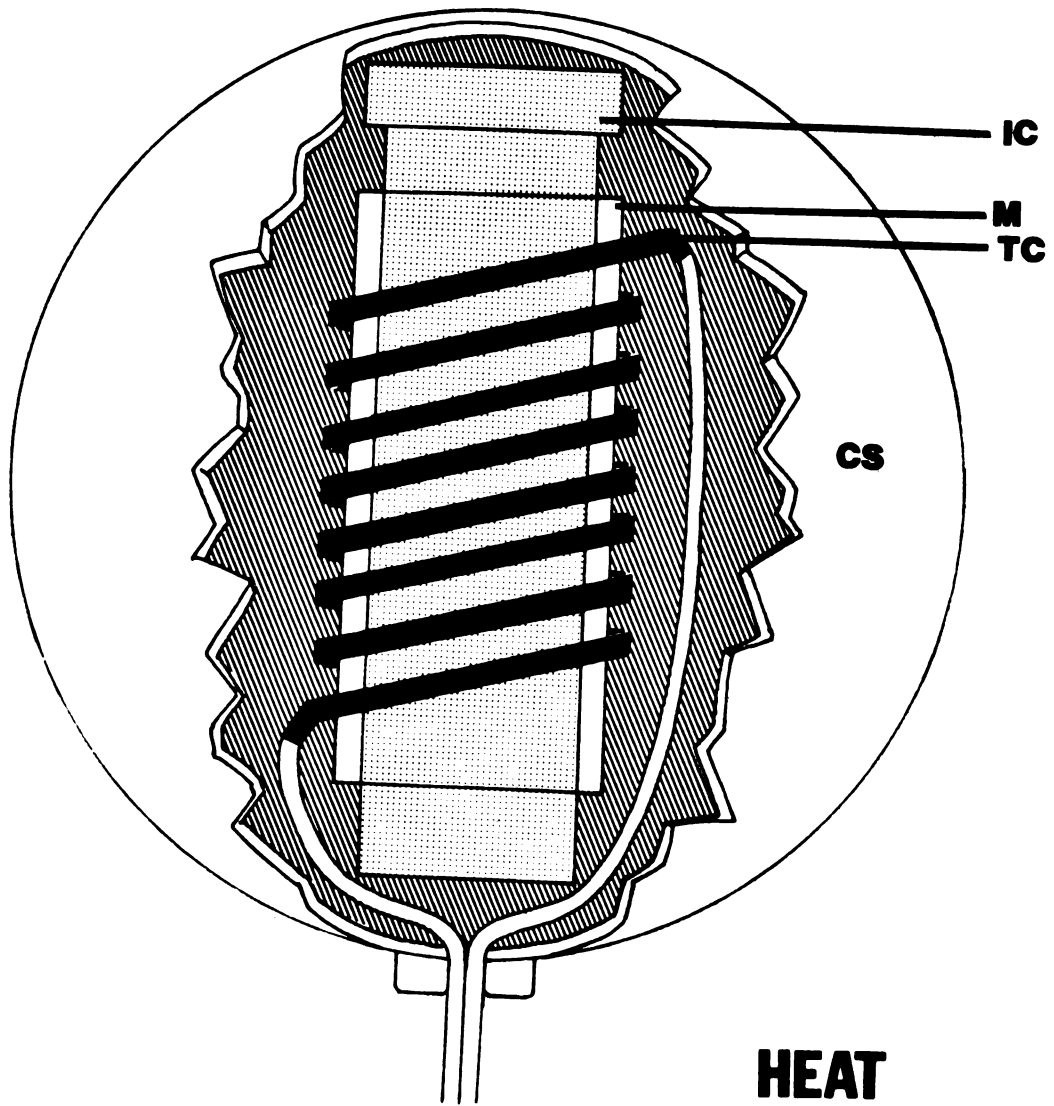
In Florida, 20 nests and 20 burrows were tested for humidity content of the air inside them in relation to that 1.5 m above the ground. These readings were obtained with a Silver Springs Electronic Hygrometer Indicator (model 15-303OE) by simply inserting the probe by hand or with a flexible rod, depending upon the circumstances.

A millimeter ruler and a Rostfrei dial caliper were used to measure the following nest parameters: Total length, width, height; cavity length, width, height; thickness of roof, base, sides; diameter of nest entrance; clipping lengths and widths of both the inner (cavity) and outer construction. The values recorded for these parameters represent maximum measurements. The procedure for measuring nest clipping lengths and widths involved randomly selecting ten clippings from both the inner and outer portions of the nest. Specifically, the lengths of the first ten chosen and widths (near the center) of the last ten, representing in each case five from both the inner and outer surfaces, were recorded. Each appropriate group of values was averaged to obtain a mean value for lengths and widths of both inner and outer clippings for a particular nest. The general form of each nest most closely resembled an ellipsoid shape; therefore, their volume was mathematically determined by $\frac{4}{3}\pi LWH$, where L = length, W = width, and H = height.

The conductance, conductivity, and insulation for each nest were determined by gently removing the nest to a sheltered area (basement or enclosed porch) out of drafts. A heat-generating bulb (Figure 8) was placed within the nest cavity and the amount of power needed to maintain the surface temperature of the bulb (monitored by two surface thermistor probes, YSI model 409, on opposite sides) at 33°C for ten minutes at a given ambient temperature was recorded (Figure 9). This 33°C temperature

Figure 8. Heat generating bulb (6.2 cm in diameter) placed in nest cavities for conductance measures. Symbols represent: IC, Iron Core; M, Mica; TC, Toaster Coil; CS, Copper Sphere.

Figure



HEAT GENERATING BULB

Figure 8.

Figure 9. Apparatus used to determine conductance values for nests and pelts. Abbreviations in figure represent: RHEO, Rheostat; AMP, Ammeter; TELET, YSI Telethermometer.

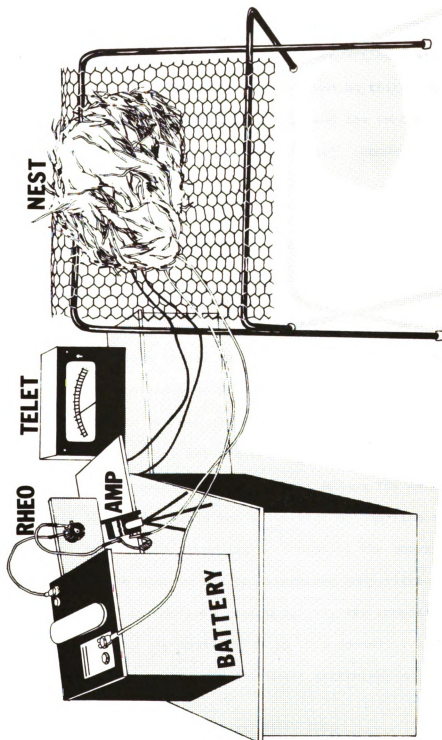


Figure 9.

was chosen simply because it was appropriately conducive for determining the conductance of these nests. This temperature also lies within the thermoneutral zone, 29.5-33.5°C, of this species (Gaertner, 1968). Conductance (cal/sec/°C) was calculated by converting power to calories per second (1 watt = 0.2391 cal/sec) and dividing this by the difference between the temperature of the bulb (33°C) and the ambient, which was measured by a YSI thermistor probe (model 401). Conductivity follows from the equation

$$K = \frac{(Q/T)d}{A(T_b - T_a)}$$

where K = thermal conductivity (heat/time/area/unit thickness/°C), Q/T = heat flow per unit time (determined from power), d = unit thickness of insulation, A = area (total surface area of heating bulb in this work), T_b = temperature of heating bulb, and T_a = ambient temperature. On the other hand insulation was calculated from I = ΔT / ((Q/T)/A), where I = insulation (°C/heat/time/area) and ΔT = T_b - T_a (Q/T, A, T_b, and T_a are defined above). The determination of these values for each nest took approximately 30-45 min. This was a function of the time required to determine the appropriate power (by manipulating the rheostat) necessary to raise the heating bulb to the predetermined temperature and stabilize it at that point. Conductance, conductivity, and insulation values have not been measured for any nests prior to this research, and this new technique seems very appropriate for their determination.

Laboratory Investigations: Nest Construction

These laboratory experiments were designed to find out whether nest construction differed with the cotton rats' place of origin, sex, experience

nesting material, and/or climate. Vegetative materials characteristic of field nests (Table 2) were gathered, boxed, and sent to Michigan for these investigations. Cotton rats collected at each site were paired for the purpose of raising litters (F_1 animals) by April 1974. All animals were housed in plastic cages (47 x 24 x 22 cm) with perforate metal lids and provided with wood shavings as bedding material. Water and Purina rat chow supplemented by lettuce and sunflower seeds were provided ad libitum. All animals were maintained at $22 \pm 3^\circ\text{C}$ on a constant light cycle (14L:10D).

Pups were born and reared in the absence of nesting material, except for the wood shavings. All litters were culled to a 1:1 sex ratio and weaned at approximately 21 days, placing males (litter-mates) into one cage and females (litter-mates) into another, thereby preventing breeding among these lab-born animals. A sufficient number of litters (27) and individuals (107) were raised to begin experimental tests by September 1974. Most of these litters (20) were produced by different pairs. No rodents used in the laboratory tests were less than 100 days of age (i.e., they were fully grown and mature).

The experimental design depicted in Figure 10 was followed. Animals from each locality (wild-caught and lab-born, F_1) were randomly assigned to two Jamison Environmental Chambers. However, no pregnant or lactating females were used, and each chamber was stocked with equal sexes of both wild-caught and lab-born cotton rats. All individuals were weighed and measured after being assigned to their appropriate chambers.

Both chambers simulated winter conditions, one for the Kansas study site (62 per cent relative humidity at 3°C), the other for the Florida site (59 per cent relative humidity at 17.3°C). These settings were

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Table 2. Composition of field nests.

Location	Number	Construction Material
Kansas	15	green foxtail
	8	brome grass and bluegrass
	7	green foxtail, brome grass, and bluegrass
Florida	26	broomsedge
	2	wiregrass
	1	pine needles and broomsedge
	1	palmetto fibers and broomsedge

Figure 10. Experimental design used for examining pertinent questions concerning nest-building. Abbreviations represent: K, Kansas cotton rats; $\bar{F}$, Florida cotton rats; M, Males; F, Females; 1, Vegetation characteristic of field nests from Florida; 2, Vegetation characteristic of field nests from Kansas; L, Lab-born (F_1) animals; W, Wild-caught animals; A, Florida simulated climate; B, Kansas simulated climate. Sixes represent the number of animals used in each treatment combination.

EXPERIMENTAL DESIGN

K		F	
M	F	M	F
1 2 1 2		1 2 1 2	
L W L W L W L W		L W L W L W L W	
A 6 6 6 6 6 6 6 6		6 6 6 6 6 6 6 6	
B 6 6 6 6 6 6 6 6		6 6 6 6 6 6 6 6	

Figure 10.

based on macroclimatic data obtained from the weather stations at each study site (Table 1). The photoperiod in each chamber was controlled by a Paragon Astronomical Dial Timer (model 4005-OSZ) adjusted to the latitude of the appropriate study site. The winter conditions used, representing the coldest season of the year, should have provided especially pronounced differences, if any occurred, in nest construction. Nests built under these conditions would also have been readily comparable to the field nests analyzed during the winter.

Two consecutive groups of animals (one group being represented by 24 animals per chamber) were each acclimated four weeks prior to testing. The cages used for acclimating and testing were like those used for maintenance. Water and Purina rat chow were supplied ad libitum. Each animal was allowed to construct four nests, two with broomsedge and two with a mixture in equal proportions by weight of brome grass, bluegrass, and green foxtail leaves. All animals were presented with nesting material simultaneously, with each group of animals beginning with a different type. The two types of nesting material were then alternated throughout the experiment. This was done to help distinguish the effect of the nesting material from any learning processes in constructing nests which might occur. The nesting material (only used once) was presented in manger-like dispensers (Figure 11) which were constantly kept full. These dispensers allowed for minimal breakage of vegetation being placed in them by the researcher and later removed by the rodent, thereby making comparative measurements on vegetative manipulation (chewing-up into various lengths and widths) possible. The quantity of vegetation pulled out of these dispensers was recorded for each animal. All vegetation was stored prior to usage at approximately 27 per cent relative humidity at $22 \pm 3^{\circ}\text{C}$.

A check to determine the moisture uptake of this vegetation in the different environmental chambers and its possible effect on the measurement of the quantity of material used by the animals was conducted. Ten trays of vegetation (five of Kansas material and five of Florida vegetation) were placed in each chamber for one week. Each tray contained 35 g of vegetation, and the difference in mean weight between climates at the end of the week was found to be 0.34 g, which was insignificant ($P > 0.5$) using a Student's t-test. The highest weight gain per 35 g of vegetation occurred, as expected, in the chamber simulating the Kansas climate, but the average was less than 0.5 g. In other words, the weight of material remaining in the dispensers at the end of a one-week test period could be subtracted from the weight of material initially placed in the dispensers for a reasonably accurate measure of the quantity pulled out.

Laboratory-made nests were categorized as follows: 1) Typical field-type nests, possessing all sides, roof, and bottom greater than 1 mm thick, 2) nests with a top less than 1 mm thick, with all other sides and bottom constructed well (> 1 mm), and 3) nests with a side less than 1 mm thick (i.e., the cage wall was used as one side of the nest) but other parts were well constructed (> 1 mm). All nests fell into one of these three categories. These nests were analyzed every seventh day in a manner similar to that already described for field nests (i.e., measured conductance, conductivity, insulation, and dimensions, except for diameter of nest entrance). A total of 384 nests constructed by 96 cotton rats were analyzed.

Laboratory Investigations: Morphological Characteristics

These laboratory experiments were designed to determine whether cotton rats inhabiting colder regions exhibited morphological characteristics which differed from those of their conspecifics in warmer habitats. Weights and measures (body and tail lengths) which had been taken, as previously mentioned, for all animals used in the nest-building tests were examined.

Since the environmental chamber simulating Kansas winter conditions was as likely as most laboratory conditions to demonstrate pelage alterations to cold regions, only those individuals in that chamber were comparatively analyzed. All Sigmodon tested in those conditions were sacrificed at the end of their nest-building careers and immediately frozen. The design for this phase of the study is represented in Figure 12. The frozen animals were thawed and skinned out through the hind legs. Fat was removed with corn meal and subsequent ether treatments. Before examination skins were allowed to dry for 12 hours. Following this, the insulation of each pelt was measured by slipping the skin around a heating bulb similar to that used for the nests (Figure 8), except that this one was only 5 cm in diameter. Skins were drawn as tight as possible around the bulb and sewn at each end with needle and thread. The fur was fluffed by three reverse strokes of a brush to provide near maximal insulation. The power (converted to cal/sec) needed to maintain the surface temperature of the heating bulb (monitored by two surface thermistor probes, YSI model 409, on opposite sides) at 37°C, for a given ambient temperature, over a 10 min period was determined. The formula for determining insulation was as previously explained. The time required to determine the insulation for each pelt was similar to

Figure 11. Manger-like dispenser 19 cm long and 15 cm high used to provide nesting material (natural grasses) to the experimental animals.

Figure 12. Experimental design used for comparing pelage characteristics between Florida and Kansas cotton rats. Abbreviations represent: K, Kansas animals; F, Florida animals; L, Lab-born (F_1) animals; W, Wild-caught animals. Twelves represent the number of animals in each category.

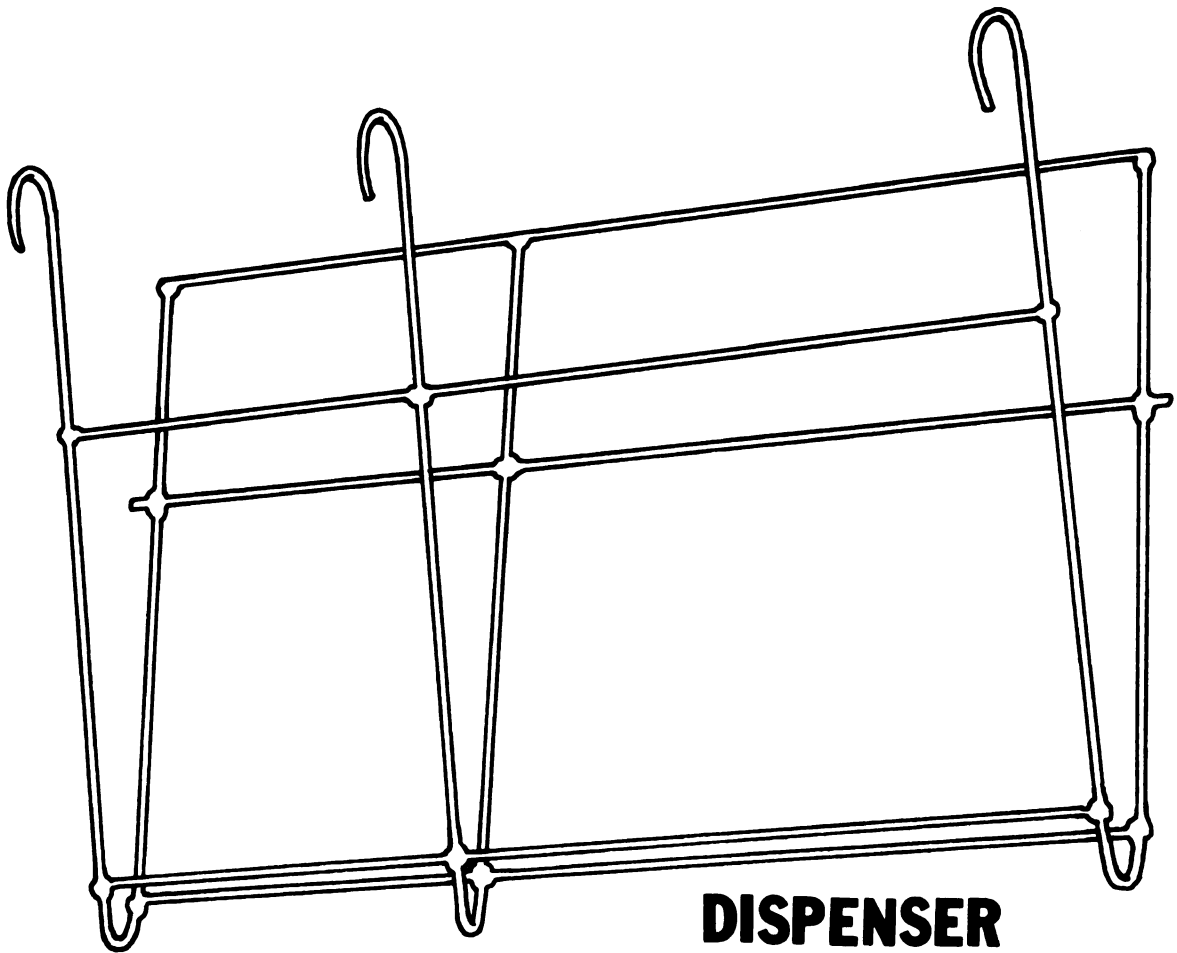


Figure 11.

EXPERIMENTAL DESIGN

	K	F
L	12	12
W	12	12

Figure 12.

that necessary for the measures on nests (i.e., 30-45 min). Although the insulation of various mammalian pelts have been measured, they represent values for just the dorsal most insulative parts. This technique has not been heretofore developed and was most useful in determining the insulation of the whole pelt.

Fur thicknesses, hair lengths, and follicle counts of both dorsal and ventral surfaces were also taken. After the hair had been brushed down (ten strokes), fur thicknesses were determined, in a manner similar to Scholander et al. (1950), but at the center of four equilateral squares lying along both the mid-dorsum and mid-venter. The appropriate values were averaged to obtain a single value for each of the dorsal and ventral surfaces.

Lengths of four guard hairs and four underfur hairs from the center of four equilateral squares positioned as indicated above were measured (from root to tip) with a Mitutoyo dial caliper (no. 505-633) while viewed under a dissecting microscope. The lengths of the four hairs in each group were averaged so as to obtain four mean values for each individual pelage: 1) Dorsal guard hairs, 2) ventral guard hairs, 3) dorsal underfur, and 4) ventral underfur.

Follicle counts (both of guard hairs and underfur) from the center of dorsal and ventral surfaces were made. This was accomplished by taking three counts in two different millimeter square areas (at opposite ends of a 0.5 cm^2 grid divided in mm^2 areas) using a dissecting microscope at 250X. These values were averaged to obtain one follicle number value per pelt for each hair group -- dorsal guard hairs, ventral guard hairs, dorsal underfur, and ventral underfur.

Analysis

Field nests from Kansas and Florida were compared with each other as well as with nests constructed by wild-caught animals in the laboratory under appropriate conditions. In other words, Kansas field nests were compared not only to field nests from Florida but also with lab nests constructed by wild-caught cotton rats (sexes pooled) from Kansas in the simulated Kansas climate using vegetative material from Kansas, and Florida field nests were likewise compared with lab nests made by wild-caught individuals (sexes pooled) from Florida in the simulated Florida climate using vegetative material from Florida. These statistical comparisons were conducted using multivariate T^2 -tests with associated simultaneous confidence intervals (Gill and Hafs, 1971). This multivariate analysis compares the entire set of nest parameters from two localities at the same time to determine if these sets are significantly different. In addition, the simultaneous confidence intervals signify those individual parameters found to be significantly different. This multivariate analysis takes into account correlations among nest parameters which might be ignored if parameters were looked at singly in a univariate analysis. The simultaneous confidence intervals indicate the probability statements which are conditioned by the fact that these are a correlated set of parameters.

Nests constructed in the laboratory were compared using an analysis of variance for a 2^5 factorial in a split-plot repeat measure design (Kirk, 1968). This analysis compared the five factors indicated in the design shown in Figure 9 (in addition, all 2-factor interactions were examined). Body weights of the animals incorporated in each treatment group for the nest-building experiments were analyzed with a 2^4 factorial

analysis of variance (Sokal and Rohlf, 1969).

Thermal conductivity for laboratory-constructed nests was compared to examine the difference between vegetative types used in the two different simulated environments with a 2×2 analysis of variance. The thermal conductivity for the field nests was compared between study sites as well as with lab nests constructed under similar climatic conditions using Student's t-tests. This analysis could not be comprehensively performed using a 2^3 analysis of variance because it is an incomplete factorial. An alternative method for the above analyses might have been a series of one-way analyses of variance with the specific combination contrasts; however, the method used was equally good for investigating the comparison (Sokal and Rohlf, 1969).

Linear regression analysis was used to determine the relationship between: 1) Insulation and volume of field and lab nests combined, and 2) insulation and weight of lab nests (Ostle, 1963).

The orientation of nest entrances at each field site was checked for randomness with a chi-square test. Paired t-tests were employed to examine the differences between burrows and their corresponding above-ground humidities, and between nests and their corresponding above-ground humidities. A Student's t-test was used to compare the difference of means between the values of burrows minus their corresponding above-ground humidities and the values of nests minus their corresponding above-ground humidities (Sokal and Rohlf, 1969). The latter test would demonstrate the difference in relative effectiveness between burrows and nests at possessing a humidity different from the above-ground air.

All pelage comparisons were made using 2×2 analyses of variance (Figure 12). Other statistical tests used in this research were done

with Student's t-tests. Homogeneity of variance was determined using a Barlett's test or an F-test, whichever was appropriate (Sokal and Rohlf, 1969).

Actual analyses were done using both the Michigan State University CDC 6500 computer and the Wang 600-14 calculator at the Museum, Michigan State University.

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RESULTS

Field Comparisons

All nests found in both Kansas and Florida were on the surface of the ground, except for one, which was situated under a pile of railroad ties (at the Florida site). These nests were closest to being elliptical in shape (Figures 6 and 7) with well-defined cavities. The material incorporated into these nests were determined (Table 2) and found to represent the most abundant grasses in the area. All material was woven into nest form, although the weaving was tighter in the Kansas nests. No stems were found in the construction of the nests, except for a very few in the outer part.

The mean nest temperature of nests in situ were significantly different ($P < 0.1$) from above-ground ambient only at the Kansas site. These mean nest temperatures were not different ($P > 0.1$) from temperatures underneath the grass adjacent to the nests, nor were these temperatures underneath the grass different ($P > 0.1$) from those above ground at either site (Table 3).

Nests from both localities had an orientation of nest entrances significantly different from random ($P < 0.05$) with the majority facing in a southeasterly direction (Figure 13). Openings to nests had an average diameter of 5.0 cm (4.9 cm in Kansas, 5.1 cm in Florida).

Each nest was situated adjacent to a runway and set in a slight depression. The cavity of the nest was nestled in the depression, while the remainder or outer part of the nest overlapped it. A ridge extended around each depression (Figure 14) surrounding the cavity of the nest. A depression was also located next to every nest ($\bar{x} = 21.1$ cm from nests) in Florida; however, only seven nests had adjacent depressions

Table 3.

Temperat

Ambient
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Within
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Note:
*Signif

Table 3. Comparison of microclimatic temperatures between the two sites.

Temperatures ($^{\circ}\text{C}$)	Kansas		Florida		n
	$\bar{x}$	range	$\bar{x}$	range	
Ambient 1.5 m above ground	7.8	3.2-12.2	26.8	20.5-31.2	30
Under grass adjacent to nest	9.1	4.0-13.5	26.1	19.0-29.9	30
Ground beneath nest	9.9	5.9-13.0	21.7	16.0-26.5	30
Within nest cavities	12.8*	7.3-19.9	24.0	19.5-28.8	30

Note: Temperatures were taken between 0930 and 1200 hours.

*Significant at the 0.1 level from ambient.

Figure 13. Orientation of nests found at the Kansas and Florida study sites.

NEST ORIENTATION

KANSAS

FLORIDA

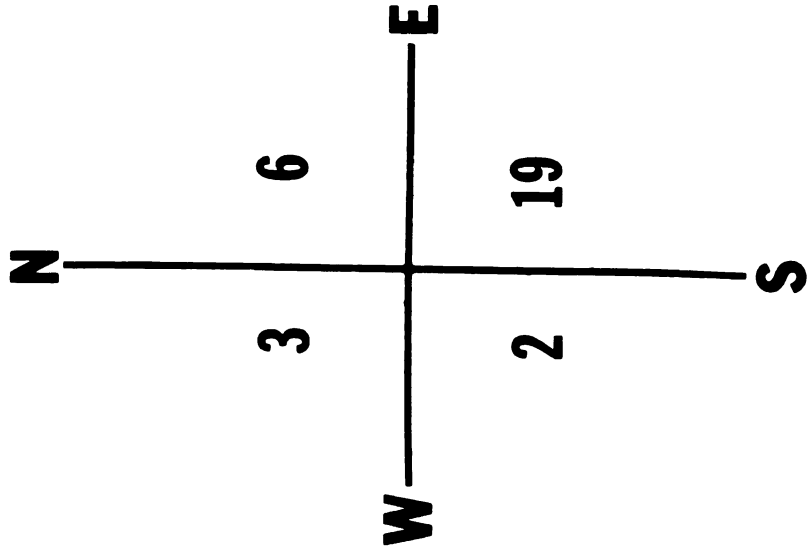
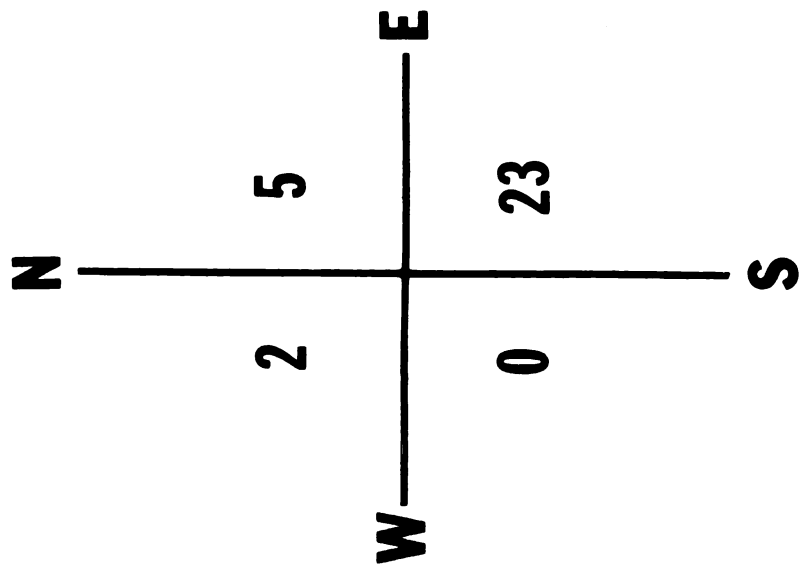


Figure 13.

Figure 14 Depression with associated ridge found under all field nests.



Figure 14.

at the Kansas site ($\bar{x} = 19.3$ cm from nests). All depressions under and adjacent to nests were measured (Table 4). There was no significant difference between field sites in any of the depressions ($P > 0.5$). Each nest, as well as its adjacent depression, was hidden by surrounding vegetation.

Burrow systems were also examined at both locations and resembled those depicted by Schendel (1940). All five burrows at the Kansas site were of the simple type, while 13 out of the 36 burrows located at Florida were complex. Even though all burrows were dug out, no nests were found inside. A few grass clippings (five - six) were found at the end of six burrows (four in Florida and two in Kansas). Twenty burrows (13 of the complex type) from Florida and the five in Kansas were thoroughly analyzed (Table 5). The burrows in Florida were significantly longer ($P < 0.1$) than those in Kansas.

Nests and burrows (20 of each) from Florida were examined for humidity content (Table 6). A comparison of the humidity content of the air within burrows, within nests, and above-ground air (1.5 m off the ground) showed significant differences ($P < 0.1$) as follows: 1) Burrows had greater humidity than the air above ground, 2) nests possessed greater humidity than the air above ground, and 3) burrows possessed a greater humidity difference from the above-ground air than did the nests.

Ten nests in each locality were observed to be devoid of water inside the nest cavities following moderate rains of 20 mm in Florida and 23 mm in Kansas. Although no direct measures of moisture were performed, tissue paper pressed to the inside cavities of the nests remained dry, while tissue placed on the outer portions became moist. Depressions under the nests seemed by touch to be drier than the surrounding ground.

Table 4. Dimensions of depressions.

Depression	Maximum Depth (cm)		Maximum Diameter (cm)		Maximum Height of Ridge (cm)	
	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	n
Under nests						
Florida Site	4.0	3.1-5.0	9.1	6.8-11.1	1.9	30
Kansas Site	4.1	3.4-5.1	9.6	7.0-12.1	1.5	30
Adjacent to nests						
Florida Site	4.3	3.7-4.8	9.9	8.9-11.0	-	30
Kansas Site	4.0	3.4-4.9	10.0	9.5-11.8	-	7

Table 5. Comparative information on burrows.

Comparisons	Florida		Kansas	
	$\bar{x}$	range	$\bar{x}$	range
Temperature ($^{\circ}\text{C}$)				
Ambient 1.5 m above ground	26.4	18.9-31.2	7.6	3.3-12.8
Burrow	22.1	16.5-24.8	13.2	6.3-14.8
Measurements (cm)				
Diameter of burrow entrances	5.1	4.0- 7.2	5.0	4.2- 7.0
Maximum length of burrows	67.1	20.3-85.3	40.3	18.8-55.7
Maximum depth of burrows	44.1	18.6-68.8	30.5	17.0-43.5

Note: Florida n = 20
 Kansas n = 5

Table 6. Relative humidities of burrows and nests at the Florida study site.

Florida Site	Relative Humidity (%)		
	$\bar{x}$	range	n
Burrow	72.2	43.1-89.8	20
Air	43.3	33.1-68.5	20
Nest	55.6	42.7-62.2	20
Air	38.1	25.7-48.7	20

Note: All relative humidity measurements were taken between 1300 and 1500 hours.

A comparison of the entire sets of parameters for field nests from Kansas and Florida (Table 7) shows the nests to be significantly different ($P < 0.01$). All parameters were also compared individually with simultaneous confidence intervals, and four parameters were found to be significantly different between Kansas and Florida: Bottom thickness, outer clipping lengths, and conductance, $P < 0.01$; outer clippings widths, $P < 0.05$.

Comparisons of Laboratory-Constructed Nests

The body weights of the animals in treatment groups used in laboratory tests were compared and found to be not significantly different ($P > 0.2$) between any two categories (Figure 15). In other words, animals used in various groups in the nest-building experiments were approximately equal in body size.

The number and type of nests analyzed in the laboratory are represented by Figure 16. Most of these nests were similar to those found in the field, and others (19) were only slightly different.

Nests constructed by wild-caught rodents in the laboratory were compared to those found in the field (Tables 8 and 9). A multivariate comparison found these nests to be similar overall (i.e., not significantly different, $P > 0.1$, in the total set of parameters, or in any individual ones, $P > 0.1$). This indicates that the wild and wild-caught animals were behaving similarly in constructing nests in both the lab and the field.

The summary for nest parameters of each treatment combination examined is shown in Table 10. No differences ($P > 0.1$) were found within climates between any of the measured parameters (i.e., Kansas animals versus Florida rodents; males versus females; lab-born versus wild-caught; and

Table 7. Comparative data on field nest parameters.

Nest Parameters	Kansas nests			Florida nests		
	$\bar{x}$	SE	range	$\bar{x}$	SE	range
Total						
Length (cm)	18.2	0.6	14.5 - 27.0	16.6	0.5	13.0 - 22.6
Width (cm)	16.6	0.4	14.0 - 23.4	15.3	0.4	11.5 - 19.0
Height (cm)	14.5	0.2	12.5 - 18.5	12.9	0.4	9.0 - 18.0
Cavity						
Length (cm)	8.4	0.2	6.5 - 11.5	9.2	0.3	7.0 - 12.0
Width (cm)	7.6	0.2	5.9 - 11.0	8.5	0.3	6.0 - 12.0
Height (cm)	7.0	0.1	5.8 - 9.2	7.6	0.2	6.3 - 10.5
Thickness						
Room (cm)	4.1	0.2	3.0 - 6.5	3.9	0.3	2.0 - 6.5
One Side (cm)	4.2	0.2	3.0 - 7.6	3.4	0.2	2.0 - 5.0
*Base (cm)	2.9	0.1	1.9 - 4.0	1.4	0.1	0.5 - 2.5
Clippings						
*Outer lengths (cm)	6.3	0.3	3.8 - 9.3	10.7	0.5	4.2 - 15.0
*Outer widths (mm)	1.8	0.1	1.1 - 3.0	3.1	0.1	1.0 - 3.8
Cavity lengths (cm)	2.6	0.2	1.0 - 4.8	3.4	0.2	1.6 - 5.6
Cavity widths (mm)	1.0	0.1	0.6 - 1.5	1.3	0.1	0.7 - 2.5
*Conductance (cal/sec/°C)	0.0076	0.0000	0.0057- 0.0096	0.0158	0.0002	0.0117- 0.0194

Note: Sample size is 30 in each category. Specific parameters marked with an asterisk (*) are significant between Kansas and Florida nests at the 0.01 level, except outer clipping widths at the 0.05 level.

Figure 15. Body weights of the cotton rats used in experimental test groups. The n for each category is six. No significant difference occurs between any two categories ($P > 0.2$). Solid vertical lines represent ranges; solid horizontal lines, means; dashed rectangles are ± 3 standard errors. Notation used to describe abbreviated groups in figure: K, Kansas Climate; F, Florida Climate; L, Lab-born (F_1); W, Wild-caught; M, Male; ♀, Female; T, animals with affinities to Kansas population; ♂, animals with affinities to Florida population. Groups: A=KLMM♂; B=KLFF♂; C=KWM♂; D=KWFF♂; E=KLMT; G=KLFT; H=KWMT; I=KWFT; J=FLM♂; N=FLFF♂; O=FWM♂; P=FWFF♂; Q=FLMT; R=FLFT; S=FWMT; U=FWFT.

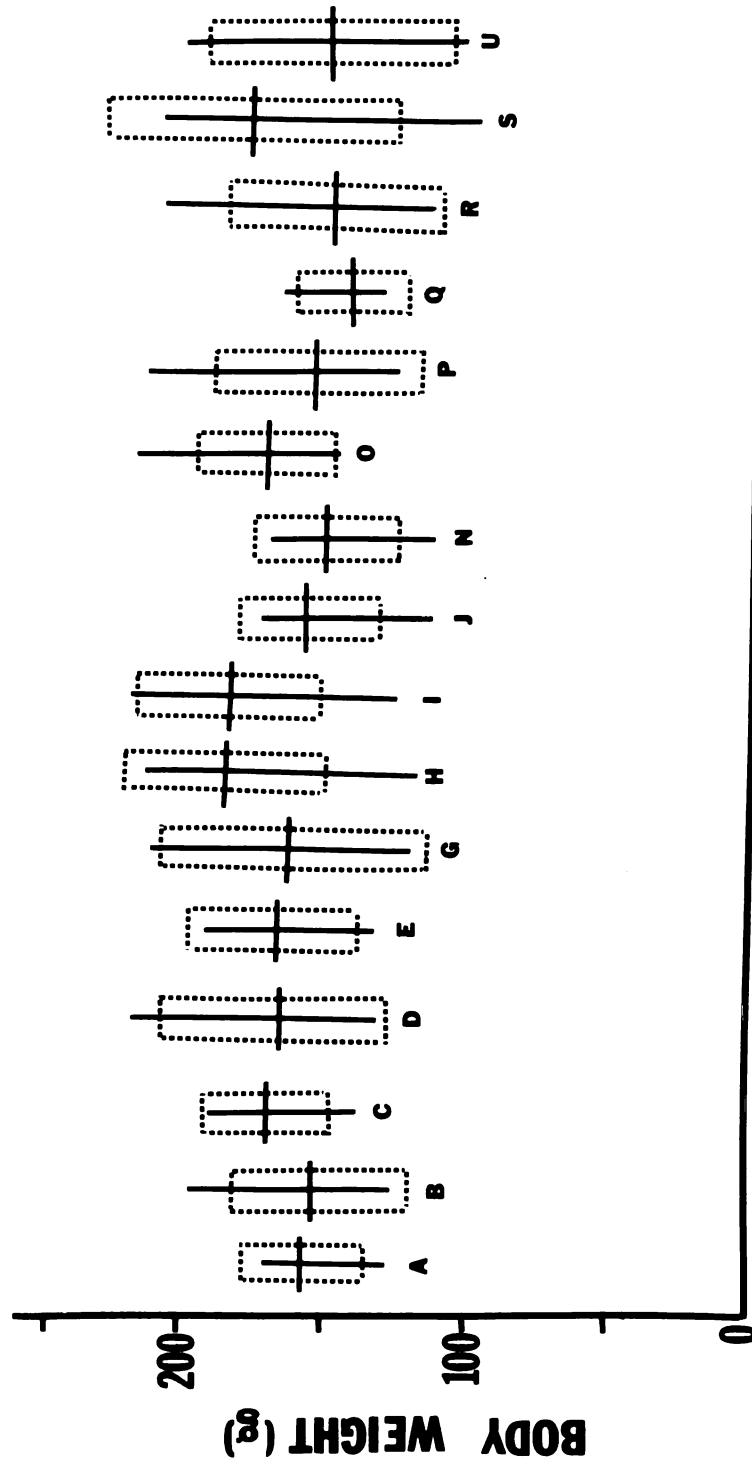


Figure 15.

Figure 16. Number and type of laboratory-constructed nests analyzed.

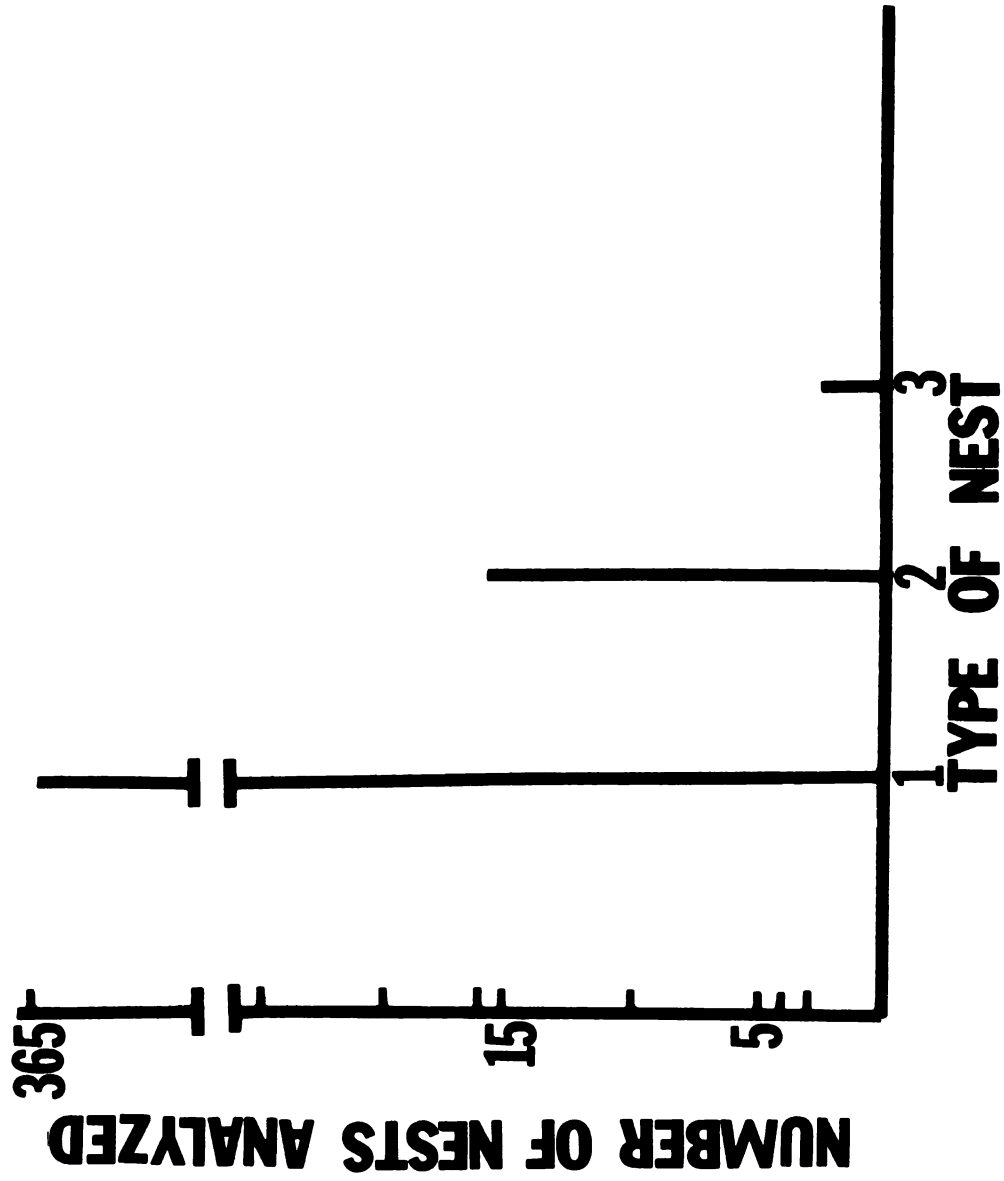


Figure 16.

Table 8. Comparison of nests constructed in the field and in the lab by wild-caught animals (in a Kansas climate).

Parameters	Field nests		Lab nests	
	$\bar{x}$	SE	$\bar{x}$	SE
Total				
Length (cm)	18.2	0.6	19.8	0.5
Width (cm)	16.6	0.4	18.4	0.4
Height (cm)	14.5	0.2	15.0	0.4
Cavity				
Length (cm)	8.4	0.2	9.1	0.3
Width (cm)	7.6	0.2	8.5	0.2
Height (cm)	7.0	0.1	8.0	0.2
Thickness				
Roof (cm)	4.1	0.2	4.8	0.3
One side (cm)	4.2	0.2	4.2	0.2
Base (cm)	2.9	0.1	2.1	0.2
Clippings				
Outer lengths (cm)	6.3	0.3	6.3	0.4
Outer widths (mm)	1.8	0.1	1.3	0.1
Cavity lengths (cm)	2.6	0.2	4.2	0.2
Cavity widths (mm)	1.0	0.1	1.2	0.1
Conductance (cal/sec/ $^{\circ}$ C)	0.0076	0.0000	0.0093	0.0002

Note: Sample size for field constructed nests is 30, laboratory constructed nests have an n of 24.

Table 9. Comparison of nests constructed in the field and in the lab by wild-caught animals (in a Florida climate).

Parameters	Field nests		Lab nests	
	$\bar{x}$	SE	$\bar{x}$	SE
Total				
Length (cm)	16.6	0.5	17.1	0.4
Width (cm)	15.3	0.4	16.0	0.3
Height (cm)	12.9	0.4	11.5	0.3
Cavity				
Length (cm)	9.2	0.3	8.5	0.2
Width (cm)	8.5	0.3	7.8	0.2
Height (cm)	7.6	0.2	7.0	0.1
Thickness				
Roof (cm)	3.9	0.3	3.0	0.2
One side (cm)	3.4	0.2	3.9	0.2
Base (cm)	1.4	0.1	1.4	0.1
Clippings				
Outer lengths (cm)	10.7	0.5	10.1	0.6
Outer widths (mm)	3.1	0.1	2.5	0.2
Cavity lengths (cm)	3.4	0.2	3.8	0.2
Cavity widths (mm)	1.3	0.1	1.3	0.1
Conductance (cal/sec/ $^{\circ}$ C)	0.0158	0.0002	0.0151	0.0003

Note: Sample size for field constructed nests is 30, laboratory constructed nests have an n of 24.

Table 10. Summary of nest parameters according to treatment combinations.¹

Treatment Combinations	L		W		H		l		w		h		R		S(1)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Kansas Climate																
Lab-born (females)																
F1	18.9	1.0	16.5	0.7	13.2	0.5	9.1	0.3	8.2	0.2	7.0	0.2	4.1	0.3	4.0	0.2
F2	18.4	0.6	17.8	0.7	13.0	0.5	9.4	0.3	8.5	0.3	7.1	0.1	4.0	0.3	4.3	0.4
K1	19.2	0.8	17.0	0.6	12.7	0.5	9.0	0.3	7.9	0.2	7.4	0.2	3.8	0.3	4.4	0.2
K2	19.8	1.0	17.4	0.6	13.9	0.5	9.2	0.2	8.0	0.2	7.6	0.1	4.3	0.3	4.7	0.3
Lab-born (males)																
F1	18.2	0.4	16.8	0.3	12.8	0.4	8.7	0.4	7.8	0.2	7.1	0.2	4.2	0.3	4.5	0.1
F2	18.5	0.6	16.8	0.5	13.0	0.4	10.0	0.4	8.8	0.2	7.6	0.1	4.0	0.3	3.9	0.3
K1	19.2	0.6	16.8	0.5	12.9	0.4	8.8	0.3	8.2	0.2	7.2	0.1	4.0	0.3	4.1	0.2
K2	19.2	0.6	17.9	0.5	13.6	0.5	10.4	0.6	8.8	0.4	7.6	0.1	4.1	0.3	4.3	0.2
Wild-caught (females)																
F1	18.5	0.5	17.7	0.5	14.0	0.4	8.4	0.2	7.7	0.1	7.2	0.2	4.6	0.2	4.9	0.3
F2	20.1	0.7	18.9	0.6	15.3	0.5	8.8	0.4	8.8	0.3	8.0	0.1	4.7	0.3	5.1	0.3
K1	20.2	0.9	17.4	0.7	14.2	0.3	8.9	0.4	8.3	0.3	7.4	0.1	4.8	0.2	4.5	0.3
K2	18.7	0.6	18.6	0.5	15.5	0.4	9.1	0.3	8.7	0.3	8.0	0.2	5.1	0.3	4.6	0.4
Wild-caught (males)																
F1	18.9	0.7	17.5	0.5	13.2	0.3	8.8	0.3	8.1	0.2	7.4	0.2	4.2	0.4	4.7	0.3
F2	18.2	0.5	17.0	0.5	12.8	0.4	8.5	0.3	8.0	0.2	7.6	0.1	3.5	0.3	4.2	0.2
K1	20.0	0.4	18.3	0.4	14.2	0.6	9.4	0.3	8.9	0.3	7.9	0.2	4.0	0.4	4.6	0.2
K2	20.3	0.7	18.2	0.5	14.4	0.4	9.2	0.4	8.5	0.3	8.1	0.2	4.4	0.4	4.6	0.3

¹Explanation of symbols used in this table are represented on page 57.

Table 10 (cont'd)

Treatment Combinations		B		OCL		OCW		ØCL		ØCW		Q		COND		
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Kansas Climate																
Lab-born (females)																
F1	1.8	0.3	6.3	0.7	1.8	0.3	4.3	0.3	1.3	0.2	167.4	13.0	0.0093	0.0003		
F2	1.8	0.2	6.1	0.6	1.7	0.3	4.8	0.4	1.0	0.1	168.9	13.1	0.0093	0.0002		
K1	1.5	0.2	5.6	0.4	1.3	0.2	3.8	0.3	1.4	0.2	166.3	11.3	0.0098	0.0003		
K2	2.0	0.2	6.1	0.4	1.6	0.2	4.0	0.2	1.1	0.1	178.7	12.2	0.0092	0.0003		
Lab-born (males)																
F1	1.6	0.2	6.4	0.7	1.7	0.2	4.4	0.6	1.1	0.1	176.0	11.3	0.0093	0.0002		
F2	1.7	0.1	6.4	0.8	1.3	0.2	4.8	0.5	1.3	0.2	146.1	13.6	0.0096	0.0003		
K1	1.5	0.2	5.5	0.2	1.3	0.2	4.5	0.3	1.1	0.2	187.8	13.1	0.0091	0.0004		
K2	1.5	0.2	7.7	0.8	1.4	.02	4.2	0.3	1.2	0.1	156.1	13.2	0.0094	0.0003		
Wild-caught (females)																
F1	1.7	0.2	5.9	0.2	1.4	0.2	4.2	0.3	1.3	0.2	194.3	8.8	0.0093	0.0003		
F2	2.3	0.3	6.8	0.4	1.3	0.2	4.3	0.3	1.2	0.2	185.6	13.0	0.0089	0.0003		
K1	1.7	0.2	6.1	0.4	1.3	0.2	4.0	0.3	1.3	0.1	173.5	9.8	0.0087	0.0003		
K2	2.4	0.3	6.4	0.5	1.3	0.2	4.3	0.3	1.1	0.1	145.5	11.9	0.0093	0.0002		
Wild-caught (males)																
F1	1.7	0.2	6.1	0.5	1.3	0.2	4.7	0.3	1.2	0.1	192.7	10.2	0.0089	0.0004		
F2	1.5	0.2	7.1	0.4	1.6	0.3	4.5	0.3	1.2	0.2	175.7	11.5	0.0089	0.0004		
K1	1.9	0.3	6.0	0.2	1.3	0.2	3.8	0.2	1.2	0.1	198.8	11.8	0.0084	0.0003		
K2	2.0	0.2	5.9	0.8	1.3	0.1	4.4	0.4	1.3	0.2	170.3	13.3	0.0094	0.0002		

Table 10 (cont'd)

Treatment Combinations	L		W		H		l		w		h		R		S(1)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Florida Climate																
Lab-born (females)																
F1	16.8	0.3	16.0	0.2	11.2	0.6	8.1	0.2	7.6	0.3	6.6	0.2	3.2	0.4	4.0	0.2
F2	16.6	0.5	15.6	0.4	11.6	0.4	8.7	0.2	8.0	0.4	7.0	0.2	3.1	0.2	3.7	0.3
K1	16.6	0.4	15.6	0.2	10.4	0.4	8.5	0.2	7.8	0.1	6.3	0.2	2.8	0.2	4.0	0.1
K2	16.9	0.6	15.1	0.5	11.4	0.5	8.1	0.3	7.6	0.2	6.9	0.6	3.3	0.2	3.6	0.2
Lab-born (males)																
F1	16.7	0.4	15.6	0.4	11.8	0.5	8.7	0.5	7.8	0.3	7.1	0.4	3.3	0.4	3.6	0.3
F2	16.5	0.4	16.0	0.3	12.1	0.4	8.5	0.3	8.4	0.3	7.1	0.2	3.6	0.3	3.8	0.2
K1	17.4	0.6	15.8	0.3	11.3	0.6	8.3	0.4	7.9	0.3	6.3	0.2	3.6	0.3	3.9	0.2
K2	16.8	0.5	15.7	0.3	11.3	0.5	8.9	0.5	7.8	0.2	7.2	0.2	2.9	0.3	3.7	0.2
Wild-caught (females)																
F1	16.9	0.6	15.5	0.4	12.0	0.3	8.4	0.3	7.5	0.1	6.9	0.2	3.2	0.2	3.8	0.2
F2	17.0	0.4	16.5	0.6	11.8	0.3	8.3	0.3	8.3	0.3	6.8	0.2	3.2	0.2	4.3	0.3
K1	15.7	0.4	15.2	0.4	11.3	0.5	8.5	0.3	7.7	0.1	7.0	0.2	2.7	0.2	3.6	0.2
K2	16.7	0.4	16.3	0.6	12.1	0.5	8.8	0.5	7.6	0.2	6.7	0.2	3.2	0.2	4.2	0.3
Wild-caught (males)																
F1	17.4	0.5	16.4	0.4	11.0	0.5	8.3	0.2	8.0	0.2	6.9	0.2	3.0	0.2	3.8	0.3
F2	16.9	0.3	16.5	0.4	12.3	0.5	8.7	0.2	8.1	0.2	7.5	0.3	3.4	0.2	4.4	0.2
K1	17.0	0.5	15.7	0.3	11.7	0.5	9.2	0.3	8.4	0.3	7.2	0.2	2.9	0.2	3.6	0.2
K2	17.5	0.7	15.6	0.3	12.5	0.6	8.4	0.2	8.0	0.2	7.1	0.2	3.5	0.4	3.7	0.1

Table 10 (cont'd)

Treatment Combinations	B		OCL		OCW		ØCL		ØCW		Q		COND	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Florida Climate														
Lab-born (females)														
F1	1.6	0.2	9.6	0.6	2.9	0.4	3.7	0.4	1.3	0.1	122.7	4.8	0.0153	0.0003
F2	1.5	0.2	10.3	0.8	2.5	0.3	4.1	0.2	1.3	0.2	101.4	8.1	0.0148	0.0004
K1	1.5	0.2	10.7	0.6	2.6	0.2	4.4	0.5	1.4	0.2	118.4	7.2	0.0153	0.0003
K2	1.2	0.1	10.3	0.8	2.3	0.2	4.3	0.4	1.3	0.1	97.3	5.3	0.0154	0.0003
Lab-born (males)														
F1	1.4	0.2	10.7	0.9	2.8	0.3	4.0	0.2	1.4	0.2	102.9	6.5	0.0155	0.0004
F2	1.6	0.1	13.2	1.1	2.5	0.2	4.4	0.2	1.3	0.2	102.9	10.3	0.0154	0.0004
K1	1.3	0.2	12.3	0.9	2.8	0.2	3.8	0.5	1.4	0.2	111.2	7.4	0.0154	0.0003
K2	1.2	0.2	9.8	0.6	3.0	0.2	4.2	0.4	1.2	0.2	84.6	9.9	0.0157	0.0003
Wild-caught (females)														
F1	1.5	0.2	9.5	0.8	2.8	0.3	3.7	0.3	1.2	0.1	111.6	7.4	0.0153	0.0002
F2	1.5	0.1	10.9	0.5	2.3	0.3	4.7	0.4	1.2	0.1	103.2	7.2	0.0154	0.0004
K1	1.6	0.2	9.5	0.9	2.3	0.2	4.0	0.4	1.5	0.1	118.2	8.3	0.0154	0.0004
K2	1.9	0.2	10.2	0.7	2.5	0.3	4.0	0.3	1.4	0.1	112.8	8.4	0.0149	0.0003
Wild-caught (males)														
F1	1.4	0.2	10.9	0.9	2.4	0.3	4.0	0.2	1.6	0.2	122.2	6.5	0.0153	0.0003
F2	1.7	0.2	10.0	0.8	2.9	0.2	4.6	0.4	1.2	0.1	111.6	7.3	0.0152	0.0003
K1	1.5	0.2	11.7	1.4	2.7	0.2	5.0	0.3	1.4	0.1	92.0	10.4	0.0159	0.0004
K2	1.7	0.2	11.4	1.3	2.4	0.2	4.0	0.3	1.2	0.1	88.9	10.9	0.0156	0.0004

Explanation of symbols: L - overall length; W - overall width; H - overall height; l - cavity length; w - cavity width; h - cavity height; R - roof thickness; S(l) - side thickness; B - base thickness; OCL - outer clipping lengths; OCW - outer clipping widths; ØCL - cavity clipping lengths; ØCW - cavity clipping widths; Q - quantity; COND - conductance; F - Florida animals; K - Kansas animals; 1 - Florida vegetation; 2 - Kansas vegetation; n = 12 for each category; all measurements in cm except, clipping widths in mm, quantity in g, and conductance in cal/sec/OC.

Kansas vegetation versus Florida material). However, nests did differ between climates (Table 11) in several respects: Total weight, thickness of roof, outer clipping lengths and widths, quantity of material used, and conductance. Two-way factor interactions were also examined and no differences occurred in the parameters measured ($P > 0.1$).

All nests constructed within the simulated environments were compared (one parameter at a time) to those nests constructed in similar field climates. There were no significant differences ($P > .01$) between any two parameters, indicating the similarity of these nests.

The clippings inside the nest cavities were compared to those in the outer construction (in field and lab nests) and found to be significantly different ($P < 0.01$) as follows: 1) Outer clipping lengths were longer than cavity clipping lengths at both field sites, 2) outer clipping widths were wider than cavity clipping widths at both field sites, although Kansas field nests showed a difference in this respect only at the 0.1 level, and 3) outer clipping lengths and widths were respectively longer and wider than those in the cavities for laboratory-constructed nests only under the simulated Florida climate.

Although the conductance values of nests within each laboratory environment did not differ with vegetational material, the vegetation from Kansas and Florida might each have been weaved and packed differently due to their structural make-up or have had physically different insulative capabilities so that heat transfer per unit thickness was very much different. However a 2 x 2 analysis of variance indicated that the thermal conductivity of these nests did not differ ($P > 0.5$) with nesting material in the same simulated climate but only between climates ($P < 0.01$). Student's t-tests indicated that field nests also differed in thermal

Table 11. Comparison of laboratory nests constructed under simulated environments.

	Simulated		Simulated		*
	Kansas Climate		Florida Climate		
	$\bar{x}$	SE	$\bar{x}$	SE	
Total					
Length (cm)	19.1	0.2	16.8	0.1	
Width (cm)	17.5	0.2	15.8	0.1	
Height (cm)	13.7	0.1	11.6	0.1	0.1
Cavity					
Length (cm)	9.1	0.1	8.5	0.1	
Width (cm)	8.3	0.1	7.9	0.1	
Height (cm)	7.5	0.1	6.9	0.1	
Thickness					
Roof (cm)	4.2	0.1	3.2	0.1	0.05
One side (cm)	4.5	0.1	3.8	0.1	
Base (cm)	1.8	0.1	1.5	0.0	
Clippings					
Outer lengths (cm)	6.2	0.1	10.7	0.2	0.001
Outer widths (mm)	1.4	0.1	2.6	0.1	0.001
Cavity lengths (cm)	4.3	0.1	4.1	0.1	
Cavity widths (mm)	1.2	0.0	1.3	0.0	
Quantity (g)	175.7	3.1	106.2	2.0	0.001
Conductance (cal/sec/°C)	0.0091	0.0000	0.0153	0.0000	0.001

* Level of significance for parameters which differed between simulated climates.

conductivity between climates ($P < 0.05$), but did not differ ($P > 0.1$) from nests constructed under similar simulated conditions. Combining the probabilities from these above independent tests of significance provides the combined evidence, using a Fisher's test for combined significance, for the difference of thermal conductivity between climates ($P < 0.01$, Figure 17). Therefore, these analyses demonstrate that the nesting material from Kansas and Florida do not have significantly different heat transfer properties, and that the material was manipulated in a comparable manner only under the same climatic conditions.

The mean values representing the volumes (cm^3) of nests are: 18346.5, Kansas study site; 13731.3, Florida study site; 19046.7 simulated climate of Kansas; and 12896.0, simulated climate in Florida. A comparison of these values demonstrated: 1) Field nests from Kansas were significantly larger ($P < 0.1$) than those from Florida, 2) laboratory nests in the simulated Kansas climate were significantly larger ($P < 0.05$) than those in the simulated Florida climate, and 3) field and laboratory nests constructed under similar climatic conditions were not different ($P > 0.4$).

The relationship between insulation and volume of field and lab nests combined were examined by regression analysis (Figure 18). Since no weights were obtained for field-constructed nests, the regression analysis between insulation and weight was only for laboratory nests (Figure 19). Regression lines were fitted to the data by the method of least squares. Both regression slopes, $Y = 5.28 + 0.00036X$ for insulation as a function of volume and $Y = 4.74 + 0.043X$ for insulation as a function of weight, are significant ($P < 0.01$). The mean predictive value given X , for comparably large sample sizes used to determine these regression lines, has a standard error along the whole line of 0.49 for insulation determined

Figure 17. Thermal conductivity of nests in relation to the climate in which the nests were constructed and the vegetative type incorporated into them. Abbreviations represent: K, Kansas climate; F, Florida climate; A, Field nests; B, Lab-nests constructed with Kansas vegetation; C, Lab-nests constructed with Florida vegetation. Top of bars represent means; dashed vertical lines, ± 3 standard errors.

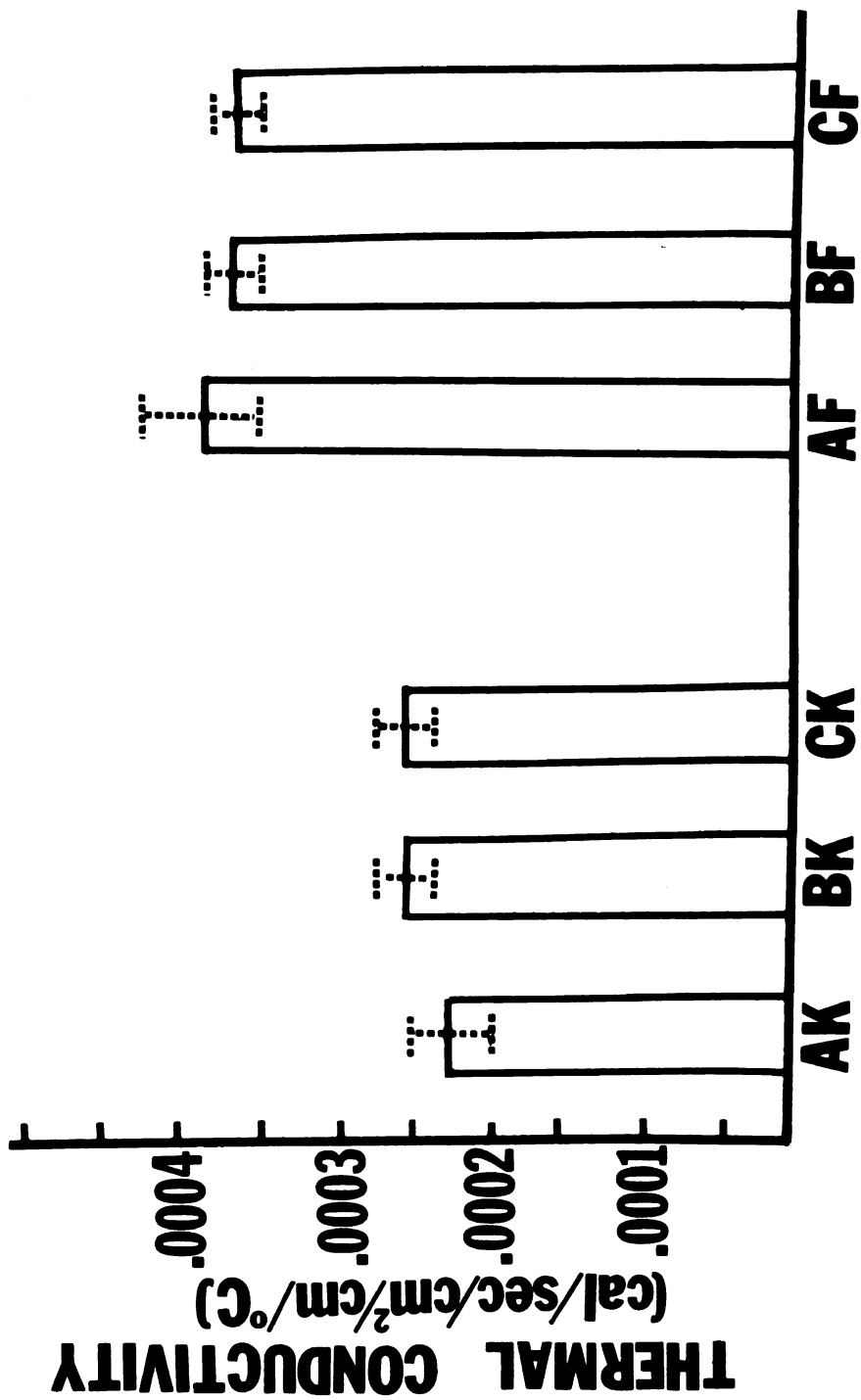


Figure 17.

Figure 18. Relationship of nest insulation to nest volume.
The regression slope is based on 444 nests, which
includes those constructed in both the laboratory
and field. The slope is significant ($P < 0.01$).

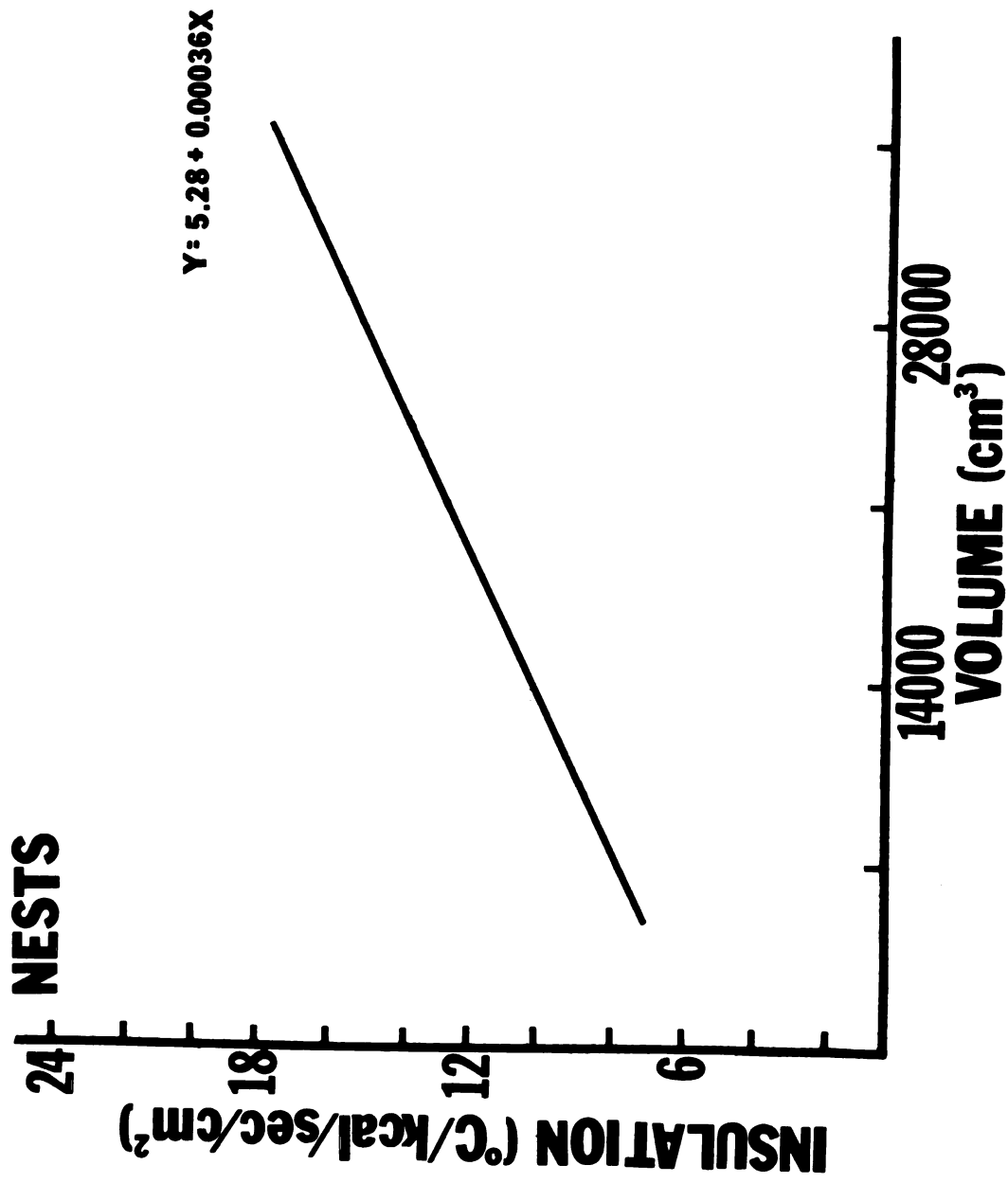


Figure 18.

Figure 19. Relationship of nest insulation to nest weight.
The regression slope is based on 384 nests, which
includes only those constructed in the laboratory.
The slope is significant ($P < 0.01$).

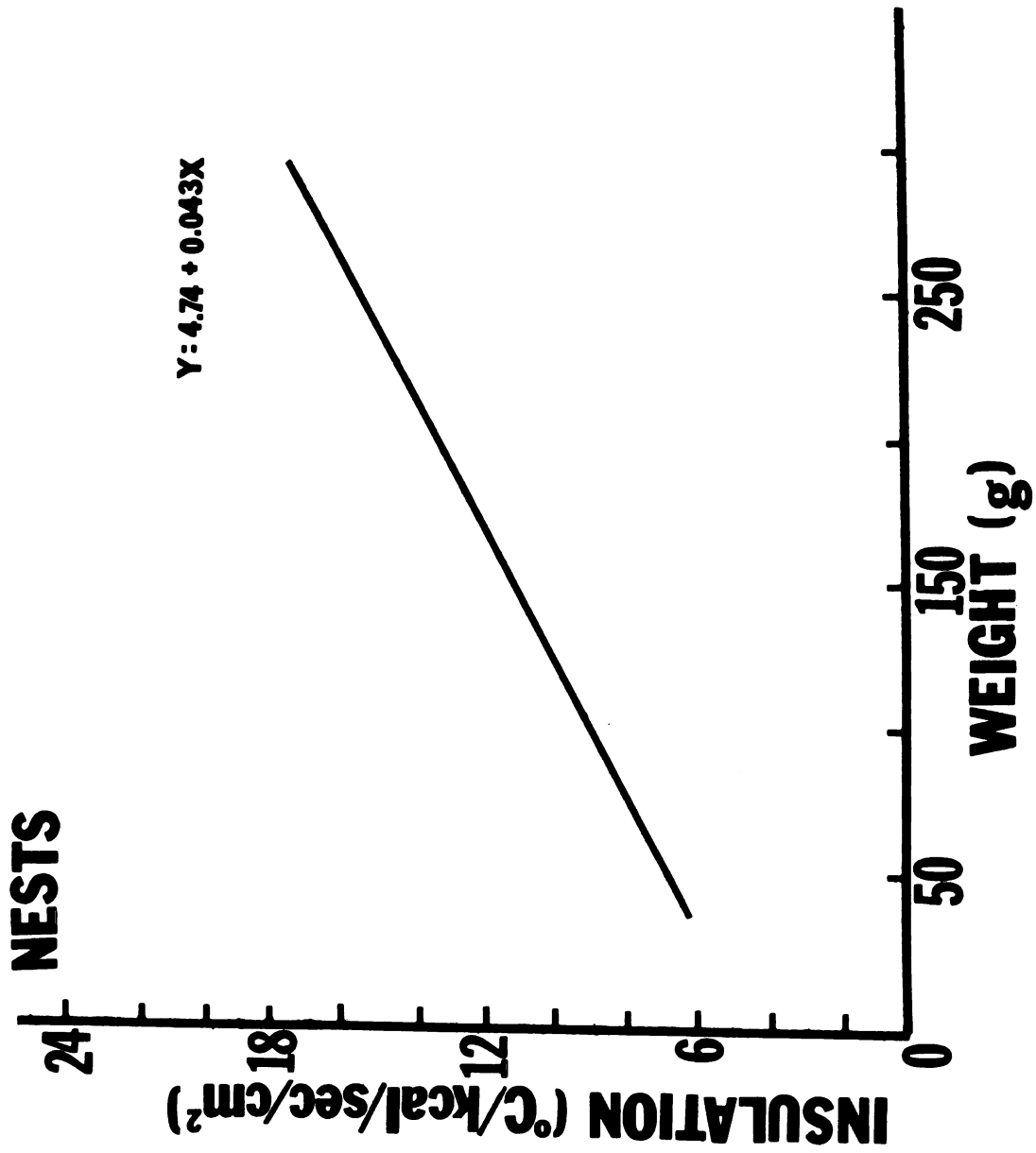


Figure 19.

by volume and one of 0.46 for insulation determined by weight (Ostle, 1963). Predictions of insulation ($^{\circ}\text{C}/\text{kcal}/\text{sec}/\text{cm}^2$) based on average volume and weight values for nests constructed in the simulated climate for Florida are 9.92 and 9.29 respectively, whereas the actual value is 7.88. Predictions of insulation based on those average values for nests constructed in the simulated climate for Kansas are 12.14 and 12.28 respectively, whereas the actual value is 13.33. However, predictions based on volume or weight for a single nest have a standard error of about eight, which is unacceptably high. Both regression equations have comparable predictive power but using weight would provide more accurate predictions.

To summarize, field constructed nests were different from the Kansas and Florida study sites. The field nests were similar to laboratory nests constructed in similar climatic conditions. Nests were constructed similarly within the same climatic chamber regardless of place of cotton rats' origin, sex, experience, or nesting material. However, nests were constructed differently under different climatic conditions. Knowing the mean weight or volume of a series of nests can provide a prediction of their insulation.

Comparison of Morphological Characteristics

Body weight (Figure 20) and tail lengths in proportion to body lengths (Figure 21) were compared between Kansas and Florida animals and found to be not significantly different ($P > 0.5$). These animal groups were those used in the nest-building experiments, and therefore consisted of both wild-caught and F_1 individuals.

The fur thickness (Figure 22), hair length (Figures 23 and 24) follicle count (Figures 25 and 26), and pelt insulation (Table 12)

Figure 20. A comparison of the body weights of wild-caught and F_1 cotton rats pooled from Florida (A) and Kansas (B). Horizontal solid lines represent mean values; vertical solid lines, range; and dashed rectangles, ± 3 standard errors.

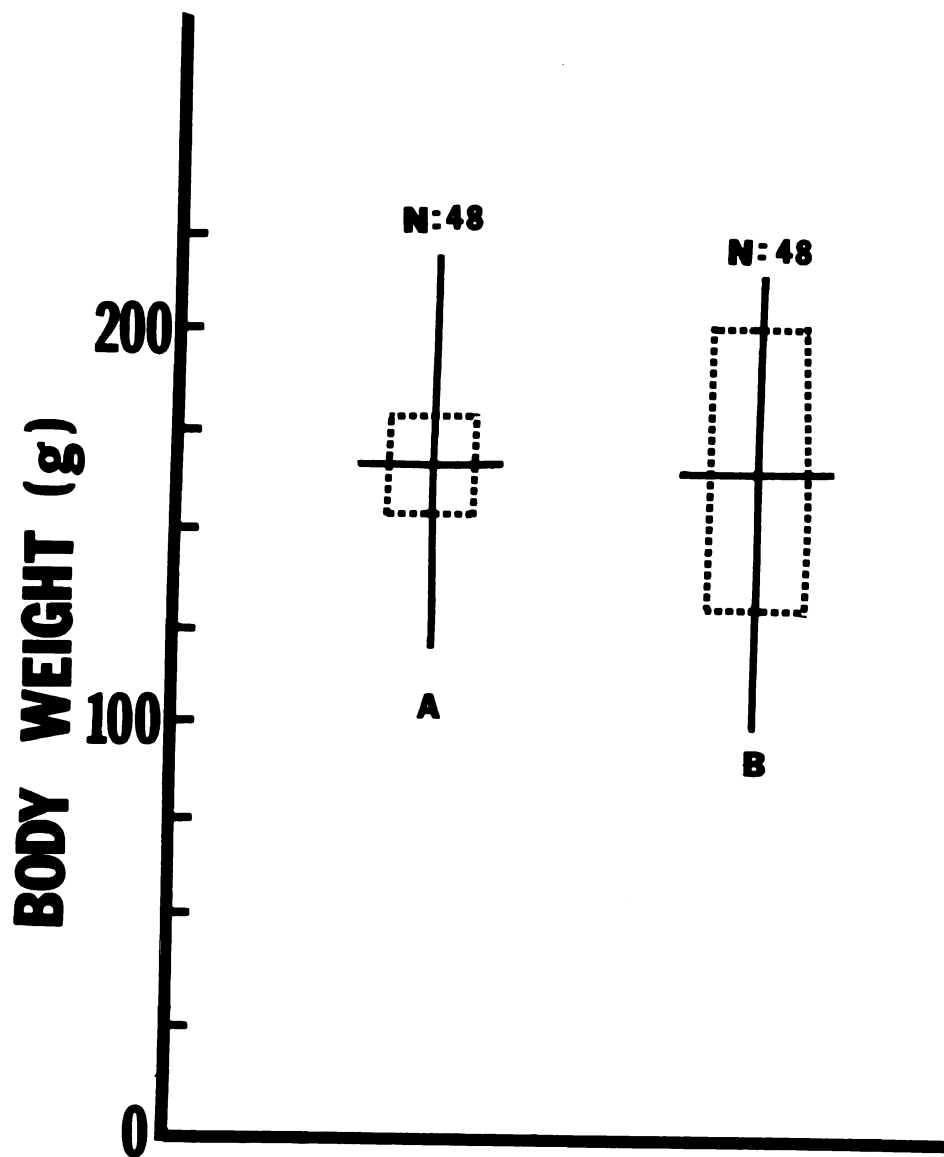


Figure 20.

Figure 21. A comparison of tail length in relation to body length between wild-caught and F_1 cotton rats pooled from Florida (A) and Kansas (B). Horizontal solid lines represent mean values; vertical solid lines, ranges; dashed rectangles, ± 3 standard errors.

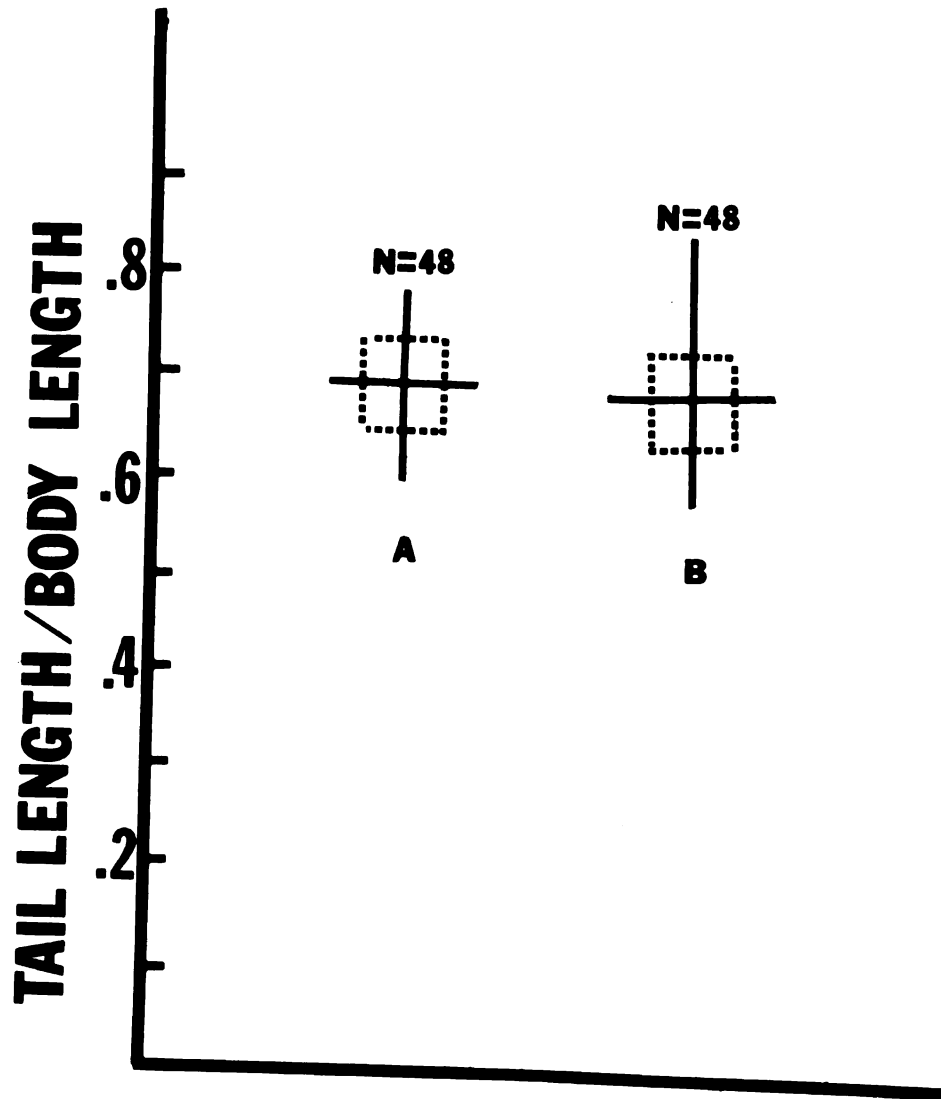


Figure 21.

Figure 22. Comparative data on pelages between groups of Sigmodon hispidus: Fur thickness. Abbreviations represent: F, Florida animals; K, Kansas animals; L, Lab-born (F₁) animals; W, Wild-caught animals; D, Dorsum; V, Venter. Bars represent means; dashed vertical lines, ± 3 standard errors.

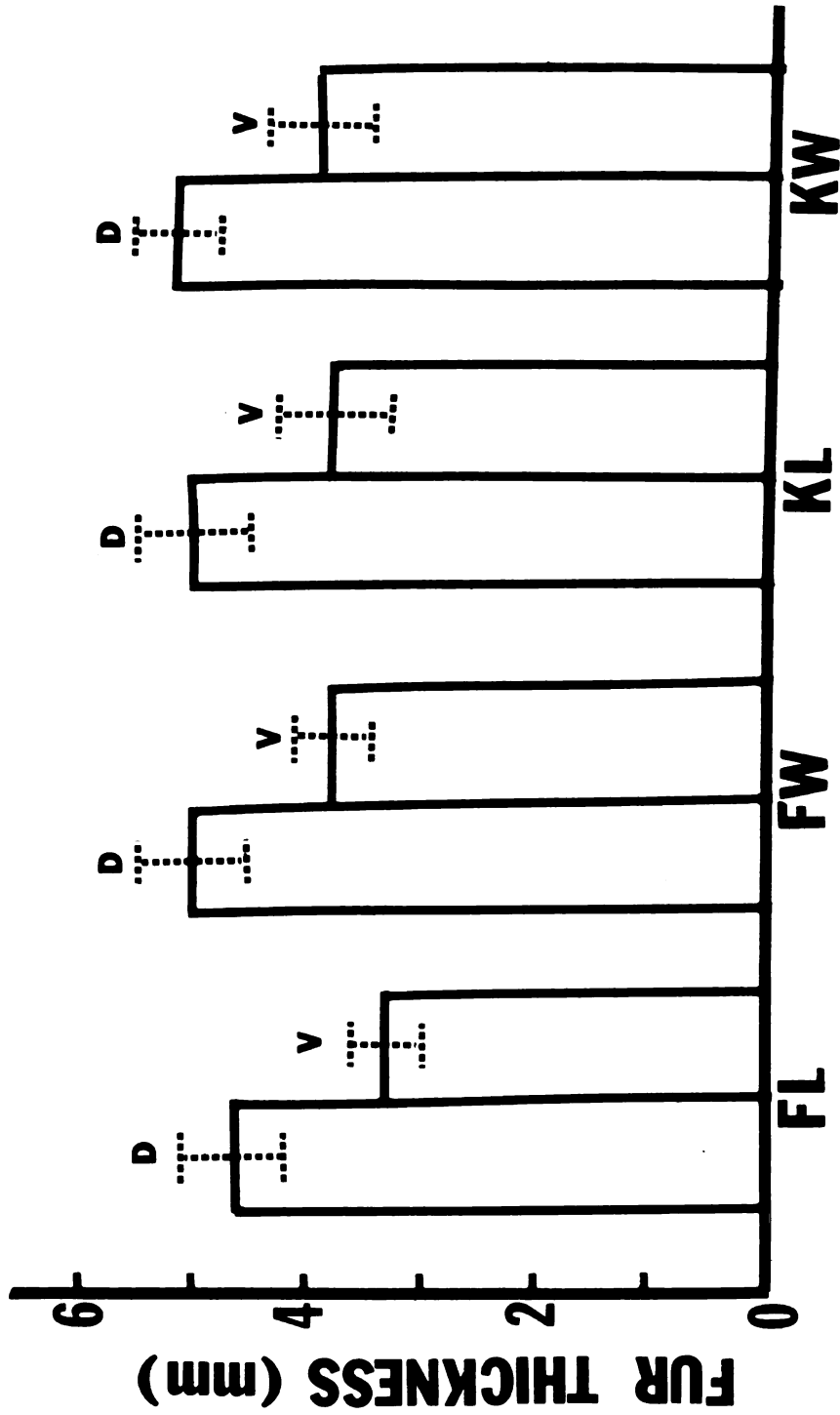


Figure 22.

Figure 23. Comparative data on pelages between groups of Sigmodon hispidus: Dorsal hair lengths. Abbreviations represent: F, Florida animals; K, Kansas animals; L, Lab-born (F₁) animals; W, Wild-caught animals; G, Guard hairs; U, Underfur. Bars represent means; dashed vertical lines, ± 3 standard errors.

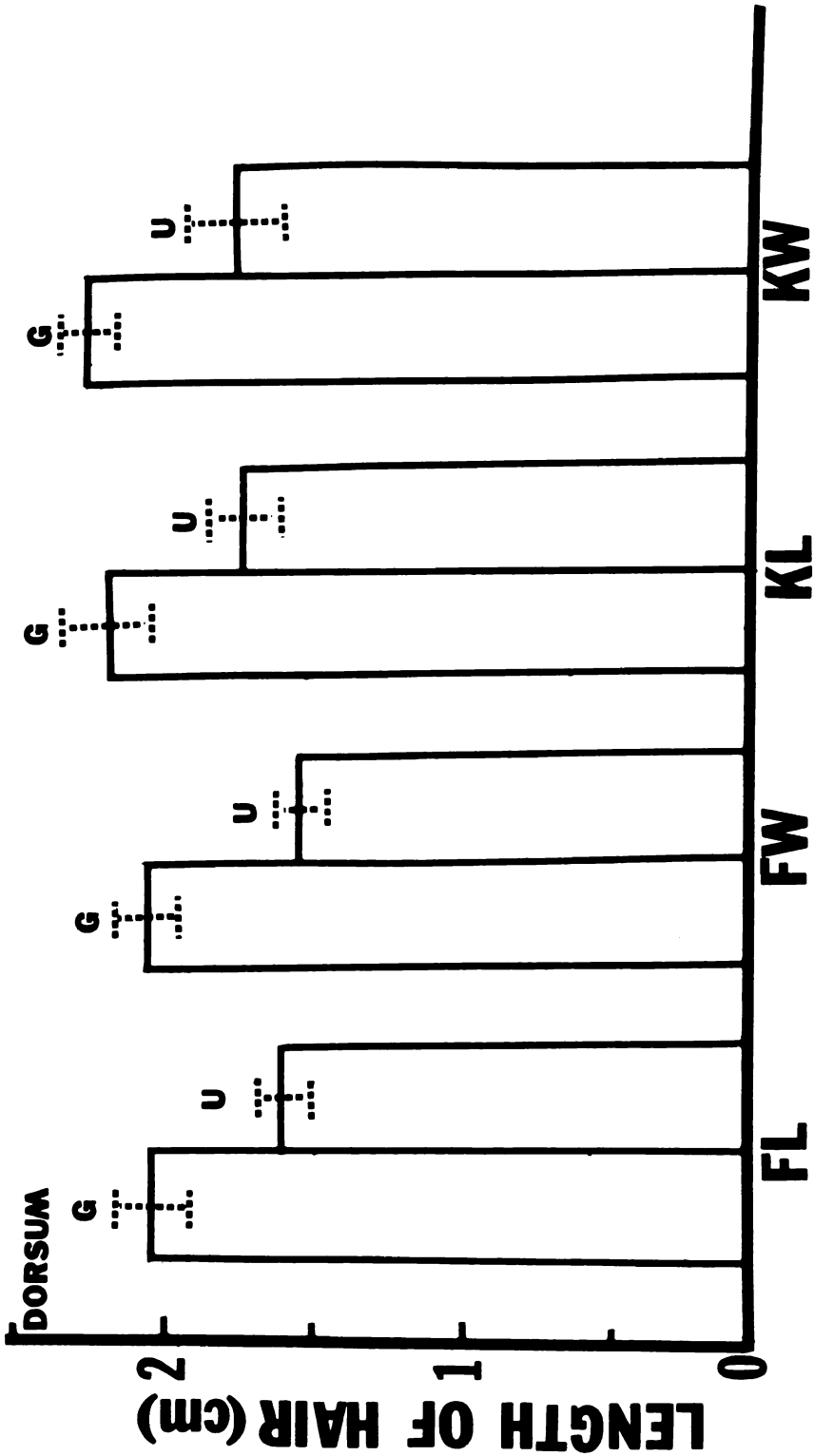


Figure 23.

Figure 24. Comparative data on pelages between groups of Sigmodon hispidus: Ventral hair lengths. Abbreviations represent: F, Florida animals; K, Kansas animals; L, Lab-born (F_1) animals; W, Wild-caught animals; G, Guard hairs; U, Underfur. Bars represent means; dashed vertical lines, ± 3 standard errors.

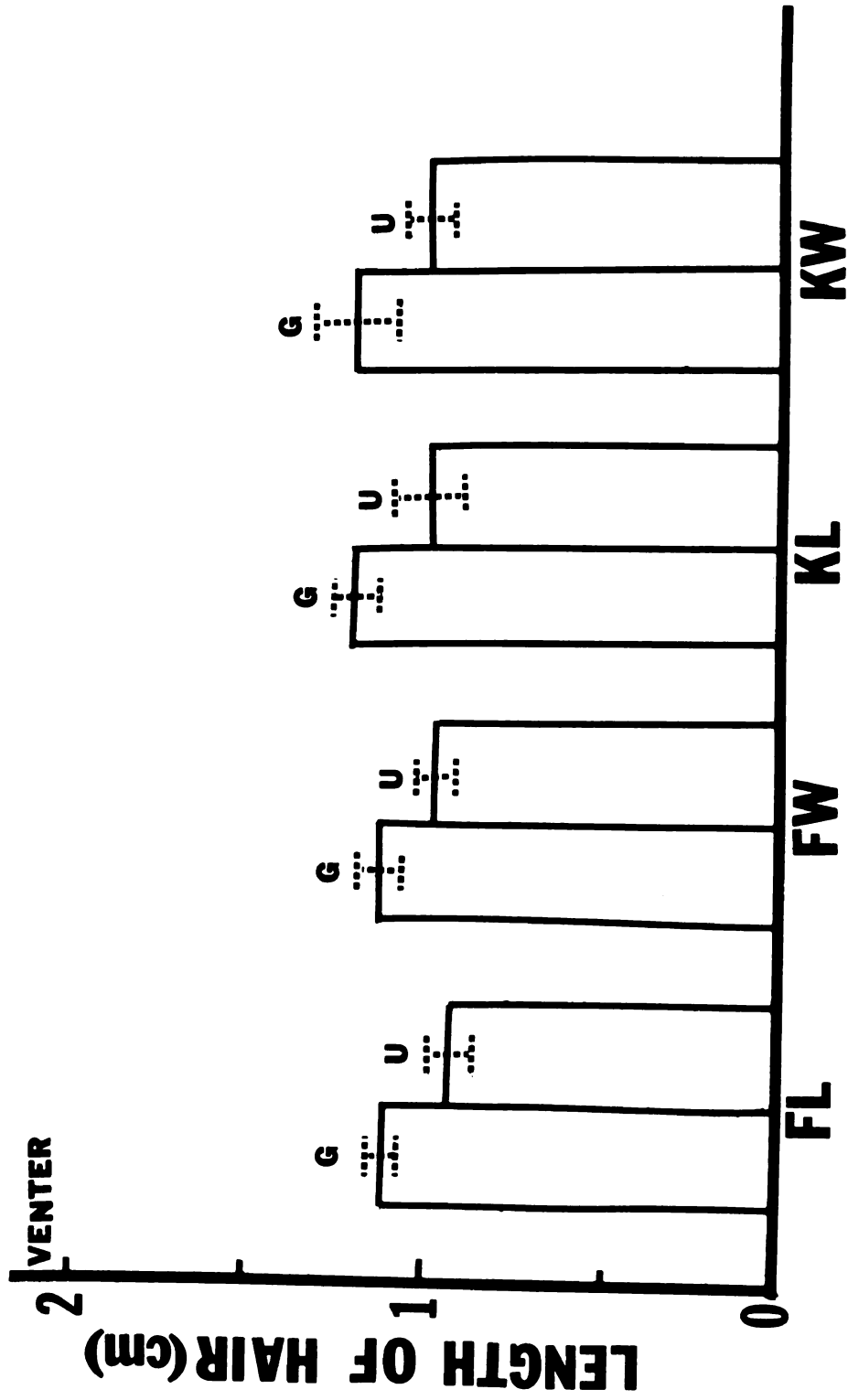


Figure 24 .

Figure 25. Comparative data on pelages between groups of Sigmodon hispidus: Dorsal follicle numbers. Abbreviations represent: F, Florida animals; K, Kansas animals; L, Lab-born (F_1) animals; W, Wild-caught animals; G, Guard hairs; U, Underfur. Bars represent means; dashed vertical lines, ± 3 standard errors.

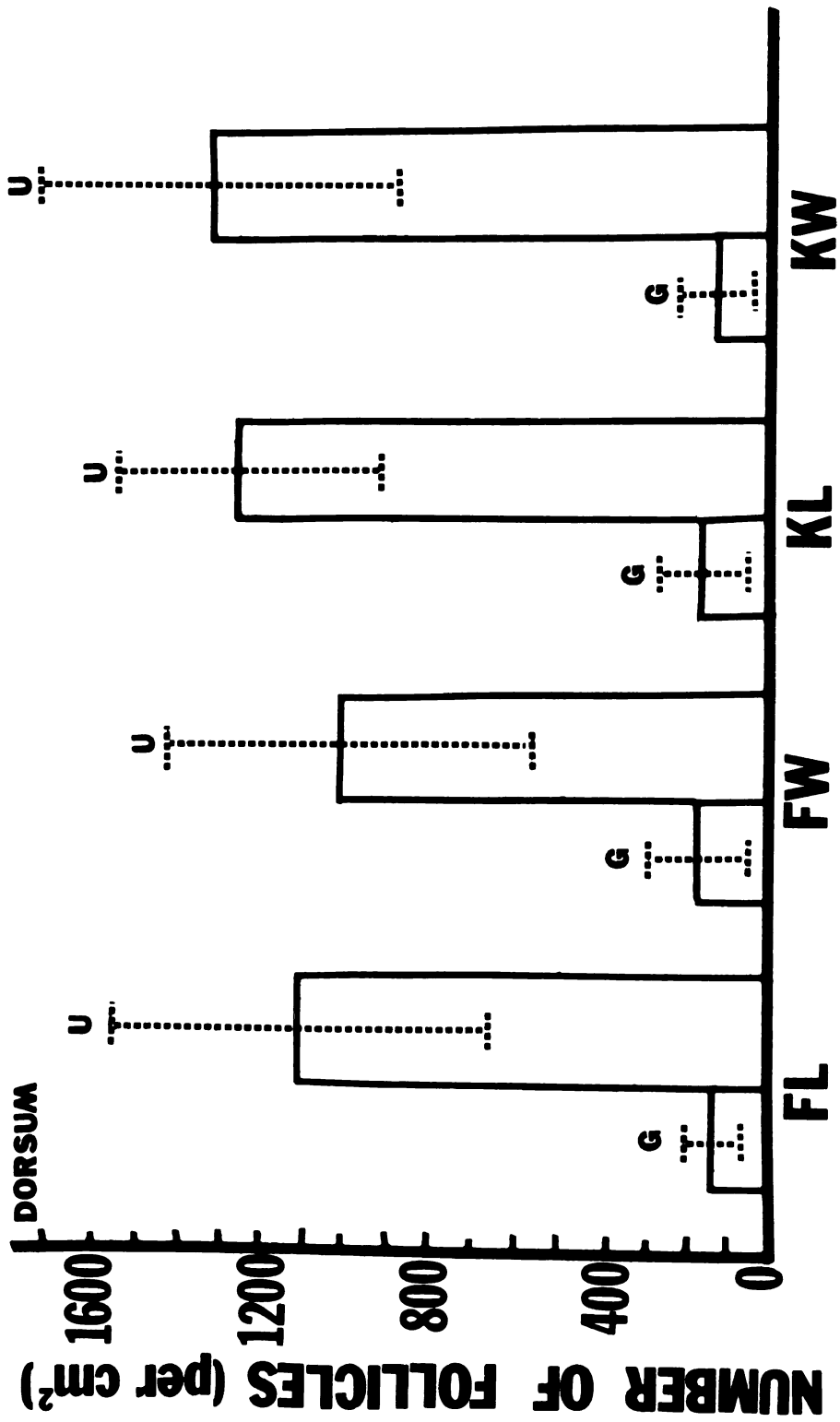


Figure 25.

Figure 26. Comparative data on pelages between groups of Sigmodon hispidus: Ventral follicle numbers. Abbreviations represent: F, Florida animals; K, Kansas animals; L, Lab-born (F_1) animals; W, Wild-caught animals; G, Guard hairs; U, Underfur. Bars represent means; dashed vertical lines, ± 3 standard errors.

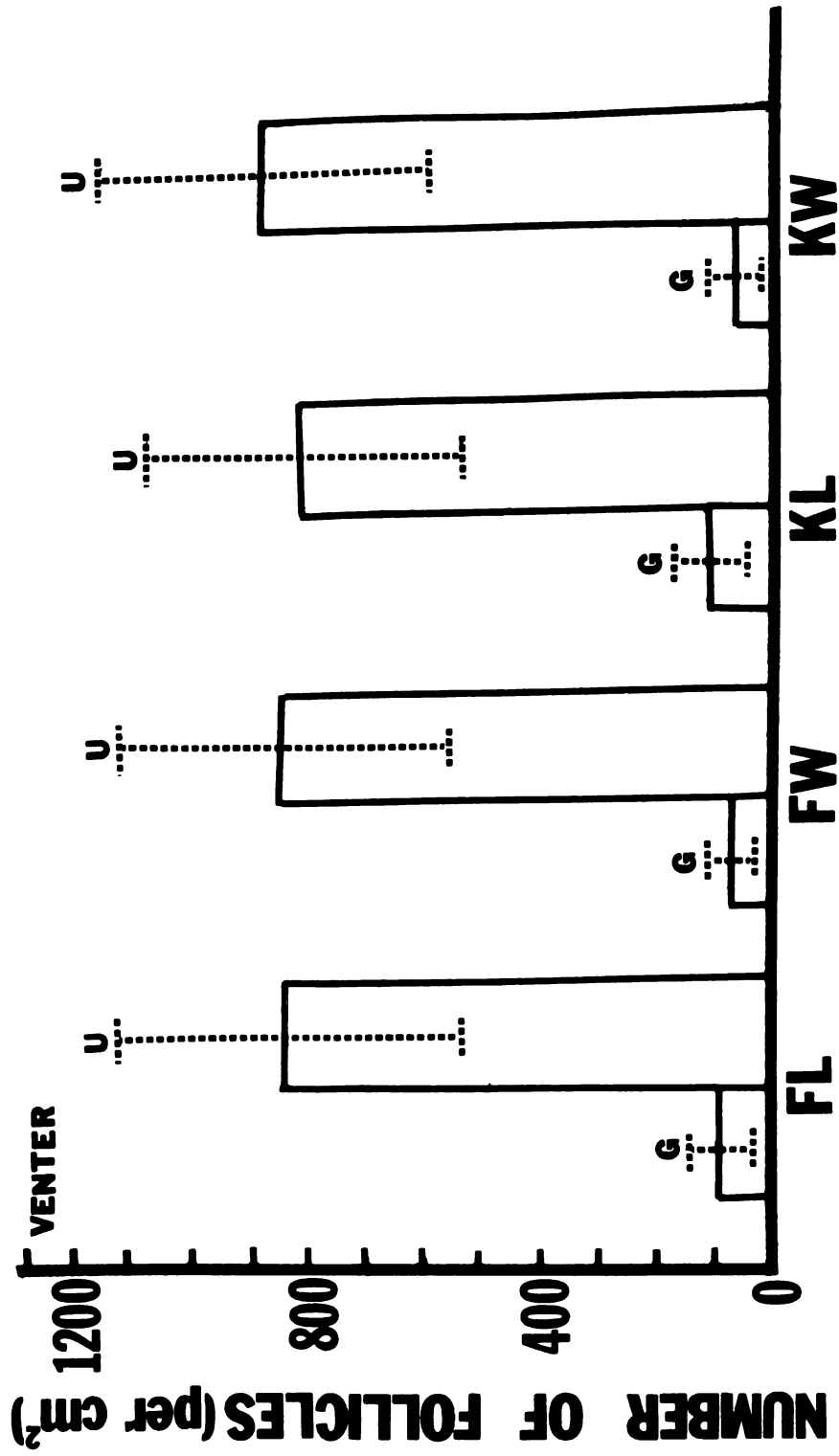


Figure 26.

Table 12. Pelt insulation of Sigmodon hispidus.

	Florida				Kansas			
	lab-born		wild-caught		lab-born		wild-caught	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Insulation ($^{\circ}\text{C/kcal/hr/m}^2$)	0.151	0.003	0.156	0.003	0.156	0.005	0.162	0.003

Note: Sample size equals 12 for each category. No significant difference between any two categories ($P > 0.1$)

were compared between lab-born (F_1) and wild-caught cotton rats whether from Kansas or Florida and between Kansas and Florida wild-caught and F_1 animals. No significant differences ($P > 0.1$) were found between animals of these categories.

The relationship between insulative values of nests and pelages is shown in Figure 27. This figure depicts the cotton rat coat to be more insulative than some tropical species, Proechimys and Sciurus, but not as insulative as the other forms shown, which are northern species. It also shows that nests (lab and field combined) constructed in Kansas or Florida climate would provide considerable insulation from environmental cold (or heat) to the animal within as opposed to being outside.

Energy Metabolism

The following calculations were performed to estimate the energy consumption of a cotton rat outside and inside of a nest at 0°C . A standard average conversion factor of 4.75 kcal produced per liter of O_2 consumed was used. This value represents the average for protein, 4.46; carbohydrate, 5.05; and lipid, 4.74.

The modified Meeh-Rubner formula reasonably determines the relationship between surface area (cm^2) and body weight (g) of an animal (Lee, 1926). This formula is: $S = 12.54 W^{0.60}$ where S = the surface area, and W = the weight. Considering the average body weight of cotton rats used in this study, 167 g, the surface area would be 262 cm^2 .

Average conductance (expressed now as $\text{cal/sec/cm}^2/^{\circ}\text{C}$) values are: 0.000178 for cotton rat pelts, 0.000075 for cotton rat pelts + Florida type nests (lab and field combined) and 0.000048 for cotton rat pelts + Kansas type nests (lab and field combined). These values show the decreased conductance indicating increased insulation for a cotton rat

Figure 27. Insulation is shown as a function of thickness for pelages and nests. Open diagrams from Scholander et al. (1950); individual pelt measurements fell within these diagrams. Closed diagrams from Hart and Heroux (1953) for Peromyscus, Heroux et al. (1959) for Rattus, and the author for Sigmodon and the nests. Closed diagrams represent mean values. Fur thickness measurements for Peromyscus, Rattus, and Sigmodon obtained by the author using the method already described in text. Nest thickness represents the average of all walls (roof, sides, and base) for nests constructed in the Kansas climate (lab and field) and Florida climate (lab and field). Abbreviations for pelt measurements: V, Proechimys semispinosus; U, Sciurus granatensis; S, Sigmodon hispidus; P, Peromyscus maniculatus gracilis; R, Rattus norvegicus; D, Dicrostonyx groenlandicus; L, Lepus americanus; A, Alopex lagopus. Abbreviations for nest measurements: K, nests constructed under a Kansas climate (lab and field); F, nests constructed under a Florida climate (lab and field).

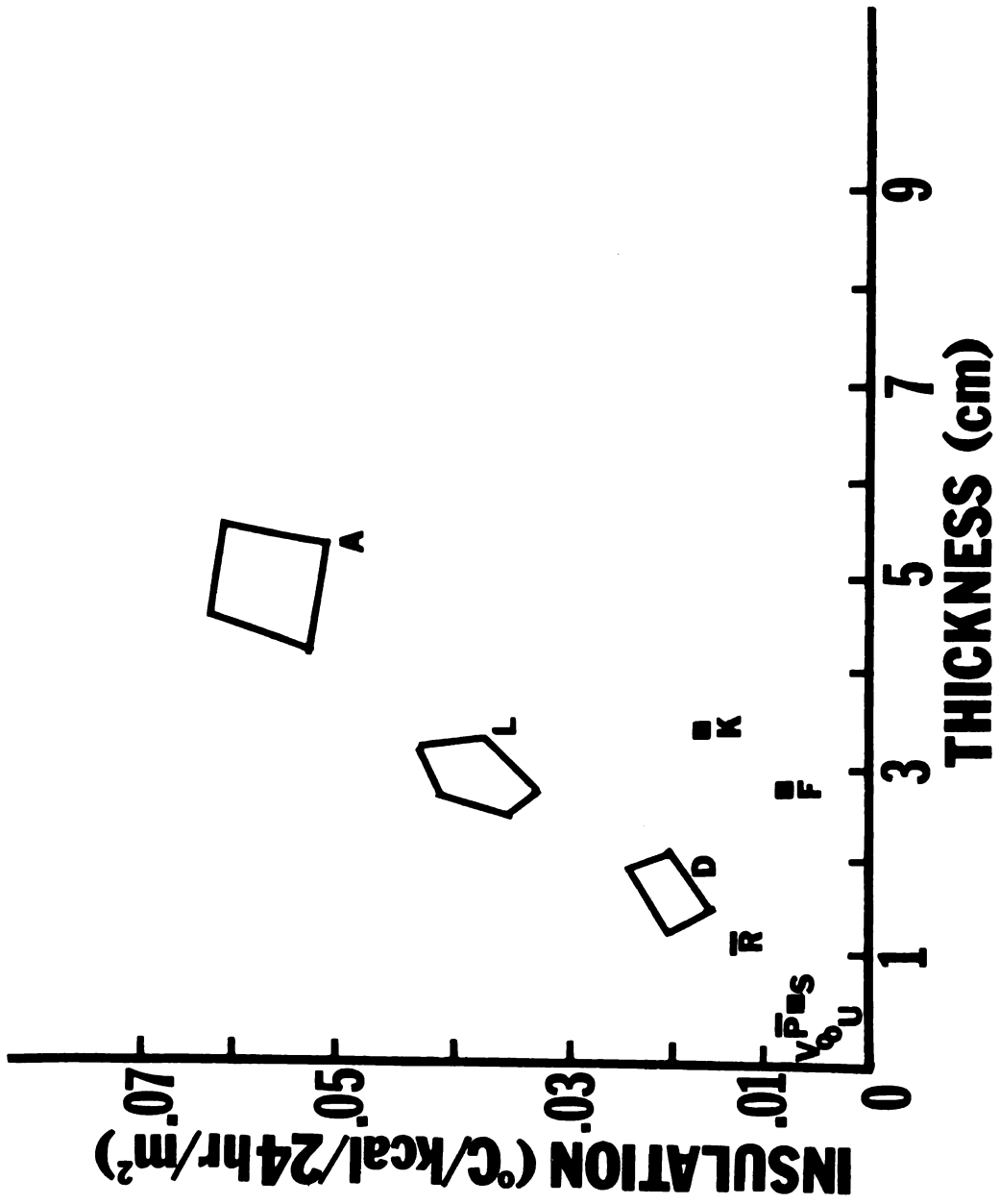


Figure 27.

in the different nest types as opposed to outside.

Conductance multiplied by (body temp - ambient) gives a value which is convertible into metabolism (cc O₂/g/hr). The above manipulations allow the metabolic rate to be determined from the average conductance values outside and inside different nest types at 0°C for a body temperature of 37°C. The metabolism in cc O₂/g/hr for a cotton rat outside its nest is 7.73; inside the Florida type, 3.27; and inside the Kansas type, 2.07. The basal metabolic rate for this species is approximately 1.38 cc O₂/g/hr (Gaertner, 1968; Bowers, 1971).

The oxygen utilized by a 167 g cotton rat per hr is convertible into energy used to maintain this animal's body temperature at an ambient of 0°C. This would amount to 6.13 kcal/liter O₂/hr outside of a nest, 2.60 inside the Florida type nest, and 1.61 inside the Kansas type nest. Consequently, much less energy would be utilized by an animal inside a nest than outside, and appreciably less energy would be needed to maintain the animal's body temperature in a Kansas type nest than in a Florida type.

DISCUSSION

Sigmodon hispidus is described as having burrow nests as well as surface nests (Stoddard, 1931; Schendel, 1940; Schwartz and Schwartz, 1959; Golley, 1962; Baar et al., 1974). However, all nests discovered in this study were of the surface type described by Strecker (1929), Halloran (1942), Lewis (1944), Hastings (1956), and Dawson and Lang (1973). The reason for finding no burrow nests at either study site is not apparent. They might have been in other burrows which went unnoticed, but a thorough search was carried out making this explanation seem implausible. It could be that surface nests are the most commonly built.

Fewer and shorter burrows were found in Kansas than in Florida (Table 5). Some populations may have greater proportions of nonburrowers than burrowers (Shump and Christian, unpublished data). Dawson and Lang (1973) did not find any burrow systems of cotton rats on their study sites in Costa Rica.

A population living in an area where burrowing is difficult or impractical, either due to a very hard, compact substrate or because of poor drainage, would be prevented or inhibited from digging many burrows. For example, one population of cotton rats may burrow extensively in sandy soil. However, another population even with the same percentage of burrowers may not construct many, if any, subterranean retreats in compact, humus soil similar to that of the Kansas site. Although rains soften compact soil, digging should still be relatively difficult. Comparable explanations for the effect of a differential facility of digging on the number and depth of burrows in various habitats have been put forth for chipmunks (Panuska and Wade, 1956) and heteromyids

(Vaughan, 1972).

It follows from the above remarks that cotton rats which can construct surface dwellings and burrows may be limited to only one of these behaviors by the habitat. In brushy areas with little ground cover (usually with sandy soil) the animals have no other recourse but to construct burrows if they are to survive. On the other hand, grasslands with good ground cover and vegetation for constructing nests may be habitats conducive to both surface and burrow nests, depending on the soil type. Therefore, several factors may be involved in this nesting-burrowing behavior, namely cover, soil type, and different propensities of the individual cotton rats to dig. It is also interesting to note that this species occasionally utilized burrows which have been abandoned by badgers or gopher tortoises (Schendel, 1940; Baar, et al., 1974), species which are probably more adept at digging.

Temperature and humidity information (Tables 5 and 6) make it apparent that burrows could be of value to an animal in avoiding extreme temperatures or desiccating conditions. One other plausible advantage for constructing burrows where they may be dug is to avoid predators while away from the primary nest site, which may very well be on the surface. This could account for all the burrows, especially the simple ones, which were found in this study. Similar conjectural explanations have been proposed for the many burrows constructed by individual chipmunks (Panuska and Wade, 1956; Thomas, 1974).

The surface nest itself should provide equable conditions to an animal within by dampening environmental variability. The relatively high humidity inside of these nests which was significantly different from the outside air could be of great value in conserving water in

dry weather. Nests were also capable of excluding water from their cavities in moderate rains, which would prevent an animal inside from becoming damp. Cavity temperatures of the nests were different from above-ground temperatures only at the Kansas site. However, this is only a transient phenomenon which is especially noticeable with variable temperatures. The significant lag-effect was not observed in Florida due to the relatively mild and stable temperatures at the time of this study. Of course, the dissimilarity among interior nest, outside under-grass, and above-ground absolute temperatures indicates that a stepwise series of barriers is formed culminating with the nest which impedes rapid equilibration with the above-ground conditions. Also, the greater the difference between the ground and above-ground temperatures, the more influential the ground temperatures would be in reducing the speed at which the interior nest temperatures would equal those above ground.

The design and position of these surface nests are capable of providing protective refugia from climatic conditions. At both field sites the bottom of the nest afforded insulation; this was particularly true in Kansas due to the significantly greater bottom thickness, which is of obvious value when the ground is frozen or cold air lies next to the substrate. The walls and roof provide both shade and insulation.

The coarser, more loosely woven outer clippings of Florida nests allow for larger air spaces than the finer, more tightly woven ones from Kansas nests. These larger air spaces are susceptible to increased convective processes which would result in a cooler nest in hot weather by not allowing these spaces to retain hot air that has been heated by the sun or by the metabolic heat production of the animal. Small air spaces, on the other hand, produced by fine, more tightly woven

clippings would not permit the heat to be lost as rapidly from the nest, and this would make the nest better suited for northern, colder regions.

Every field nest was found to possess a depression beneath its nest cavity. Many functions might be attributed to such a depression. The formation of air spaces between the nest cavity and the bottom of the depression would be relatively inaccessible to convection. This should help reduce the energy required by the rodent to maintain the interior nest temperature in cold weather, even though some heat would be lost by the animal from the nest cavity to the cool ground. During warm conditions, the cool ground in the depression beneath the nest would be of value in removing some heat from the animal through the base of the nest in lieu of convective processes. If moisture in the form of rain soaking through the ground or urine reaches the nest depression, subsequent evaporation might allow for the maintenance of a relatively high humidity in the nest. This would be helpful in preventing excessive water losses from the animal. The ridge around every depression, enclosing the nest cavity, should help prevent running water caused by moderate rains from accumulating in the nest and soaking the animal. Aside from this, the depression allows the nest to have a slightly lower profile than would exist otherwise, which may help conceal it from predators.

The orientation of nest entrances facing in a southeasterly direction could prevent direct access of prevalent westerly and cold northerly winds. This orientation could also allow the early morning winter sun to shine into the cavity somewhat, causing the interior of the nest to heat up, even if the entrances were closed, because less material would be in that position than toward the rear of the nest. This would be of obvious

value to the cotton rat within the nest following a cool or cold winter evening.

The finding that nests in Kansas were more heavily constructed and more insulative than those in Florida is contrary to the idea (see Dawson and Lang, 1973) that nests constructed by cotton rats in the northern parts of their range may not be a response to cold. In fact, it was formerly thought (Dawson and Lang, 1973) that cotton rats nests were similar from south to north. My detailed measurements show that mere differences or similarities in gross configuration do not indicate insulative properties. Although the nests from Kansas were twice as insulative, they were not twice as large; therefore, as substantiated from the conductivity measures of field as well as lab nests, it appears that chewing-up material into finer pieces which can be packed tighter (i.e., putting more material into the same space) is the key to greater insulation.

Mean insulative predictions for nests based on volume or weight were shown by regression analysis to be relatively good. Nevertheless, it is apparent that the predictions are high for Florida type nests and low for Kansas type nests. This indicates that factors in addition to volume and weight determine the insulative capabilities of nests (e.g., the degree of chewing-up and weaving of the nesting material). Obviously predictions of the insulation based on a single nest would not be very useful. Therefore, it is the contention of the author that while mean predictive values of nest insulation are reasonable and of use for large sample sizes (e.g., 200-400) an accurate determination of insulation, especially for single nests, is best accomplished by actual measurement.

Laboratory evidence indicates that nests are built the same in any given climate regardless of the cotton rats' place of origin, sex, experience, or nesting material. In fact, the differences which occurred in the nests were only between different simulated climates. Since no interaction effects were found with climate and any other factor, it appears that the magnitude of difference noted in the parameters for nests in different climates is similar no matter what factors (at least considering those examined in this study) are involved. Therefore, it is valid to promulgate the generalization that climate is the primary factor modifying nest construction.

The cotton rat, regardless of place of origin, constructs a given type of nest under given environmental conditions. If genetic variations in nest-building were associated with environmental temperature gradients, animals from the northern parts of their range would be expected to construct larger and more insulating nests under constant temperatures than the more southerly located conspecifics. Therefore, a genetically based behavioral cline would be present from south to north. This does not appear to be the case with cotton rats.

Both sexes of Sigmodon construct a similar type of nest when under the same climatic conditions. Since these animals are agnathic and presumably solitary except for breeding (Meyer and Meyer, 1944; Inglis, 1955; Summerlin, 1968; Summerlin and Wolfe, 1973; Layne, 1974), members of each sex would be able to survive, especially in fluctuating climates, only if capable of similar thermoregulatory responses. In fact, it seems unlikely that one sex should be at a selective advantage in such a basic regard as conserving energy and surviving in different environments.

The similarity found in nests built by both sexes does not apply

to pregnant or lactating females, which were not incorporated into this research. Lab mice in the presence of litters (Noirot, 1974) and pregnant lab rats (Kinder, 1927; Richter, 1937; Denenberg et al., 1969) have been shown to make larger nests than other females, presumably for accomodating the young and possibly for protecting them from the weather.

It is worth noting at this time that cotton rats have been observed to huddle in nest boxes in severe weather (Dunaway and Kaye, 1961); however, the frequency with which this occurs under natural conditions is uncertain. Huddling would, no doubt, be of value in withstanding harsh temperatures (Sealander, 1952) and conserving energy (Pearson, 1960; Bryant and Hails, 1975).

It is interesting that lab-born cotton rats with no previous experience at building nests are able to construct them just like the wild-caught animals. Since this species leaves the nest at an early age (Meyer and Meyer, 1944; Shump and Shump, 1975), the ability to construct a refuge without prior practice could insure its survival by providing relatively rapid protection from environmental conditions.

Cotton rats also utilized different nesting materials (various grass species) in a similar fashion. This is reasonable in view of the habitats they occupy and the comparability of nesting materials used (i.e., usually dominant grasses which are pliable and of somewhat comparable structure).

This data on nesting behavior indicates that Sigmodon hispidus possess a behavioral plasticity which allows them to construct different nests in different climatic conditions. Other investigators have shown that nests are valuable in helping animals conserve energy in severe environments (Pearson, 1960; Gaertner, 1968; Bryant and Hails, 1975;

Glaser and Lustick, 1975). Nest-building behavior, coupled with the presence of suitable habitat due to man's actions of creating ruderal habitats, may have allowed cotton rats to occupy regions which were otherwise inhospitable.

Many adaptations seemingly could have occurred in northern populations of Sigmodon, and those concerning morphology were examined. It has been reported that mammals occupying the northern parts of their ranges possess larger bodies (Bergmann, 1847), but this was not found for cotton rats. There does not appear to have been a selective advantage for increased body size in this species.

An obvious characteristic of cotton rats is their long, relatively naked tail. This appendage may be a route of considerable heat loss (Kirksey et al., 1975) and might be expected to be proportionately smaller in northerly distributed populations (Allen, 1906). However, this was not found to be the case. These animals are capable of modifying climatic conditions by behavioral mechanisms, and selection pressures affecting tail length might be similar for Kansas and Florida populations.

Another morphological characteristic which has been shown to differ between southerly and northerly distributed mammals is the insulation of the fur (Scholander et al., 1950). The insulative values obtained in this study for cotton rat pelts are comparable to those obtained for other species of similar fur thickness (Scholander et al., 1950; Hart and Heroux, 1953; Heroux et al., 1959; Birkebak, 1966; Dawson and Webster, 1967). The technique in this paper for measuring insulation gives a composite value of dorsum, sides, and venter. Previous studies have just measured insulation of dorsal parts, which gives a maximal value. If maximum insulation had been determined as in previous

insulative studies, those values reported here for Sigmodon pelts would be slightly higher. The method presented in this paper for determining pelt insulation should provide a more realistic value for fur insulation than previous methods which only used the dorsum.

The possibility exists that the pelts measured in this study were of less than maximal thickness due to acclimation rather than acclimatization effects, but since the animals were on a semi-natural photoperiod for a total of eight weeks, this difference would be negligible. This conclusion is warranted since researchers have demonstrated that natural photoperiod controls seasonal changes in the fur of various mammal species and that similar alterations can be induced in pelage quality with artificially regulated light cycles (Bissonnette, 1935; Bassett et al., 1944; Bassett and Lewellyn, 1949; Hamond, 1952; Morris, 1961; Hart, 1964). In other words, the short photoperiod used in this study should cause the acquisition of a thicker, winter type pelage.

This research shows that the pelage insulation is similar for Kansas and Florida cotton rats. In fact, their pelage does not differ in any parameter measured. Selection has not, at least yet, acted upon the cotton rats to result in significant modifications of the pelage in northerly distributed forms. Consequently, it would seem that these animals are sufficiently protected from the macroenvironment by their habits (i.e., nest-building and burrowing) and microclimates without the necessity for these morphological alterations.

Subcutaneous fat deposits might provide some insulation from cold conditions. Northern populations may have become adapted for increased fat accumulation over southern forms. If this were so, it would probably be to provision the animal with energy stores during the time of severe

winter food shortage. Cotton rats lose considerable weight in cold weather (Dunaway and Kay, 1961), and the lipid deposits alone are not sufficient to sustain them during harsh winter conditions (Fleharty et al., 1972). Consequently, any insulation derived from these fat deposits would be for a limited duration.

One other possible adaptation to various environmental conditions unexplored in this research, concerns metabolic rates. Bowers (1971) measured the basal metabolism of several populations of Sigmodon hispidus occupying various parts of the species' range. He found a different metabolism in only one of those populations. In other words, apparently little selection has occurred for different metabolic rates in populations inhabiting diverse climatic regions.

The environmental factor or factors most affecting the northward dispersal of hispid cotton rats are presently unknown, but many authors (Cockrum, 1952; Goertz, 1964; Hoffmann and Jones, 1970; Fleharty et al., 1972) have speculated that severe weather might limit distribution by limiting availability of food. Subfreezing weather appears to prevent this species from moving out of refuges and foraging (Goertz, 1964), and this might result in starvation, especially during prolonged cold conditions when energy demands are at a peak. It seems that lipid deposits alone are insufficient for cotton rat survival during periods of cold weather when food is unavailable or the weather prevents foraging (Fleharty et al., 1972). Provided with suitable habitat the northern dispersal of these rodents may be stopped unless they have some method limiting depletion of fat deposits or of replenishing these depleted energy stores. It is reasonable to assume that cotton rats would try to minimize energy losses by constructing refuges (i.e., burrows and/or

surface nests). This research demonstrates, among other things, that hispid cotton rats possess the capabilities of altering nest construction to suit diverse climatic conditions. It also shows that nests could provide considerable insulation and be of immense value for cotton rats in conserving energy, thereby helping them to survive during unfavorable weather conditions.

SUMMARY

Nest construction by the hispid cotton rat (Sigmodon hispidus) was examined from two different climatic regions, Florida and Kansas. A field and laboratory phase were designed to determine factors which might affect nest construction. The field phase was used to determine if nests in fact differed between diverse climatic localities. Thirty field-constructed nests were found by fitting a leather harness with an attached string on the animals and following them to the nests. Nests were compared between Kansas and Florida and found to differ significantly in several specific parameters: 1) Thickness of the base, 2) lengths and widths of clippings incorporated into the outer construction, and 3) conductance. The entire set of nest parameters was simultaneously compared between Florida and Kansas using multivariate analysis and was found to be significantly different. In other words, nests differ between Florida and Kansas.

The laboratory phase of this study was designed to determine if nests were constructed differently as a result of the cotton rats' place of origin, sex, nesting material utilized, experience, and/or climate. Vegetation characteristic of field nests and live-trapped cotton rats from both field sites were sent back to Michigan for these determinations. Wild-captured and laboratory born (F_1) cotton rats of equal sexes and from both areas were placed in two environmental chambers. Each chamber was adjusted to simulate winter conditions characteristic of one field site; so climates of both localities were simulated. Each rodent was allowed to construct four nests, two with vegetation brought from its home locality plus two with vegetation from the other locality. Under the influence of a given climate, these animals constructed a given type

of nest regardless of population differences, sex, nesting material used, or experience. Differences in nest construction only occurred between simulated climates. These data indicate that hispid cotton rats have a behavioral plasticity for the construction of different nest types to suit different climates. Due to the diversity of climates that this species occupies, behavioral plasticity for constructing different nest types would be valuable in modifying climatic conditions around itself which are conducive to survival.

A technique was developed to measure the conductance of nests. Nests constructed in both simulated and field Florida climates had conductance values about two times greater than those nests built in both simulated and field Kansas climates. In other words, Kansas type nests are approximately twice as insulative as the Florida type.

More burrow systems were constructed in the Florida than in the Kansas habitat. This is believed to be related to the soil type as well as to other factors discussed in the text.

Body size, tail length in proportion to body length, fur thickness, hair length, follicle count, and pelt insulation were compared between Florida and Kansas Sigmodon. No differences were found to exist between these two populations in any of the above morphological characteristics.

A technique like that utilized to measure nest conductance were used to determine the insulation of cotton rat pelts. The insulation of Sigmodon pelts was found to be comparable to those values for other mammals with similar fur thickness.

BIBLIOGRAPHY

BIBLIOGRAPHY

- Allen, J.A. 1906. The influence of physical conditions in the genesis of species. Ann. Rep. Smith, Inst. (1905), pp. 375-402.
- Baar, S.L., E.D. Fleharty, and M.F. Artman. 1974. Utilization of deep burrows and nests by cotton rats in west-central Kansas. South-western Nat., 19:440-443.
- Baker, R.H. 1956. Mammals of Coahuila, Mexico. Univ. Kans. Pub. Mus. Nat. Hist., 9:125-335.
- _____. 1969. Cotton rats of Sigmodon fulvenventer group (Rodentia: Muridae). In J.K. Jones, Jr. ed., Contributions in Mammalogy. Publ. Mus. Nat. Hist. Univ. Kans. Misc. Publ., 51:177-232.
- _____ and J.K. Greer. 1962. Mammals of the Mexican state of Durango. Mus. Mich. State Univ. Biol. Ser., 2:25-154.
- Barnett, S.A. 1956. Endothermy and ectothermy in mice at -3°C . J. Exp. Biol., 33:124-140.
- _____. 1965. Adaptation of mice to cold. Biol. Rev. Cambridge Phil. Soc., 40:5-52.
- Bassett, C.F. and L.M. Lewellyn. 1949. The moulting and fur growth pattern in adult mink. Amer. Midl. Nat., 42:751-756.
- _____, O.P. Pearson, and P. Wilke. 1944. The effect of artificially increased day-length on moult, growth and priming of silver fox pelts. Amer. Fur Breeder, 17:32-35.
- Bergmann, C. 1847. Ueber die Verhältnisse der Wärmeökonomie der Thiere zu ihrer Grösse. Gottinger Studien, pt. 1, pp. 595-708.
- Birkebak, R.C. 1966. Heat transfer in biological systems. Int. Rev. Gen. Exp. Zool., 2:269-344.
- Bissonnette, T.H. 1935. Relations of hair cycles in ferrets to changes in the anterior hypophysis and to light cycles. Ant. Rec., 63:159-168.
- Blair, W.F. 1958. Distributional patterns of vertebrates in the southern United States in relation to past and present environments. In C.L. Hubbs, ed., Zoogeography. Amer. Ass. Adv. Sci., pp. 433-468.
- Bowers, J.R. 1971. Resting metabolic rate in the cotton rat Sigmodon. Physiol. Zool., 44:137-148.

- Brown, J.H. 1968. Adaptation to environmental temperature in two species of woodrats, Neotoma cinerea and N. albigula. Misc. Pub. Mus. Zool., Univ. Mich., no. 135, 48 pp.
- Bryant, D.M. and C.H. Hails. 1975. Mechanisms of heat conservation in the litters of mice (Mus musculus L.). Comp. Biochem. Physiol. A. Comp. Physiol., 50:99-104.
- Burt, W.H. 1946. The Mammals of Michigan. Univ. of Michigan Press, Ann Arbor, xv + 288 pp.
- Carpenter, R.E. 1966. A comparison of thermoregulation and water metabolism in the kangaroo rats Dipodomys agilis and Dipodomys merriami. Univ. Calif. Pub. Zool., 78:1-36.
- Cockrum, E.L. 1948. The distribution of the hispid cotton rat in Kansas. Trans. Kans. Acad. Sci., 51:306-312.
- _____. 1952. Mammals of Kansas. Univ. Kans. Pub. Mus, Nat Hist., 7:1-303.
- Cory, C.B. 1912. The mammals of Illinois and Wisconsin. Field Mus. Nat. Hist. Pub., 153 Zool. Ser., 11:1-505.
- Coulianos, C.C. and A.G. Johnels. 1963. Note on the subnivean environment of small mammals. Arkiv. fur Zoologi, 15 ser., 2:363-370.
- Daniel, M. 1964. Ecological factors affecting rodent populations. Acta Soc. Zool. Bohemoslov., 28:278-299.
- Davis, W.B. and R.J. Russell. 1954. Mammals of the Mexican state of Morelos. J. Mamm., 35:63-80.
- Dawson, G.A. and J.W. Lang. 1973. The functional significance of nest building by a Neotropical rodent (Sigmodon hispidus). Amer. Midl. Nat., 89:503-509.
- Dawson, N.J. and M.E.D. Webster. 1967. The insulative value of mouse fur. Quart. J. Exp. Physiol., 52:168-173.
- Denenberg, V.H., R.E. Taylor, and M.X. Zarrow. 1969. Maternal behavior in the rat: An investigation and quantification of nest-building. Behaviour, 34:1-16.
- Dunaway, P.B. and S.V. Kaye. 1961. Cotton rat mortality during severe winter. J. Mamm., 42:265-267.
- Erickson, A.B. 1949. Summer populations and movements of the cotton rat and other rodents on the Savannah River Refuge. J. Mamm., 30:133-140.
- Fleharty, E.D., J.R. Choate, and M.A. Mares. 1972. Fluctuations in population density of the hispid cotton rat: factors influencing a "crash." Bull. So. Calif. Acad. Sci., 71:132-138.

- Gaertner, R.A. 1968. Seasonal Variations in the Energy Budgets of the Harvest Mouse, Reithrodontomys fulvescens, and the cotton rat, Sigmodon hispidus. Unpublished Ph.D. dissertation, Univ. Arkansas, 149 pp.
- Geiger, R. 1950. The Climate Near the Ground. Harvard University Press, Cambridge, Mass., 286 pp.
- Genoways, H.H. and D.A. Schlitter. 1966. Northward dispersal of the hispid cotton rat in Nebraska and Missouri. Trans. Kans. Acad. Sci., 69:356-357.
- Getz, L.L. 1961. Factors influencing the local distribution of Microtus and Synaptomys in southern Michigan. Ecology, 42:110-120.
- Gill, J.L. and H.D. Hafs. 1971. Analysis of repeated measurements of animals. J. Anim. Sci., 33:331-336.
- Glaser, H. and S. Lustick. 1975. Energetics and nesting behavior of the northern white-footed mouse Peromyscus leucopus noveboracensis. Physiol. Zool., 48:105-113.
- Goertz, J.W. 1964. The influence of habitat quality upon density of cotton rat populations. Ecol. Monogr., 34:362-371.
- Golley, F.B. 1962. Mammals of Georgia. Univ. Georgia Press, Athens, xii +218 pp.
- Goodpaster, W.W. and D.F. Hoffmeister. 1952. Notes on the mammals of western Tennessee. J. Mamm., 33:362-371.
- Halloran, A.F. 1942. A surface nest and the young of Sigmodon in Texas. J. Mamm., 23:91.
- Hamilton, W.J., Jr. 1940. Life and habits of field mice. The Scientific Monthly, 50:425-434.
- Hammond, J., Jr. 1952. Control of reproductive and pelt changes in ferrets: Some experiments with animals kept entirely upon artificial light. J. Agr. Sci., 42:293-304.
- Hart, J.S. 1956. Seasonal changes in insulation of the fur. Can. J. Zool., 34:53-57.
- _____. 1964. Geography and season: Mammals and birds. In D.B. Dill, ed., Handbook of Physiology, Sect. IV, Adaptation to the Environment. Washington, D.C., Amer. Physiol. Soc., pp. 295-321.
- _____. 1971. Rodents. In G.C. Whittow, ed., Comparative Physiology of Thermoregulation, Vol. II: Mammals. Acad. Press, New York, pp. 1-149.

- Hart, J.S. and O. Heroux. 1953. A comparison of some seasonal and temperature induced changes in Peromyscus: Cold resistance, metabolism, and pelage insulation. *Can. J. Zool.*, 31:528-534.
- Hastings, C.E. 1956. Nest of the cotton rat. *J. Mamm.*, 38:416.
- Hayward, J.S. 1965. Microclimate temperature and its adaptive significance in six geographic races of Peromyscus. *Can. J. Zool.*, 43:341-350.
- Heroux, O., F. Depocas, and J.S. Hart. 1959. Comparison between seasonal and thermal acclimation in white rats. *Can. J. Biochem & Physiol.*, 37:473-478.
- Hibbard, C.W. 1960. An interpretation of Pliocene and Pleistocene climates in North America. 62nd Annual Report, Mich. Acad. Sci., Arts & Ltrs., 1959-1960, pp. 5-30.
- _____, C.E. Ray, D.E. Savage, D.W. Taylor and J.E. Guilday. 1965. Quarternary mammals of North America. The Quarternary of the United States, VII Congress Int. Ass. Quarternary Res., Princeton Univ. Press, 509-525 pp.
- Hill J.E. and C.W. Hibbard. 1943. Ecological differentiation between two harvest mice (Reithrodontomys) in western Kansas. *J. Mamm.*, 24:22-25.
- Hoffmann, R.S. and J.S. Jones, Jr. 1970. Influence of late-glacial and post-glacial events on the distribution of Recent mammals on the northern Great Plains. pp. 355-394. In W. Dort, Jr. and J.K. Jones, Jr., eds., *Pleistocene and Recent Environments of the Central Great Plains*. Sp. Publ. Dept. Geol., Kansas, 3:1-433.
- Hooper, E.T. 1949. Faunal relationships of recent North American rodents. *Univ. Mich., Misc. Pub. Mus. Zool.*, 72:1-28.
- _____, and M.E. Hilali. 1972. Temperature regulation and habits in two species of jerboa genus Jaculus. *J. Mamm.*, 53:574-593.
- Howard, W.E. 1951. Relation between low temperature and available food to survival of small rodents. *J. Mamm.*, 32:300-312.
- Inglis, J.M. 1955. Population Dynamics of the Cotton Rat (Genus Sigmodon). Unpublished MS thesis, Univ. Florida, 129 pp.
- Johnson, H.M. 1951. Preliminary ecological studies of microclimates inhabited by the smaller arctic and subarctic mammals. *Proc. Sec. Alaskan Sci. Conf.*, 2:125-131.
- Johnson, M.S. 1926. Activity and distribution of certain wild mice in relation to biotic communities. *J. Mamm.*, 7:245-277.
- Jones, J.K., Jr. 1964. Distribution and taxonomy of mammals of Nebraska. *Univ. Kans. Pub. Mus. Nat. Hist.*, 16:1-356.

- Kinder, E.F. 1927. A study of the nest building activity of the albino rat. *J. Exp. Zool.*, 47:117-161.
- King, J.A., D. Maas, and R.G. Weisman. 1964. Geographic variation in nest size among species of Peromyscus. *Evolution*, 18:231-234.
- Kirk, R.E. 1968. *Experimental Design: Procedures for the Behavioral Sciences*. Brooks/Cole Pub. Co., California, iii + 577 pp.
- Kirksey, E.R., J.F. Pagels and C.R. Blem. 1975. The role of the tail in temperature regulation of the cotton rat, Sigmodon hispidus. *Comp. Biochem. Physiol.*, 52A:707-711.
- Kirmiz, J.P. 1962. *Adaptation to Desert Environment: A study on the Jerboa, Rat and Man*. Butterworth, London, 168 pp.
- Layne, J.N. 1969. Nest-building behavior in three species of deer mice, Peromyscus. *Behaviour*, 35:288-303.
- _____. 1974. Ecology of small mammals in a flatwoods habitat in north-central Florida, with emphasis on the cotton rat (Sigmodon hispidus). *Amer. Mus. Novitates*, *Amer. Mus. Nat. Hist.*, No. 2544, 48 pp.
- Lee, C.T. and P.T.P. Wong. 1970. Temperature effect and strain differences in the nest-building behavior of inbred mice. *Psychon. Sci.*, 20:9-10.
- Lee, M.O. 1926. Determination of the surface area of the white rat with its application to the expression of metabolic results. *Amer. J. Phys.*, 89:24-33.
- Lewis, J.B. 1944. The cotton rat in lower Piedmont Virginia. *J. Mamm.*, 25:195.
- Lynch, C.B. 1973. Environmental modification of nest-building in the white-footed mouse, Peromyscus leucopus. *Anim. Behav.*, 22:405-409.
- MacMillen, R.E. and A.K. Lee. 1970. Energy metabolism and pulmocutaneous water loss of Australian hopping mice. *Comp. Biochem. Physiol.*, 35:355-369.
- McNab, B.K. 1966. The metabolism of fossorial rodents: A study of convergence. *Ecology*, 47:712-733.
- Meyer, B.J. and R.K. Meyer. 1944. Growth and reproduction of the cotton rat, Sigmodon hispidus hispidus, under laboratory conditions. *J. Mamm.*, 25:107-129.
- Morris, L. 1961. Photoperiodicity of seasonal rhythm of wool growth in sheep. *Nature*, 190:102-103.
- Muul, I. 1968. Behavioral and physiological influences on the distribution of the flying squirrel Glaucomys volans. *Misc. Pub. Mus. Zool. Univ. Mich.*, no. 134, 66 pp.

- Nicholson, A.J. 1941. The homes and social habits of the wood-mouse (Peromyscus leucopus noveboracensis) in southern Michigan. Amer. Midl. Nat., 25:196-223.
- Noirot, E. 1974. Nest-building by the virgin female mouse exposed to ultrasound from inaccessible pups. Anim. Behav., 22:410-420.
- Ostel, B. 1963. Statistics in Research. Iowa State Univ. Press, Ames, 585 pp.
- Panuska, J.A. and N.J. Wade. 1956. The burrow of Tamias striatus. J. Mamm., 37:23-31.
- Pearson, O.P. 1960. The oxygen consumption and bioenergetics of harvest mice. Physiol. Zool., 33:152-160.
- Pruitt, W.O., Jr. 1959. Microclimates and local distribution of small mammals on the George Reserve, Michigan. Misc. Pub. Mus. Zool., Univ. Mich., no. 109, 27 pp.
- Reinig, W.F. 1939. Besteht die Bergmannsche Regel zu Recht? Arch. Naturgesch., N.F., 8:70-88.
- Rensch, B. 1936. Studien uber klimatische Parallelitat der Merkmalsausprägung bei Vögeln und Säugern. Arch. Naturgesch., N.F., 5:317-363.
- Richter, C.P. 1937. Hypophyseal control of behavior. Symp. Quant. Biol., 5:258-269.
- Robinson, P.F. 1959. Metabolism of the gerbil, Meriones unguiculatus. Science, 130:502-503.
- Schendel, R.R. 1940. Life History Notes of Sigmodon hispidus texianus with special Emphasis on Populations and Nesting Habits. Unpublished MS thesis, Oklahoma State Univ., 40 pp.
- Schmidt-Nielsen, K., B. Schmidt-Nielsen and A. Brokaw. 1948. Water conservation in desert rodents. J. Cell. Comp. Physiol., 32:331-360.
- Scholander, P.F. 1955. Evolution of climatic adaptation in homeotherms. Evolution, 9:15-26.
- _____, V. Walters, R. Hock and L. Irving. 1950. Body insulation of some arctic and tropical mammals and birds. Biol. Bull., 99:225-236.
- Schwartz, C.W. and E.R. Schwartz. 1959. The Wild Mammals of Missouri. Univ. Missouri Press and Missouri Cons. Comm., Smith-Grievess Co., Kansas City, Mo., xvi + 341 pp.
- Sealand, J.A., Jr. 1952. The relationship of nest production and huddling to survival of Peromyscus at low temperatures. Ecology, 33:63-71.

- Shump, K.A., Jr. 1974. Nest construction by the western harvest mouse. *Trans. Kans. Acad. Sci.*, 77:87-93.
- _____ and A.U. Shump. 1975. The cotton rat. *Cen. Lab. Anim. Care, Mich. State Univ.*, no. 1, pp. 506
- Sokal R.R. and F.J. Rohlf. 1969. *Biometry*. W.H. Freeman and Co., 776 pp.
- Stark, H.E. 1963. Nesting habits of the California vole, Microtus californicus, and microclimatic factors affecting its nests. *Ecology*, 44:663-669.
- Stiemie, S. and J.A.J. Nel. 1973. Nest-building behavior in Aethomys chrysophilus, Praomys (Mastomys) natalensis, and Rhabdomys pumilio. *Zool. Afr.*, 8:91-100.
- Stoddard, H.L. 1931. *The Bobwhite Quail*. Charles Scribners, Sons, New York, 550 pp.
- Strecker, J.K. 1929. Notes on the Texas cotton and Attwater woodrats in Texas. *J. Mamm.*, 10:216-220.
- Summerlin, C.T. 1968. A Study of Social Behavior of the Cotton Rat, Sigmodon hispidus. Unpublished MS thesis, Univ. Alabama, 31 pp.
- _____ and J.L. Wolfe. 1973. Social influences on trap responses and activity of the cotton rat, Sigmodon hispidus. *Ecology*, 54: 1156-1159.
- Thomas, K.R. 1974. Burrow systems of the eastern chipmunk (Tamias striatus pipilans Lowery) in Louisiana. *J. Mamm.*, 55:454-459.
- Thomsen, H.P. 1945. The winter habits of the northern white-footed mouse. *J. Mamm.*, 26:138-143.
- Thorne, O. 1958. Shredding behavior of the white-footed mouse, Peromyscus maniculatus osgoodi, with special reference to nest building, temperature and light. *Thorne Ecol. Res. Sta., Bull. Ho. 6*, 75 pp.
- Vaughn, T.A. 1972. *Mammalogy*. W.B. Saunders, Co., Philadelphia, 463 pp.
- Vorhies, C.T. 1945. Water requirements of desert animals in the Southwest. *Arizona Agr. Exp. Sta., Tech. Bull.*, 107:487-525.
- Wolfe, J.L. 1970. Experiments on nest-building behaviour in Peromyscus (Rodentia: Cricetinae). *Anim. Behav.*, 18:613-615.

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