METEOROLOGICAL FACTORS CONTROLLING THE EMERGENCE OF THE EASTERN SPADEFOOT TOAD, *SCAPHIOPUS HOLBROOKI HOLBROOKII* HARLAN

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Chapter I

INTRODUCTION

Scaphiopus holbrooki holbrookii, the Eastern Spadefoot, can exist in an area for many years before it is detected. Its apparent scarcity can be explained by its secretive, fossorial habitat, protective coloration, and nocturnal behavior. Spadefoots are present at the surface locally in small numbers on any one night. They emerge only when conditions are optimum. One authority has suggested that temperature, moisture, and barometric pressure exert control over emergence.[1]

It was the purpose of this research to discover the most important meterorological parameters and investigate how they control the behavior of Scaphiopus.

Initially the response, emergence to breed was distinguished from emergence to feed. Breeding is controlled by temperature and initiated by rainfall.[2] Because of the close relation of the two emergence responses it is hereby hypothesized that moisture and temperature exert an active control over emergence to feed.

FOOTNOTES FOR CHAPTER I

[1]Arthur N. Bragg, Gnomes of the Night (Philadelphia: University of Pennsylvania Press, 1965), p. 40

[2]Kenneth L. Gosner and Irving H. Black, "The Effects of Temperature and Moisture on the Reproductive Cycle of Scaphiopus h. holbrooki," American Midland Naturalist, LIV, 1 (1955), 202.

Chapter II

LITERATURE REVIEW

Factors Effecting Emergence

The Eastern Spadefoot Toad was first described by Harlan in 1835.[1] Subsequently, its life history was outlined by Nichols (1852),[2] Abbott (1884)[3] Pike (1886),[4] Hargitt (1888).[5] These naturalists emphasized that reproductive behavior is initiated and controlled by rainfall.

Because of its nocturnal, fossorial habits the observation of the ecology of this animal has been limited to more recent literature. In 1905, Ditmars, commenting on the emergence of the Spadefoot Toad, explained that "at night or after heavy showers it ventures abroad for food, sometimes lingering in the vicinity of a rain-pool and uttering its plaintive cry."[6] Ditmars associates the activity above ground, both emergence for mating and emergence for feeding, with rainfall. Stone observed Scaphiopus holbrooki emerging from dry sand in New Jersey pine barrens.[7] Allen relates the following story and explains the importance of temperature:

> While encamped in the bottomlands of the Tchoutacahoueffa River about three miles north of Biloxi, Mississippi, during the latter half of the month of March and the first part of April, 1932, I noticed that every night the spade-foots came forth, temperature permitting.[8]

Campbell tells of his encounter with *Scaphiopus hammondii* in Arizona:

> I was hunting owls with the aid of a flashlight when I ran across a spadefoot hopping around in a small clearing in a scrub-oak forest. That was August 31, 1931, at 9:00 P.M. The ground thereabouts was fairly sandy, and, as the rainy season was well along, not very dry. No burrows could be found in the immediate vicinity. September 4, at night, I collected another of the same species in a sandy washbottom a half-mile or so from the place where the first was taken. Both were adults.[9]

Smith noticed an increased number of spadefoots on nights attended by light precipitation. He explained:

> It is probable that after breeding they scatter widely, and since they do not sing, when they do emerge merely for food, it is seldom that they are found. How frequently they do come out at night is not known, but the writer has observed adults at night in the sand dunes near Medora, Kansas, hopping about in considerable numbers in light showers. The evening following this particular one was clear and only a single specimen, an adult, was secured.[10]

While studying the breeding behavior of *Scaphiopus holbrooki*, Ball maintained a number of individuals in a pen. He made the following observations:

> In the out-of-door pen as well, moisture strongly affected the toads. More of them emerged during rainy or humid weather, and their burrows were then shallower. Situated at the foot of a slope near boggy ground, the soil of the pen never became dry. After moderately heavy rain, one or more toads occasionally remained above ground next day if cloudiness prevailed, taking advantage of shade afforded by vegetation and the framework of the pen.[11]

Ball concluded that, "high temperature favored emergence of *Scaphiopus*. When conditions of extreme heat and humidity were combined, . . . the animals were most active."[12]

In the Handbook of Amphibians and Reptiles of Kansas, Hobart Smith, writing of Scaphiopus bombifrons, states that, "individuals emerge when moisture is abundant and the temperature high; the surface of the ground, as well as the ground below the surface, must be damp."[13] Thus, S. bombifrons emerges when moisture and temperature are at the proper levels.

Burger suggests that humidity is an important effector of emergence of Scaphiopus holbrooki. He found that in Virginia, "on warm humid nights, averaging about one night in ten, spadefoots sally forth from their burrows in search of food."[14] Scaphiopus hammondi exhibits digging reactions in response to evaporation and is sensitive to a humidity change of 10% at a temperature of 27°C.[15] Because of the moist skin of amphibia, heat is lost to the environment by evaporation. The heat lost, under certain conditions, may be greater than the heat produced by the animal.

> . . . in Rana esculenta at 3°C. the cooling by evaporation would lower the body temperature to only half a degree above freezing; while at 30°C. the body temperature dropped to 25.4°C. In dry air, frogs are always colder than their environment, while in high humidities they are warmer than their surroundings.[16]

Comparing the number of toads active in moist air to the number active in dry air, Pearson states that "it appears that nights of activity were associated with nights of high air moisture."[17]

Green in a study of the nocturnal behavior of Scaphiopus holbrooki, discovered a temperature boundary below which emergence will not take place. He explains:

> The period of greatest activity was between the hours of 9 and 11 P.M. As the temperature fell close to the 50°F. mark the number of toads observed decreased until it was impossible to find one when the temperature fell below 50°F. Males and females could frequently be seen with just their heads exposed at the mouth of the burrow.[18]

Pearson established that more spadefoots, Scaphiopus holbrooki, were likely to be active when the daily maximum-minimum temperature was within a 50° to 90°F. temperature range.[19]

Spadefoot toads, once they are at the surface, must face constant danger of desiccation. "This danger," according to Bragg, "depends on intensity of local rainfall, evaporation rate, temperature, and wind, . . ."[20] Bragg describes the spring emergence in three steps:

(1) approach to the surface,
(2) breaking of the soil,
(3) final emergence.[21]

The spadefoot comes to the surface presumably in response to low oxygen level. With warming of the soil, metabolic processes increase causing an increase in oxygen consumption. The final emergence, according to Bragg, depends on conditions of moisture and temperature and, perhaps, barometric pressure.[22]

In the book, Gnomes of the Night, Bragg recounts instances of emergence coincident with rainfall. He explains:

> . . . after warm rains one finds considerable more animals active in nature than when there has been no rain, even when covering a smaller territory

> in a shorter time. This could not be consistently true if there were not more spadefoots above ground to be found.[23]

The above observation may not apply unconditionally to all spadefoots, for Bragg intimates that "those in the Spea group (*hammondi*, *bombifrons*, and *intermontanus* at least) emerge more frequently than those of the other group (*holbrooki* and *hurteri*), . . ."[24]

In Pearson's aforementioned paper, "Population Ecology of the Spadefoot Toad," he writes the following:

> A direct correlation was indicated between activity rate and amount of daily rainfall. . . . A significant positive correlation coefficient of 0.31 existed for plot 1 data (t.=3.2,P. 0.01), and of 0.37 for those from plot 2 (t.=3.2,P. 0.01). It is concluded that on days of recorded rainfall and activity, the greater the amount of rainfall the higher the activity rate.[25]

Variation in Emergence Responses Due to a Size Differentia

Many of the naturalists who have observed the nocturnal activity of *Scaphiopus* have noted that the number of adults above ground varied more through the night and on different nights than the number of juveniles. The young toads were more tolerant to extremes of the eco-climate conditions. Kellogg relates the following concerning *Scaphiopus hammondii*:

> In suitable sandy areas, this nocturnal spadefoot comes out of its burrow during the summer months after it gets too dark for one to see objects without the aid of a flash light. Along the Powder River near Powderville in Montana, on June 15, 1916, while lying upon my cot, I heard a curious rustling in the dry leaves about our tent. Upon investigation with a

> flash light many small spadefoot toads were found. They scattered about on the sandy soil.[26]

While collecting Scaphiopus in April, 1932, Allen noticed that:

> All specimens seen or taken did not exceed the length of 25 or 30 mm., excepting one, a full grown individual, observed on a night attended by a light precipitation. At this time the immature specimens were noticed to be more abundant.[27]

In their study of Scaphiopus bombifrons, Trowbridge and Trowbridge were unable to observe adults in nature except at time of breeding.[28]

The adult Eastern Spadefoot on a given night, according to Green, does not remain above ground as long as the juveniles. "The larger individuals," he comments, "become less common as the evening progresses and the temperature drops."[29]

Another anuran, the Pacific Tree Frog, in the adult stage exhibits nocturnal activity; however, the juveniles are diurnal. The young, with a size range of 9 to 11 mm., tolerate higher environmental temperatures than the adults. Cunningham and Mullally conclude the following:

> Whereas the adults have relatively low eccritic temperatures, the young are active at thermal levels close to those at which tadpoles have been found. It is interesting to note that the relatively more thermophilic tadpoles and recently metamorphosed hylas voluntarily tolerate body temperatures within a few degrees of their upper lethal. . . . The function of these near-critical body temperatures seems to be endurance of high environmental temperatures and thermally increased physiological efficiency.[30]

Recently metamorphosed Hurter's Spadefoots show diurnal activity similar to the Pacific Tree Frog. Bragg writes the following:

> . . . if the conditions of temperature are not too severe and, especially if the whole ground is moist, young juveniles of Hurter's Spadefoot may be out feeding during the daytime.[31]

Hutchison demonstrates the relationship between body size and oxygen consumption for lunged salamanders to be: $M=1.1W^{0.856}$, where M is the rate of metabolism expressed in cm^3 O_2 and W is the weight in grams. From his data the graph, figure 1, was constructed. It can be shown that an increment increase in weight is not accompanied by an equal increase in O_2 consumption. Thus a large animal carries on a lower metabolism per unit of weight.[32] In a more recent paper Hutchison derived the following regression equations:

(1) the regression of metabolism, M, in cc of O_2/hr on body size, W, in grams, $M\text{-}KW^{0.71}$;

(2) the regression of surface area, SA, in cm^2 on body size, W, in grams, $SA=13.52W^{0.58}$;

(3) the regression of tidal volume, V_T, in cm^2, on body size, W, in grams, $V_T=2.63W^{0.73}$.*

Hutchison also found there is an inverse relation between body size and ventilatory rate.[33] Consequently, for any significant increase in weight, and for the larger animal, the following relationships hold:

(1) the metabolism is less per unit weight,
(2) the surface area is less per unit weight,

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*As the exponent of the "x" variable approaches zero, the dependency of the "y" variable decreases. Conversely, when the exponent of the "x" variable is 1, an increase in the "x" variable causes a proportional increase in the "y" variable.

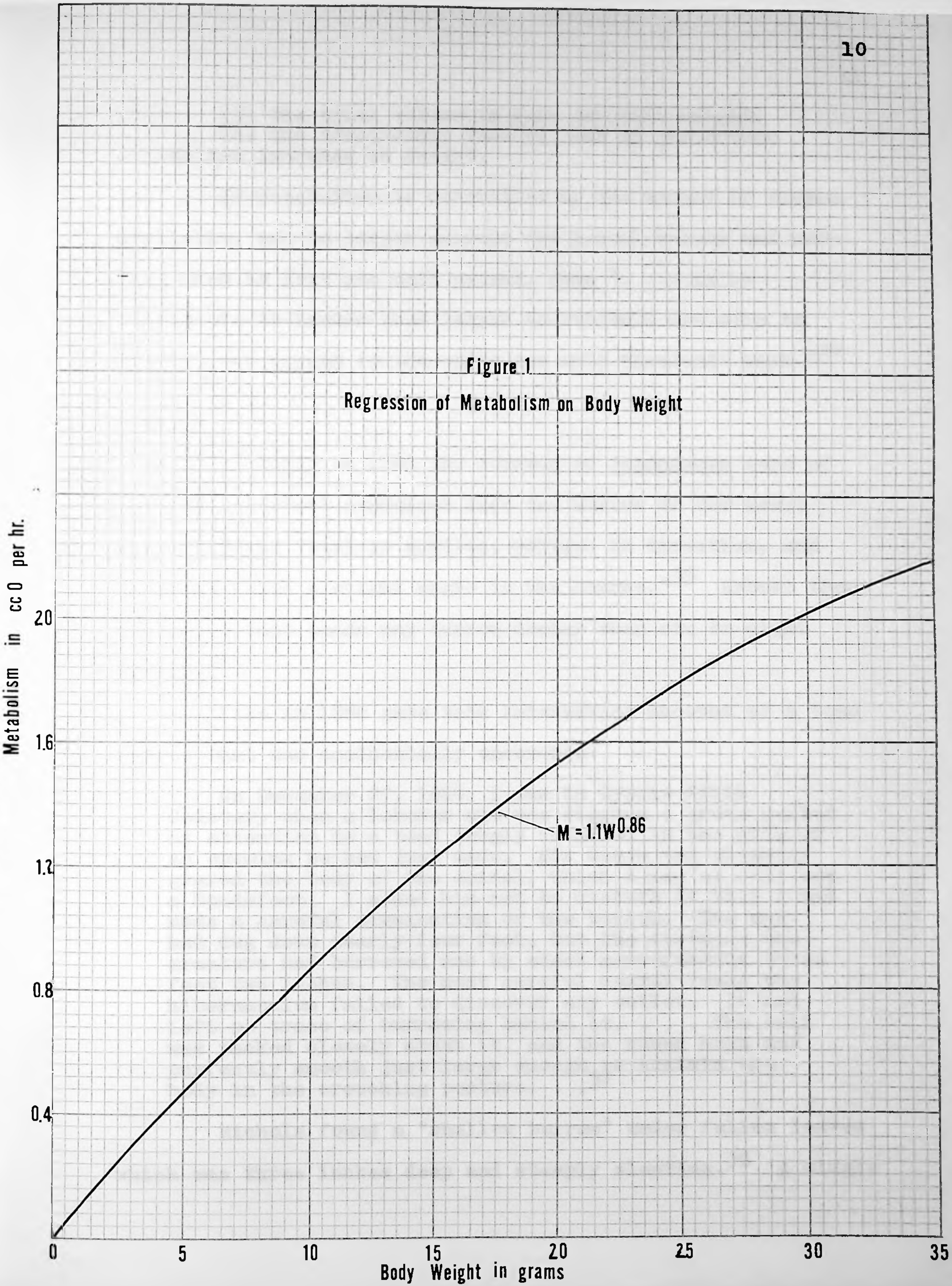

Figure 1
Regression of Metabolism on Body Weight

(3) the tidal volume is less per unit weight,
(4) the ventilatory rate is less in proportion to the increase in weight.

If metabolism is controlled by the amount of oxygen available, and in larger anurans the buucal volume and surface area is less per unit weight, then ". . . it is reasonable to assume that larger individuals are able to supply less oxygen to the cells per unit time/unit work."[34]

Burrows

As early as 1884 the burrows of Scaphiopus were of interest. Abbott explained that the burrow of the adult spadefoot was "oval in outline, oblique in direction, and generally with a slight angle in the course."[35] Abbott then suggested that toads may burrow deeper than six to eight inches.[36]

Pike in 1886 gave this interesting account of a toad burrow that was accidentally uncovered:

> On December 27, 1884, I was in Cypris Hills Cemetery when a laborer who was digging a grave called my attention to a toad snugly imbedded in the side of an opening he had just made. His spade had slightly grazed the body of the animal, which I saw at once was a Spadefoot. I asked him not to disturb it till I had made a careful examination of the burrow. The man had dug down nearly four feet, but the distance the creature had burrowed was by exact measurements three feet two inches. The most careful search round the hibernaculum failed to discover any outlet. It had left no trace of burrowing behind it, . . . The soil was packed closely about it, and the round hole was perfectly smooth just large enough to contain the body in the crouching posture. . .[37]

Nichols found a "shallow burrow" under fallen leaves which was three inches deep and steeply slanting.[38] A single male specimen of Scaphiopus holbrooki was found in Miami in sandy soil at a depth of six inches.[39] Wright relates that in November, a spadefoot was discovered a foot below the surface. The burrow was covered with decayed leaves.[40]

Ball found spadefoots in midsummer resting at depths as great as 2.1 meters below the soil surface. He measured the wintering depth of Scaphiopus holbrooki, in an experimental pen, to be at least 60 cm.[41]

The shape of the spadefoot's burrow is not a result of an innate behavioral pattern, but is the consequence of an active negative photo-taxis and the soil characteristics. Ball explains:

> . . . Whenever one burrowed, it left no opening intentionally. Sometimes, when the soil was sufficiently moist, the earth would not entirely fall in upon the toad, thus leaving a rimmed depression at the point of entrance, but the animal always burrowed deeply enough to allow the crumbling earth to shut out all light.

The passage continues with an explanation of the method by which toads burrow.

> In burrowing, the fore-limbs thrust against the earth above, thus forcing the toad downward and backward through the soil loosened by the hind-feet. In soft earth the animal tunnels almost vertically downward in an irregularly spiral course, but ultimately comes to rest in a horizontal position with head down between the fore-limbs.[42]

Linsdale noticed Scaphiopus hammondii in shallow burrows which extended downward 45° from the horizontal.[43] This same species, S. hammondii, has been found to burrow under rocks.

> In order to get under the rock, the spadefoot toad burrows horizontally through the sand, forming a pocket. The animal then closes the opening to this pocket by pushing sand into it. This action conserves moisture and hides the entrance.[44]

In Florida, Duellman and Schwartz measured a single burrow to be one and a half inches in diameter and eight inches in depth.[45]

In different geographic areas, and under dissimilar eco-climate conditions, Scaphiopus has been found to burrow to practically any depth. It is Bragg's contention that the burrow level depends on soil moisture. The depth of the burrow is inversely proportional to the soil moisture.

> . . . Captive spadefoots which I have studied have been found just below the surface of the earth when it was moist but as far down as they could go (two or three feet in some cases) as the soil became drier and I know of one case wherein a spadefoot was discovered 15 feet below the surface under natural conditions.[46]

Bragg iterates that spring emergence from the burrow is controlled by ground temperature and moisture. Further, it is necessary that the proper temperature level and the proper moisture level be coincident.[47]

Mullally and Cunningham's paper on "Aspects of the Thermal Ecology of the Yosemite Toad," Bufo canorus propounds four important elements of the thermal ecology of anurans. The following two elements apply to a fossorial habitat: (1) soil is a very poor conductor of heat, and insolation of soil surface causes a moderate rise in temperature only for the upper few inches;[48] (2) toads which inhabit burrows maintain lower body temperature and derive necessary moisture from soil.[49] The last two elements apply to terrestrial habitation; they are: (3) normally, evaporative cooling holds the body temperature a few degrees lower than the surroundings; (4) animals which remain sufficiently long on a substrate surface establish a thermal balance and equilibrate with the temperature of the substrate.[50]

The burrow of Scaphiopus is in a subterranean atmosphere composed of two zones. The upper six inches is similar to the atmosphere proper and fluctuates seasonally and daily; however, the oxygen content may be less.[51] Below 6 inches (15.24 c.m.), gasses are dissolved in a surface film of water and colloids on the soil particles. This is essentially an anaerobic condition with little oxygen present.[52]

The soil around the burrow is always at saturation with the relative humidity of 100% whenever the moisture content is above the maximum hygroscopicity.*[53] For example, in sand with a maximum hygroscopicity of 0.41%, the relative humidity is 100% until at 0.32% moisture content, it falls to 69% (see chart of figure 2).[54]

The temperature at soil surface varies more than the air above or soil below. The depth of heat penetration depends on insolation, atmospheric conditions, and soil type.[55] The graph of figure 3 indicates variations in daily

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*The hygroscopic content is the water absorbed on the surface of the soil particles.[56]

temperature range at various depths for the month of July, 1922, in arid soil of Tucson, Arizona. Notice that at increasing depths the diurnal temperature range decreases more per unit depth.

Figure 2

*

Relation Between Moisture Content and Relative Humidity of the Soil Air in Sand[57]

Max hygroscopicity, 0.41%

Moisture content, per cent	Relative humidity of the soil air, per cent
8.5	100
5.79	100
2.21	100
1.34	100
0.62	100
0.32	69

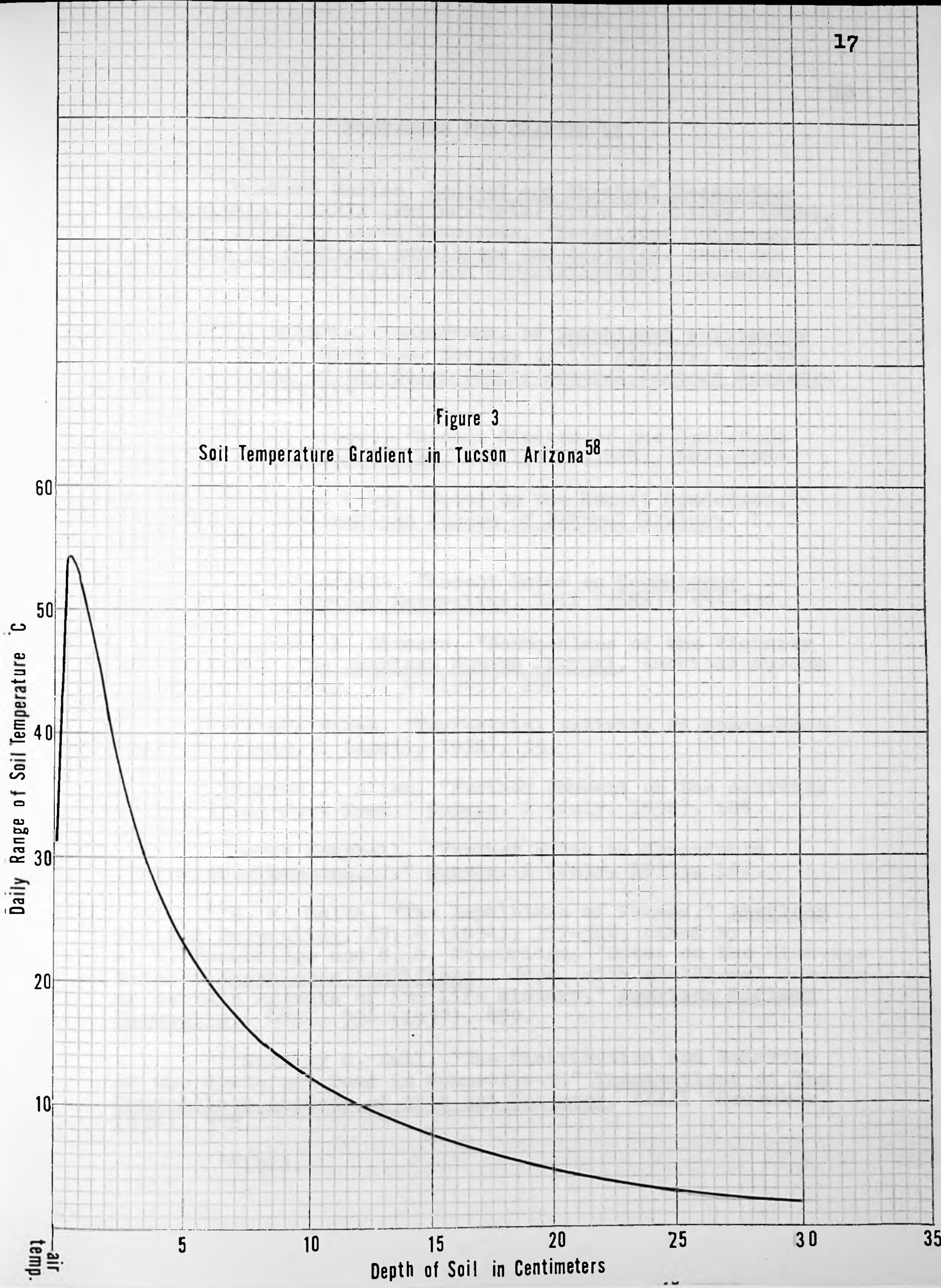
Figure 3
Soil Temperature Gradient in Tucson Arizona[58]
Daily Range of Soil Temperature °C
60
50
40
30
20
10
air temp.
5
10
15
20
25
30
35
Depth of Soil in Centimeters

FOOTNOTES FOR CHAPTER II

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[5]C. W. Hargitt, "Recent Notes on Scaphiopus holbrookii," American Naturalist, XXII (1888), 535-537.

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[20]Arthur N. Bragg, Gnomes of the Night (Philadelphia: University of Pennsylvania Press, 1965), p. 39.

[21]Ibid., p. 40.

[22]Ibid., p. 41.

[23]Ibid., p. 42.

[24]Ibid.

[25]Paul G. Pearson, "Population Ecology of the Spadefoot Toad," Ecological Monographs, XXV, 3 (1955), 240.

[26]Remington Kellogg, "Notes on the Spadefoot of the Western Plains (Scaphiopus hammondii)," Copeia, 1 (April, 1932), 36.

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[46]Arthur N. Bragg, Gnomes of the Night (Philadelphia: University of Pennsylvania Press, 1965), p. 34.

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[49]Ibid., p. 62.

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[51]Royal N. Chapman, Animal Ecology (New York: McGraw-Hill Book Co., Inc., 1931), p. 365.

[52]Ibid., p. 366.

[53]Ibid., p. 366.

[54]Ibid., p. 365.

[55]W. C. Allee and others, Principles of Animal Ecology (Philadelphia: W. V. Saunders Co., 1949), p. 220.

[56]Chapman, op. cit., p. 364.

[57]Chapman, op. cit., p. 365.

[58]Allee, op. cit., p. 219.

Chapter III

MATERIALS AND METHODS

The animals in this study were from one population with possibly three colonies. Here in 1939, Green discovered <u>Scaphiopus holbrooki</u> for the first time in West Virginia.[1] The colonies are in Ceredo, West Virginia, located on either side of the Chesapeake and Ohio main line. Green describes the colony as follows:

> In the twenty-five years which this area has been under observation the Spadefoots have utilized at least three distinct regions, each more or less inaccessible to the other. The Ceredo population since 1939 indicates that it has maintained a status quo in numbers despite alterations of the environment such as the construction of a drive-in theater and a baseball diamond.[2]

Individuals were located at night by their red eye shine as they emerged from the cinders in the bed of the railroad. As the map of figure 4 shows, there are four possible mating ponds. The westernmost pond usually contains water except during the dry seasons. The others are only temporary and are formed after heavy rains. This population is exposed to a great deal of antagonism by man. Trains run over the burrows weekly, herbicide is sprayed on the railroad bed in the summer, and when toads are mating children throw a barrage of sticks and rocks.

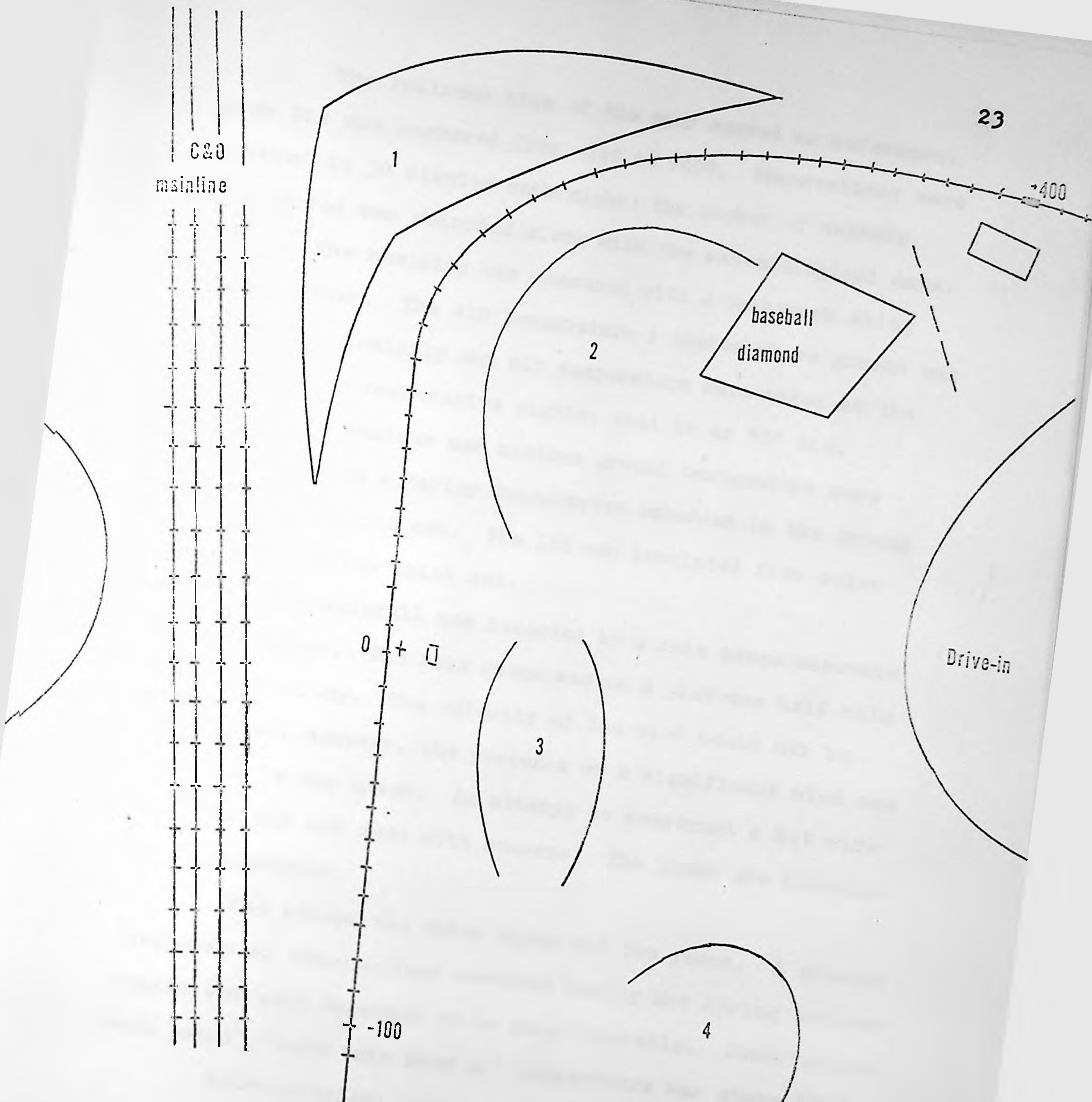


Figure 4
Breeding Sites——Ceredo, W. Va.

The railroad ties of the spur served as reference; each tie was numbered from -100 to +400. Observations were limited to 30 minutes each night; the number of animals discovered was recorded along with the meteorological data.

The humidity was measured with a Bacharach sling psychrometer. The air temperature 2 inches above ground was recorded. Humidity and air temperature were taken at the same spot on consecutive nights, that is at "0" tie.

The maximum and minimum ground temperature were recorded using a Taylor thermometer embedded in the ground 6 inches in a tin can. The lid was insulated from solar rays by a 2 inch thick sod.

The rainfall was recorded by a rain gauge accurate to 0.1 inches. The rain gauge was on a plot one half mile from the colony. The velocity of the wind could not be determined; however, the presence of a significant wind was recorded in the notes. An attempt to construct a hot wire anometer did not meet with success. The plans are included in the appendix.

The colony was under study for two years. A greater frequency of observations occurred during the spring because conditions were expected to be more favorable. Observations were usually made only when air temperature was above 45°F.

Meteorological data from 44 single observations is presented in Table 1. U.S. Weather Bureau reports from the local airport provided rainfall, wind, maximum and minimum air temperature, change in barometric pressure, and dew point. Weather Bureau data for humidity was substituted wherever field measurements were missing. This occurs in observations 1, 2, 3, 18, and 26. The amount of rainfall measured in the rain gauge in the field was recorded in red along with the rainfall reported by the Weather Bureau.

In the earlier observations the distance from the tip of snout to the end of the urostyle was measured with calipers; the average of three measurements was recorded as the length. Later the individuals were weighed with an Ohaus 250 gram spring balance. Each toad captured was marked by toe clipping. The toes were marked consecutively with the most proximal toe designated as number one. The point of capture was indicated by recording the tie number.

Breeding was observed on two days, May 25 and May 26, 1968, at which time mated pairs were marked. The data from these observations is given in Table 2.

Table 1

METEOROLOGICAL DATA FROM FIELD NOTES

Date		Air Temp. °C	Hum. %	Gnd. Temp. Max °F	Gnd. Temp. Min °F	Rain-Fall inches	No. Toads
3 April 67	1	9.5	51	-	-	0.33	0
5 April 67	2	13.9	84	-	-	0.08	0
10 April 67	3	11.1	86	-	-	0.87	0
13 April 67	4	13.5	95	-	-	0.22	0
14 April 67	5	22.0	35	66	55	0.00	0
16 April 67	6	17.0	76	68	56	0.00	3
17 April 67	7	20.0	41	65	59	0.98	0
19 April 67	8	13.5	66	67	50	0.00	0
20 April 67	9	15.5	96	60	57	0.35	5
21 April 67	10	14.5	43	67	57	0.40	0
22 April 67	11	11.5	90	68	52	0.10	2
26 April 67	12	8.5	95	67	48	0.34	0
29 April 67	13	11.0	78	68	46	0.00	1
1 May 67	14	21.3	71	64	55	0.20	0
3 May 67	15	6.0	92	66	50	0.00	0
5 May 67	16	16.0	85	68	52	0.00	2
7 May 67	17	9.5	85	61	58	2.31	8*
8 May 67	18	10.6	88	62	51	0.22	17
15 May 67	19	9.9	89	67	50	0.55	0
18 May 67	20	12.0	98	73	53	0.00	2
19 May 67	21	15.8	96	70	62	0.06	2
24 May 67	22	13.0	98	68	55	0.00	10
12 June 67	23	20.0	87	80	59	0.00	1
13 June 67	24	21.8	85	78	67	0.00	3
23 June 67	25	20.5	87	82	70	0.00	0
3 July 67	26	15.4	90	79	64	0.00	1
7 July 67	27	21.0	86	74	64	0.04	0
10 July 67	28	23.0	88	81	67	1.30	4
23 July 67	29	21.0	94	87	61	0.96	0
5 August 67	30	20.5	90	86	67	0.50	1
8 August 67	31	23.0	66	-	-	0.00	0
21 August 67	32	17.8	82	-	-	0.00	0
30 March 68	33	14.2	72	-	-	0.00	0
31 March 68	34	16.0	100	-	-	0.62	1
19 April 68	35	15.5	55	-	-	0.00	0

*Males were observed calling on this night.

Table 1 (continued)

Date		Air Temp. °C	Hum. %	Gnd. Temp. Max °F	Gnd. Temp. Min °F	Rain-Fall inches	No. Toads
27 April 68	36	17.2	100	--	--	0.05	2
25 May 68	37	17.0	87	--	--	1.37	43*
26 May 68	38	23.5	--	--	--	0.65	8**
10 Sept. 68	39	16.5	63	--	--	0.14	1
14 Sept. 68	40	16.0	90	--	--	0.00	0
18 Sept. 68	41	16.8	95	--	--	0.25	0
22 Sept. 68	42	18.5	95	--	--	0.00	0
23 Sept. 68	43	19.5	90	--	--	0.00	0
17 Oct. 68	44	19.3	81	--	--	0.00	2

*Mating occurred on May 25, 1968.

**Mating occurred on May 26, 1968.

Table 2

DATA FROM MARKED SPADEFOOTS

Date	Initial Captures		Recoveries	
	Toes Marked	Size cm.	Toes Marked	Size
29 April 67	L1	4.5		
5 May 67	L2	5.5		
	L3	6.5		
7 May 67	L4	-		
	L5	5.3		
	R1	4.9		
	R2	--		
	R3	4.5		
	R4	6.0		
	L1R1	5.6		
	L2R2	5.5		
8 May 67	L1R2	5.8	L1	4.6
	L1R3	6.4		
	L1R4	5.0		
	L1R5	5.0		
	L2R3	4.0		
	L2R4	5.4		
	L2R5	5.6		
	L3R1	-		
	L3R2	5.0		
	L3R3	5.1		
	L3R4	6.5		
	L3R5	5.7		
	L4R1	6.0		
	L4R2	5.0		
	L4R3	-		
	L4R4	4.4		
18 May 67	L12R1	5.0		
	L12R2	5.0		
19 May 67	L12R3	5.2	L4	5.5
24 May 67	L12R4	5.4	L4R3	6.0
	L12R5	6.3		
	L13R1	4.6		
	L13R2	4.4		
	L13R3	4.5		
	L13R4	4.2		
	L134R5	5.0		
	L123R1	4.6		
	L123R2	4.7		

Table 2 (continued)

Date	Initial Captures			Recoveries		
	Toes Marked	Size cm.	Tie No.	Toes Marked	Size cm.	Tie No.
12 June 67	L13R5	-	-			
13 June 67	L14R1	-	-			
	L14R2	-	-			
	L14R3	-	-			
7 July 67	L134R5	5.7	-	L1R4	-	38
	L14R4	4.2	217			
	L14R5	4.7	114			
10 July 67	L1R12	4.5	298			
	L2R12	5.2	228			
	L3R12	4.9	156			
	L4R12	4.5	95			
	L5R12	6.3	59			
	L1R13	5.3	4			
	L2R13	5.5	96			
	L3R13	5.0	271			
22 July 67	L4R13	5.7	178			
	L5R13	5.9	253			
	L1R14	4.4	345			
	L2R14	-	142			
	L3R14	-	97			
5 August 67...	-	-	-	L1R13	4.9	5

Table 2 (continued)

SPADEFOOTS MARKED DURING BREEDING CHORUS*

Toads in Amplexus		Solitary Toads	
Male	Female	Male	Female
L5R14	L4R14	L123R3	L5R15
L1R15	L2R15	L23R1	L124R1
L4R15	L3R15	L23R2	L124R5
L123R4	L123R5	L23R3	L23R5
L124R2	L124R3	L23R4	
L124R4	L1234R1	L24R1	
L1234R3	L1234R2	L34R1	
L1234R4	L1234R5	L34R2	
L24R2	L24R3	L34R3	
L24R4	L24R5	L34R4	
L1R123	L2R123	L34R5	
L3R123	L4R123		
L5R123	L1R124		
L2R124	L3R124		
L5R124	L1R1234		

*Breeding chorus occurred on May 25, 1968, when air temperature was 21.4°C., humidity was 85%, and water temperature was 12.8°C.

FOOTNOTES FOR CHAPTER III

[1] N. Bayard Green and Neil D. Richmond, "Two Amphibians New to the Herpetofauna of West Virginia," Copeia, 2 (July 28, 1940), 127.

[2] N. Bayard Green, "The Eastern Spadefoot Toad, *Scaphiopus holbrooki holbrooki* Harlan, in West Virginia," *Proceedings of the West Virginia Academy of Science*, XXXV (1963), 16.

Chapter IV

EXPERIMENTAL RESULTS

Bivariable Regression Analysis

Each of seven variables was analyzed separately to determine its correlation with the number of emerged toads per night.

Barometric pressure change was found to have an insignificant correlation, r=-0.19, with the number of emerged toads. Therefore it was not considered in the multiple regression analysis.

The wind velocity showed a low correlation with emergence, r=0.14. It must be noted that in the data sheet the wind speed was recorded at an arbitrary time in a weather station some distance away and therefore is not a good indication of the wind velocity in the field.

The minimum ground temperature with r=-0.10, the maximum ground temperature with r=-0.26, and the average ground temperature with r=-0.20 do not seem to be significantly correlated with emergence. It was assumed, however, that ground temperature would affect the toads in their burrows and maximum and minimum ground temperature values were used in multiple regression analysis.

The graph of air temperature versus emergence, figure 5, shows no specific relationship. The negative correlation coefficient, $r=-0.16$, and the regression equation, $y=-0.11x + 3.40$, do not display the complete picture of the relative variation between the two variables. No toads appeared when the temperature was 10°C. or below. This is the limiting temperature for emergence and is graphically represented by an asymptote at 10°C.

Humidity is correlated to emergence by a factor of $r=0.25$. The linear regression equation of emergence on relative humidity is $y=0.04x - 2.24$ (see figure 6). Solving for the x intercept, that is when the number of toads is zero, we find it to be 56%. When the humidity is 56% or lower, no toads would emerge irrespective of the other factors.

There is a positive correlation of emergence and rainfall, $r=0.50$. This relation is expressed by the regression equation, $y= 2.81x + 0.75$. Solving for x when y equals zero, we get 0.27 inches. One would not expect to see any toads unless the rainfall was above this value (see figure 7).

Multivariable Regression Analysis

Regression analysis utilizing an IBM 620 computer was conducted for seven variables represented as follows: x_1=rainfall, x_2=humidity, x_3=air temperature, x_4=wind, x_5=maximum ground temperature, x_6=minimum ground temperature, and x_7=number of toads per thirty minutes. The information

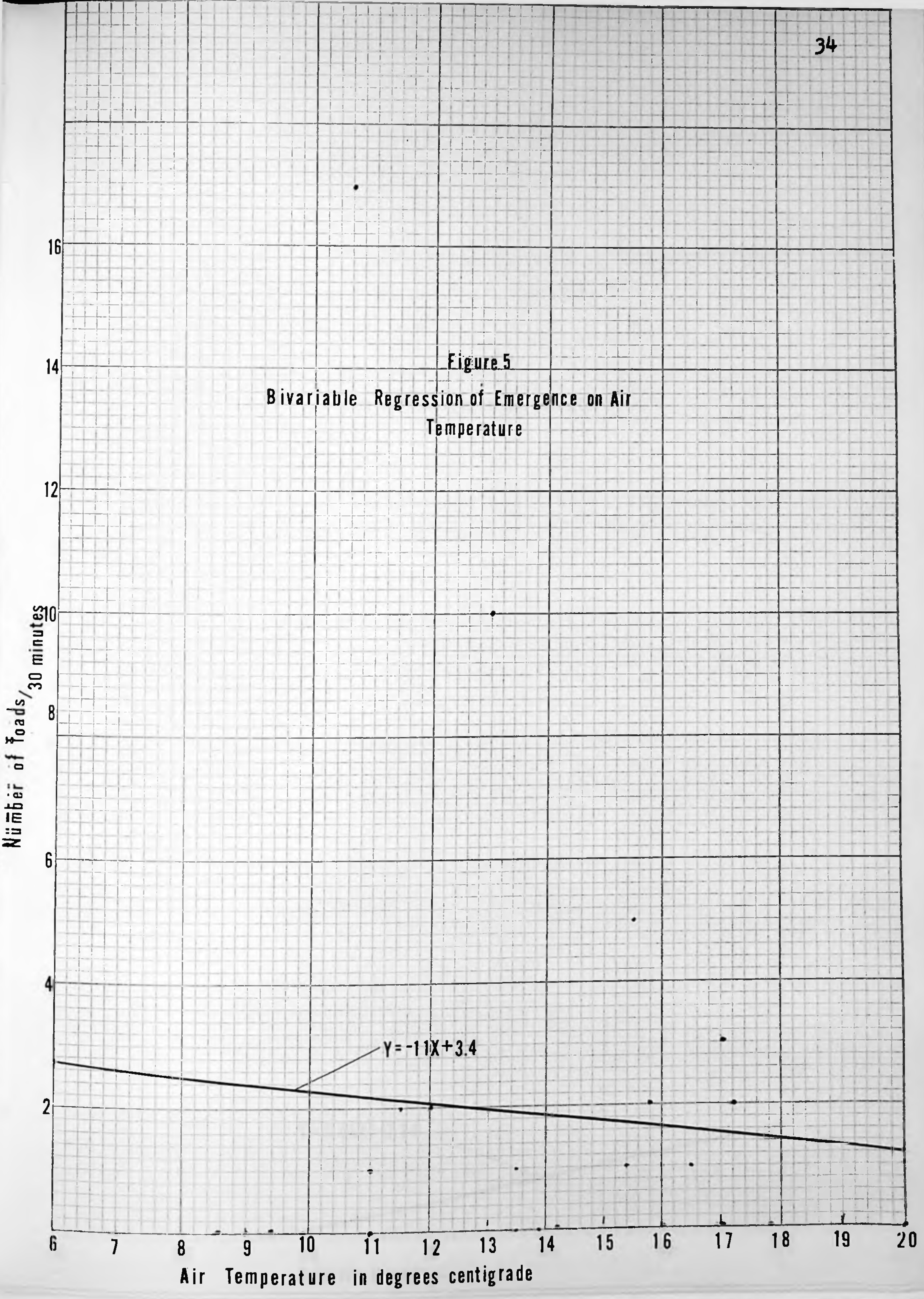


Figure 5

Bivariable Regression of Emergence on Air Temperature

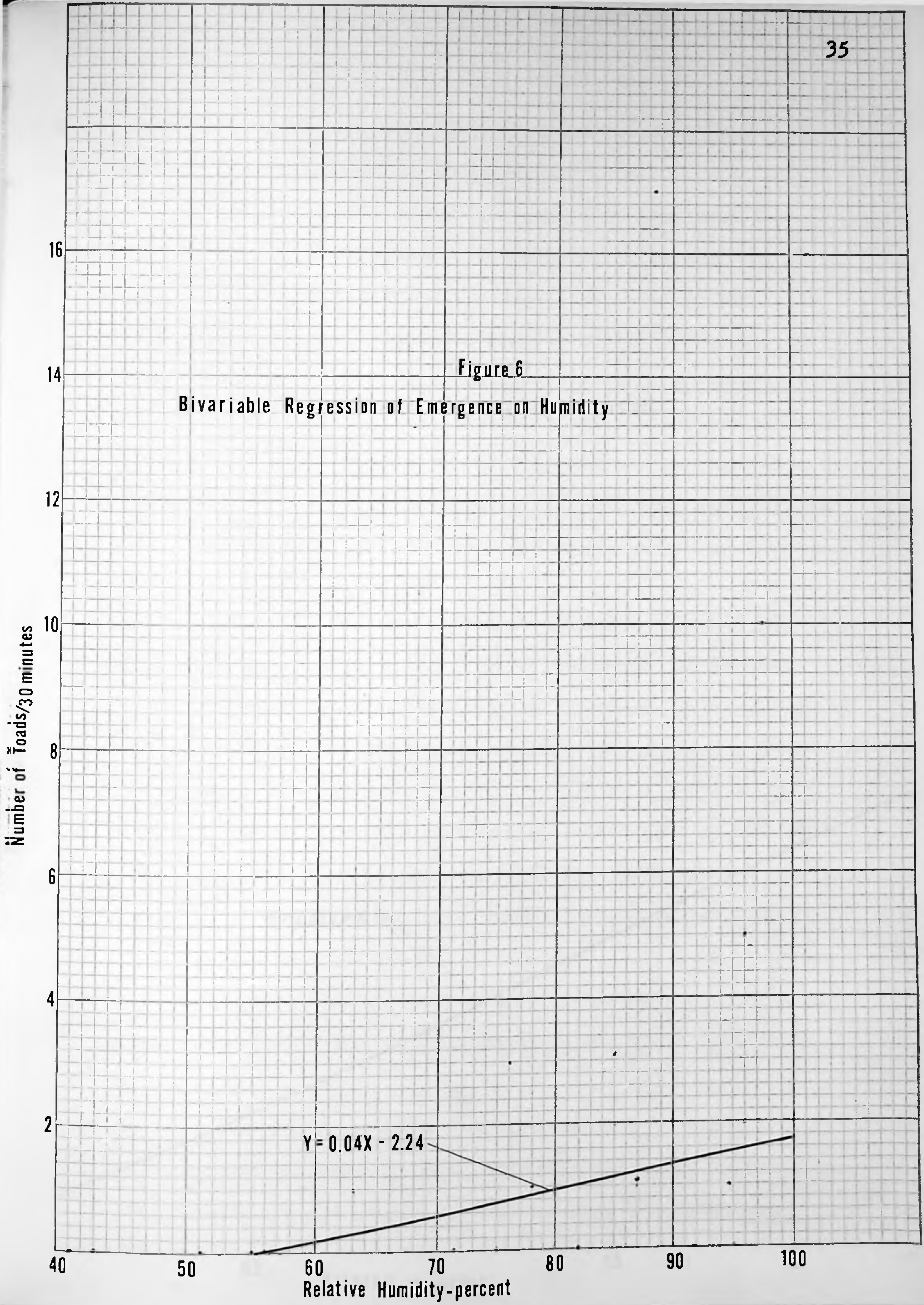
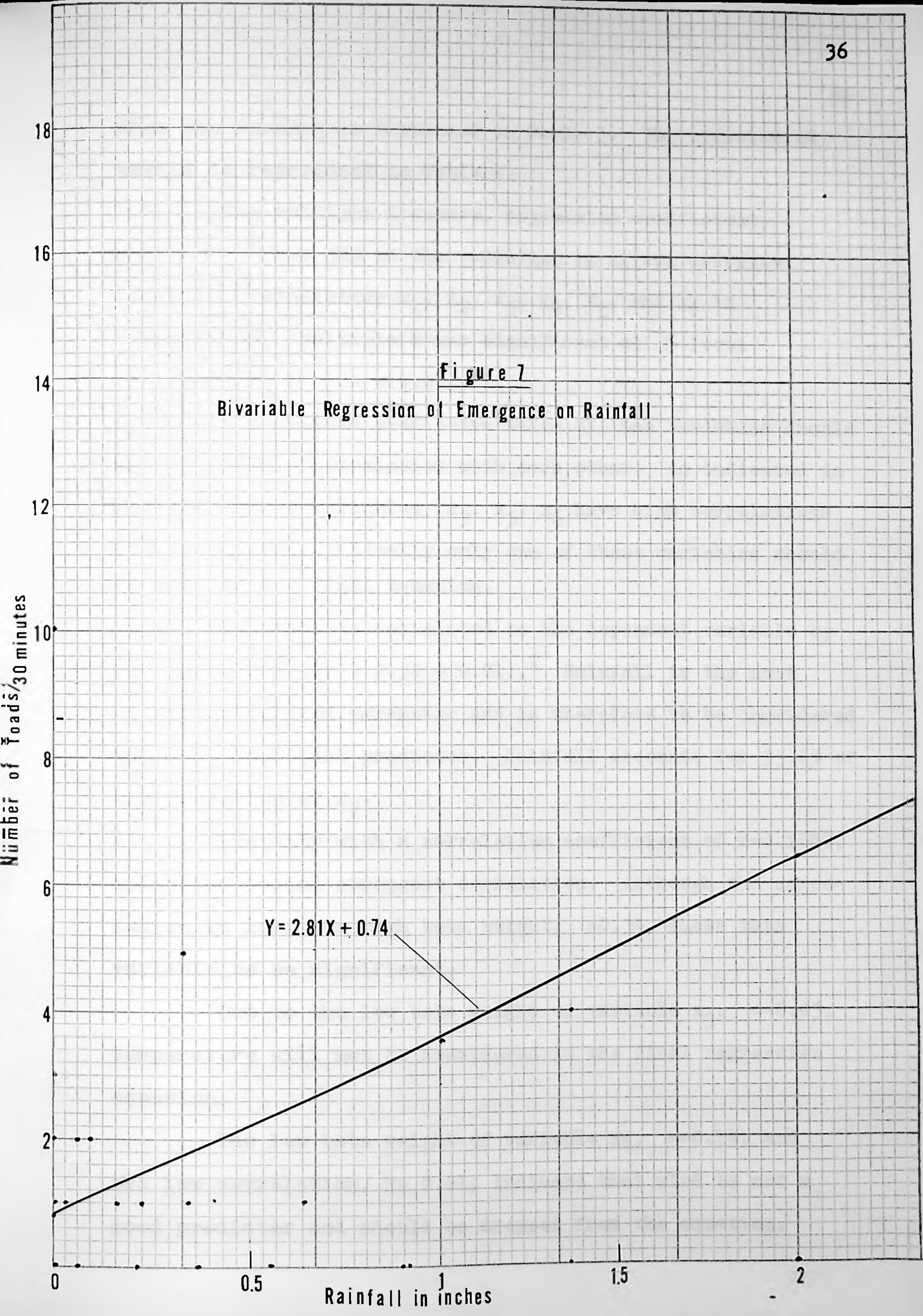


Figure 6
Bivariable Regression of Emergence on Humidity
Y = 0.04X - 2.24
Number of Toads/30 minutes
16
14
12
10
8
6
4
2
40
50
60
70
80
90
100
Relative Humidity-percent

Figure 7

Bivariable Regression of Emergence on Rainfall



from the readout is tabulated in Table 3. The correlation matrix is reproduced in Table 4.

The multiple R square, regression coefficient, was 0.50. Thus 50% of the variation in x_7 was accounted for by the predictors x_1, x_2, x_3, x_4, x_5, and x_6 in combination. Multiple R was significant at 5% level (F= 3.04, Pr F 2.60 = 0.05).[1]

For maximum predictive value all the variables should have near-zero correlation with each other. As indicated in Table 4, three variables, x_3, x_5, x_6 have high correlations with each other. Ideally only one of these variables should be used in the final equation.

Rainfall is correlated to the dependent variable by r=0.53(t=3.05, Pr t 2.50 = 0.01).[2] Rainfall is the most highly correlated parameter and is therefore to be considered the most important predictor. Rainfall accounts for 35.6% of the variation of x_7.

Humidity with a correlation coefficient of r=0.1698, indicates second strongest correlation. Although the correlation is low, the high beta weight, =0.34, shows this variable to be significant.

Due to the low beta weight of variable x_3, =-0.03, temperature will not be considered in the final regression equation.

The low beta weight of variable x_4, =-0.14, and the low correlation, r= 0.01, indicate that wind is not a good predictor and should be dropped from the equation.

The large negative beta weight, =-0.54, of maximum ground temperature suggests that x_5 is a suppressor variable.[3] The minimum ground temperature has a low beta weight of 0.24, and can be considered of less importance. The maximum ground temperature has a higher negative correlation and will be used in the final equation.

A five-variable-regressions analysis with x_1= rainfall, x_2=humidity, x_3=temperature, and x_4=wind, gave a multiple R of 0.57 which is significant at 1% level (F= 4.54, Pr F 4.02 = 0.01). Comparing the multiple R's of the 7-variable and 5-variable regressions, testing at the 5% level of significance, it was found that maximum and minimum ground temp did not increase the predictive value of the 7 variable equation (F= 2.875).[4]

A four-variable regression analysis with x_1=rainfall, x_2=humidity, x_3=1/maximum ground temperature, x_4=number of emerged toads yielded a multiple R of 0.68 and a R^2 of 0.46. Thus this 4 variable equation accounts for 46% variation of x_4. Statistical comparison of 4-variable and 7-variable equations indicated the difference in R's was not significant at 5% level (F=0.45).

A three-variable regression analysis was run with x_1= rainfall, x_2=humidity, and x_3=number of emerged toads. From the comparison of the R's of the 4-variable and 3-variable regressions, it was found that at the 5% significance level the addition of x_3= 1/maximum gnd. temp., increased the predictive value of the equation (F=5.139).

A comparison of the R's of the 5-variable and 3-variable equations gave a low F of 0.25. This indicated that variables for wind and air temperature effects did not increase the predictive value of the equation.

Therefore the best prediction of behavior will occur with the 4-variable regression equation, $x_4=4.05x_1 + 0.0759x_2 + 167.4x_3 - 13.298$. The data from all the regression analyses is presented in Table 5.

Table 3

INFORMATION FROM REGRESSION ANALYSIS OF SEVEN VARIABLES

Parameter	Mean	Standard Deviation	Beta Weights	B Weights
Rainfall........x_1	0.34 in.	0.49	0.5962	0.04566
Humidity........x_2	81.20%	17.7	0.3438	0.07400
Temperature.....x_3	16.0°C	4.8	-0.0348	-0.00273
Wind............x_4	5.4 mph.	2.76	-0.1463	-0.02028
Maximum Ground Temperature.....x_5	21.8°C	4.15	-0.5476	-0.05046
Minimum Ground Temperature.....x_6	13.9°C	3.76	0.2496	0.02540
Emergence.......x_7	2.16T*	3.82	------	-------

*T equals the number of toads emerged for 30 minutes.

Table 4

CORRELATION MATRIX OF SEVEN VARIABLES

	1	2	3	4	5	6	7
1	1.00	-0.12	0.03	0.31	-0.04	0.03	0.53
2	-0.12	1.00	-0.25	-0.32	0.33	0.10	0.16
3	0.03	-0.25	1.00	0.01	0.53	0.76	-0.20
4	0.31	-0.32	0.01	1.00	-0.18	-0.05	0.01
5	-0.04	0.33	0.53	-0.18	1.00	0.72	-0.26
6	0.02	0.10	0.76	-0.05	0.72	1.00	-0.10
7	0.53	0.16	-0.20	0.01	-0.26	-0.10	1.00

Table 5

INFORMATION FROM FOUR REGRESSION ANALYSES

Number of Variables	Multiple R Square	Multiple R	Degrees of Freedom	F
7	0.50355	0.70961	(6, 18)	3.04
5	0.33562	0.57933	(4, 36)	4.54
4	0.46368	0.68094	(3, 21)	6.05
3	0.32587	0.57085	(2, 38)	9.18

FOOTNOTES FOR CHAPTER IV

[1]H. D. Brunk, An Introduction to Mathematical Statistics (Waltham: Blaisdell Publishing Co., 1965), pp. 392-393.

[2]Ibid.

[3]J. P. Guilford, Fundamental Statistics in Psychology and Education (New York: McGraw-Hill Book Co., 1950), p. 438.

[4]Ibid., p. 289.

Chapter V

DISCUSSION AND CONCLUSIONS

Ditmars (1905),[1] Smith (1934),[2] and Ball (1936),[3] have expressed the importance of rainfall in effecting emergence. It has been found in this study that emergence is strongly correlated to rainfall. The correlation coefficient of r=0.5 compares reasonably with Pearson's figure of r=0.37.[4] The lower calculated limit of precipitation is 0.27. Thus, one would not expect any toads unless rainfall was greater than 0.27. In the field, for ten observations, Scaphiopus emerged when rainfall was less than 0.27. Two investigators, Smith (1950),[5] and Ball (1936),[6] indicated that the Spadefoot toad displays a significant response to ground moisture. It is therefore concluded that emergence is dependent on accumulated rainfall or soil moisture rather than the amount of precipitation.

Pearson noticed that the nights of high activity were associated with high air moisture.[7] It has been determined that Scaphiopus hammondi is sensitive to humidity changes of 10%.[8] The amount of heat lost to the environment by evaporative cooling depends on the relative humidity. Humidity is correlated with emergence by a correlation factor of r=0.25(t=1.71). The lower limit of activity has been determined to be 56% relative humidity. This value is verified by field observations.

The value, 10°C, suggested by Green for the lower thermal limit of activity has been confirmed in this study.[9] In one instance, spadefoots were calling from a pond with water temperature of 12°C. As the air temperature changed from 10°C to 9.5°C, several males began migrating to the railroad bed to burrow. With normal rainfall, no activity was observed whenever air temperature approached 10°C.

The air temperature, the maximum ground temperature, and the minimum ground temperature have negative correlations with emergence. These three parameters are significantly correlated between themselves. Air temperature is correlated more to minimum ground temperature. This difference in correlations can be explained as follows. The maximum ground temperature is dependent on insolation. During the day, the maximum will be reached and the surface of the ground will be hotter than the air above it. The air temperature follows the surface temperature. At night, insolation is at a minimum, and the surface cools quickly by radiation to the atmosphere. The soil temperature then follows the air temperature; the ground minimum will depend on the atmospheric minimum.

Emergence and the inverse of maximum ground temperature are correlated by, $r=0.33$. It seems <u>Scaphiopus</u> reacts negatively to high ground temperatures. If on a given day the ground temperature is higher, then the upper layers of soil retain heat longer and fewer toads emerge. The eastern species evolved in a xeric habitat in the Sonoran region where a negative thermotaxis would be of significant adaptive value.[10] It carried this behavior with it into the mesic environment of the East.

The number of juvenile spadefoots active at night was always greater and emergence took place under more severe conditions. In the course of an evening, larger individuals became less common as the temperature declined.[11] Kellogg (1932),[12] Allen (1932),[13] and Trowbridge and Trowbridge (1937)[14] have discerned similar behavior in other species of Scaphiopus. Juveniles and tadpoles of many anurans tolerate extremes in temperature that are very close to their lethals.[15] The larger individuals carry on lower metabolism per unit weight. Lower metabolism results because larger anurans cannot supply as much oxygen to the cells per unit time/ unit work.[16] Thus, both developmental and physiological characteristics are responsible for the ability of the young to tolerate greater environmental extremes.

Individual spadefoots, in this colony, were found burrowed between, around and under the tracks in the railway bed. Some individuals were seen emerging from rocks inside the ties. A recently emerged toad was readily distinguished because of a covering of white cinder dust.

Scaphiopus has been reported to burrow as great as fifteen feet or as shallow as three inches, under different weather and seasonal conditions. The depth to which spadefoots burrow is inversely related to the suitability of the terrestrial environment. When conditions are extremely unfavorable, such as in winter or times of drought, Scaphiopus will be found at lower depths.

The emergence of Scaphiopus holbrooki is expressed in the following equation of four variables.

$$Y = 4.05x_1 + 0.0759x_2 + 167.4x_3 - 13.298$$

Y=Number of Emerged Toads Per 30 Minutes

x_1=Rainfall Per 24 Hours in Inches

x_2=Percent Relative Humidity

x_3=1/Maximum Ground Temperature, °C.

To summarize, emergence involves two related responses. First, a toad must move up through the soil completing ascension. Secondly, the toad must advance onto the surface. Bragg relates how his captive spadefoots would approach the surface and break through the soil without coming out.[17] Both Green (1963),[18] and Bragg (1965),[19] have noticed that Scaphiopus may lie for long periods at the mouth of their burrows. It appears that different sets of stimuli operate for each phase of behavior. Ascension is dependent on soil moisture and maximum ground temperature provided the ambient temperature ranges above certain levels. The advance phase is under control of air moisture if the air temperature is above a certain level, 10°C, and light intensity below a certain level.

FOOTNOTES FOR CHAPTER V

[1]Raymond L. Ditmars, "Batrachians of the Vicinity of New York," The American Museum Journal, American Museum of Natural History, V, 4 (1905), 191.

[2]H. M. Smith, "The Amphibians of Kansas," American Midland Naturalist, XV, 4 (1934), 377-528.

[3]Stanley C. Ball, "The Distribution and Behavior of the Spadefoot Toad in Connecticut," Transactions of The Connecticut Academy of Arts and Sciences, XXXLL (December, 1936), 372.

[4]Paul G. Pearson, "Population Ecology of the Spadefoot Toad," Ecological Monographs, XXV, 3 (1955), 240.

[5]H. M. Smith, "Scaphiopus bombifrons," The Handbook of Amphibians and Reptiles of Kansas (Lawrence: University of Kansas Press, 1950), p. 67.

[6]Ball, loc. cit.

[7]Pearson, loc. cit.

[8]G. Kingsley Noble, The Biology of the Amphibia (New York: Dover Publications, 1954), p. 421.

[9]N. Bayard Green, "The Eastern Spadefoot Toad, Scaphiopus holbrooki holbrooki Harlan, in West Virginia," Proceedings of the West Virginia Academy of Science, XXXV (1963), 18.

[10]Vasco M. Tanner, "A study of the genus Scaphiopus," Great Basin Naturalist, I, 1 (1939), 5.

[11]Green, loc. cit.

[12]Remington Kellogg, "Notes on the Spadefoot of the Western Plains (Scaphiopus hammondii)," Copeia, 1 (April, 1932), 36.

[13]Morrow J. Allen, "Further Comment on the Activity of the Spade-foot Toad," Copeia, 2 (July, 1932), 104.

[14]A. H. Trowbridge and M. S. Trowbridge, "Notes on the Cleavage Rate of Scaphiopus bombifrons Cope, with additional remarks on certain aspects of its life history," The American Naturalist, LXXL, 739 (1937), 478.

[15]John D. Cunningham and Don P. Mullally, "Thermal Factors in the Ecology of the Pacific Treefrog," Herpetologica, XII, 1 (1956), 78.

[16]Victor H. Hutchison, Walter G. Whitford, and Margaret Kohl, "Relation of Body Size and Surface Area to Gas Exchange in Anurans," Physiological Zoology, XLI, 1 (1968), 84.

[17]Arthur N. Bragg, Gnomes of the Night (Philadelphia: University of Pennsylvania Press, 1965), p. 40.

[18]Green, loc. cit.

[19]Bragg, loc. cit.

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