STUDIES ON THE BIOLOGY AND MORPHOLOGY

OF SCHISTOCERCA OBSCURA FABR.

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By

LESTER GLEN DUCK

Bachelor of Science

Northwestern State Teacher's College

Alva, Oklahoma

1937

A THESIS

Submitted to the Department of Entomology

Oklahoma Agricultural and Mechanical College

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

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APPROVED:

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PREFACE

This thesis grew out of a suggestion by Professor F. A. Fenton concerning the need for information on certain members of the Orthopteran genus *Schistocerca*. As the work progressed, it became more and more evident that a thorough understanding of the genus can come only through a close examination of the biology of each species. *Schistocerca obscura* Fabr. was selected for study since it was the most abundant species at hand. It is hoped that further work may be done both with this species and with the other species of the genus.

The research for the following thesis was done at the Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma, extending from June, 1938, until July, 1939. Except for those cases mentioned, the rearing was carried out in a greenhouse.

Much of the library work was done at Iowa State College, Ames, Iowa, during the winter quarter of 1939, at which time the author was enrolled in that school.

Thanks are due to Professor F. A. Fenton, head of the Entomology Department of Oklahoma Agricultural and Mechanical College, for his careful consideration and help with the problem as well as for furnishing ideal conditions for study. I wish also to thank Dr. T. H. Hubbell of the Department of Biology of the University of Florida for his valuable suggestions and help in determining the species of *Schistocerca*. I wish also to express my appreciation to the students of the department for supplying specimens and particularly to my wife, Marie Duck, and Mr. Charles Hovey for their help in the work.

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REVIEW OF LITERATURE

A study of the literature relating directly to Schistocerca obscura shows that practically no work has been done with the insect. Its sporadic occurence as an economic species is probably responsible for this lack of interest, although Uvarov (1928) states that all North American species of Acrididae are in need of life history study.

Morgan (1901) did some work with this species incidental to his more thorough study of Melanoplus differentialis Thom. He found that in Mississippi the eggs were deposited the first of November, and that hatching occurred the last of May. With this work the molts were found to be on an average of ten days apart. With the exception of this brief notice, no other mention of the biology of Schistocerca obscura was found in literature.

Gable (1926) mentions an outbreak of Schistocerca obscura at Pleasanton, Texas, in which much damage to crops resulted. It is interesting to note that a modified cattle dip was used as a control spray. Due to the hourly migrations of the swarms, they were easily sprayed at early morning while "roosting" in the near-by trees.

Since the above represents the literature concerning this species other than systematic descriptions, references to particular phases of the subject are discussed in the part of the thesis with which that particular topic is being considered.

PART I

THE BIOLOGY OF SCHISTOCERCA OBSCURA FABR.

Introduction

Part I of this thesis deals with the life history of *Schistocerca obscura* Fabr. A description of the nymphs is included as well as notes on the biology of the species under both greenhouse and field conditions.

Schistocerca obscura represents one of the more stable species of the genus and is therefore a valuable subject for study since accurate determinations are possible in the adult stage. A certain plasticity in form and color does occur in the nymphal stages, however, and in such a manner as to suggest a possible relationship to those species exhibiting the phase phenomenon, which is discussed in the paragraphs immediately following. As will be seen later, this species also shows definite characteristics, both in the adult and nymphal stages, of typical non-migrating grasshoppers.

Uvarov (1928) has suggested that the terms "grasshopper" and "locust" be used as follows: all Acrididae, which at some time in their history, form swarms and migrate, will be known as "locusts". Those Acrididae which live in a solitary condition and do not swarm or migrate will be known as "grasshoppers". In general, these terms have not been strictly adhered to, although some attempt has been made by various workers to distinguish between the Acrididae in this manner.

The periodic swarming and migration of locusts has long been a subject for much conjecture among people. Numerous attempts have been made to explain the mass outbreaks of these insects, which often swept across the country devouring every bit of vegetation in their paths. It was not until 1921, when Uvarov (1921) first tentatively advanced his theory of the phases of locusts, that any thing like a satisfactory explanation had been offered. This theory was at first looked on as being fantastic, but experimentation has substantiated Uvarov's ideas until today the theory of the phases of locusts is generally looked on as being a fact.

To quote Uvarov (1928), "The main starting-point on the theory is that all gregarious Acrididae, or true locusts, belong to a polymorphic species, that is, such as are not constant in all their characters, but are capable of producing a series of forms, differing from each other not only morphologically, but also biologically. This series is continuous, i.e., the extremes are connected by the intermediate ones, but these extreme forms are often so strikingly distinct that they have been taken for different species. These extreme forms I propose to call the phases of locusts, one of them being, by its habits a typical locust, while the other is an equally typical solitary grasshopper. ... The phases are therefore the temporary condition of a polymorphic species....

The swarming phases generally speaking, is characterized by the following principal features: the eggs develop with a diapause; the hoppers are colored orange, or yellow, with well defined black markings, and are inclined to form bands and wander; the adults are constant in their morphological and color characters (the latter, however, undergoing changes in connection with sexual maturation), form dense swarms, and to not develop the sexual products without a migratory flight, owing to an imaginal diapause.

The solitary phase may be characterized as follows: the eggs can develop without a diapause; the hoppers are variable in color, and as a rule their color corresponds to that of their surroundings; they do not form bands and do not wander in masses; the adults are variable in their morphological and color characters (but do not change color in connection with the maturation of the genital products), do not form swarms, and develop sexually without a diapause or migratory flight."

Practically nothing has been done, physiologically, to explain the cause of such morphological and color changes as may occur in either the solitary or gregarious forms, although workers have been able to produce the changes experimentally by controlled temperature conditions (Hamilton 1926), controlled carbon dioxide concentration (Husain 1936), and by crowding the individuals (Uvarov and Hamilton 1936, Johnston 1932, Faure 1932-33, Husain 1936, Plotnikov 1924, Rubtzov 1935). Since Schistocerca obscura shows characters suggesting both a typical gregarious and a typical solitary species, and being closely related phylogenetically to at least one species which is definitely proven to exist as a gregarious species, it is thought that it would prove valuable to make a study of its habits and characteristics. As shown later, this species is remarkable in that, considering its variations typical of a solitary species, the variations do not coincide with Robtzov's (1935) interpretation of the application of Vavilov's (1921) Law of Homologous Series in Variation to non-swarming grasshoppers. Rather, the nymphal forms themselves strongly suggest a swarming condition.

In thinking of Schistocerca obscura as a swarming species, we first see that it does occasionally form large swarms and migrate to some extent. References to this condition are very few in literature. Gable (1926) mentions such an outbreak near San Antonio, Texas. In this report he states that Schistocerca obscura is closely related to a gregarious species in Mexico, but fails to give the name of the species. On October 16, 1938, the author investigated an outbreak near Gotebo, Oklahoma, and found the species involved to be Schistocerca obscura. The insects were present in large numbers along the edge of a wheat field, which was margined with a heavy growth of elm. The elm, as it is in this region, was located along the bank of a stream bed. Females were ovipositing around the bases of the small elm scrubs, and both males and females showed strong flight tendencies. Small groups would leave the ground, partially circle the field, and set off in a definite direction and eventually pass out of sight. Most of the individuals, however, remained within a comparatively short distance of the flushing place.

Probably the most direct evidence in favor of a gregarious condition is in the coloration of the nymphs. As described later, two distinct types exist. A dark type which is constant in its characteristics, and a green type which shows much variation. This condition is one on which most emphasis has been placed by workers in determining the phases.

The large difference in size, between the sexes, further indicates that the species is present in this region as a solitary phase of a gregarious species. If this is so, one would expect some variation toward a swarming phase at some place in its distribution.

That the percentage of nymphs of Schistocerca obscura showing the dark phase fluctuates from to year and from one locality to another is shown by comparing the work of Morgan (1901) with the present work. Morgan states that fully one half of the nymphs bred at Bolivar, Mississippi, showed the dark coloration. With my work at Stillwater, Oklahoma, in 1938, less than one per cent of the numphs were of the dark color. Morgan fails to say under what conditions his rearing was done.

Uvarov (1928) states that the presence of colored stripes in the eyes of the numphs is an indication of the gregarious condition. Later work (Uchida 1934) has shown that this characteristic is not peculiar to the gregarious nymphs alone, but that it may occur in those species existing only as typical solitary species. These stripes are present in the eyes of Schistocerca obscura nymphs, but occur more clearly in the eyes of the dark colored forms.

History and Synonomy

The genus Schistocerca belongs to the Acridii, the typical group of the sub-family Cyrtacanthacrinae. In this genus the fastigium is deflexed and passes insensibly into the frontal costa, lateral carina are wanting on the pronotum, the mesosternal lobes are longer than broad and usually produced and strongly acutangulate posteriorly on the inner sides, the hind tibiae have smooth sides with numerous spines on the outer margin and the second tarsal joint is only half as long as the first.

There are two genera in the group, Acridium and Schistocerca, which were separated by Stal in 1873, because of the broader anal cerci and apical fissate subgenital plate of the males of Schistocerca.

Schistocerca obscura, or the greater obscure locust, as it is known in literature, was first described by Fabricius in 1798, as Gryllus obscurus. The description of Fabricius is as follows:

obscurus

> 33-4.G.Obscurus linea dorsali flava.
> Habitat in America boreali Dom.v.Rohr.
> Statura et magnitudo G. neruobi. Caput obscurum antennis ferrugineis punctaque verticalli flava, postice spinis flavis apica nigris.

Burmeister, in 1838, renamed the species Acridium obscurum. In 1839 Serville described and named the species as new under the name of Criquet Olivatre (Acridium olivaceum).

In 1899, Scudder revised the genus and included the previously unrecognized North American forms. Kirby has followed this work with his Synoptic Catalog of the Orthoptera, in which he has failed to recognize the synonyms as established by Scudder.

Blatchley in 1920 brought together the descriptions and the keys to the members of the North American species as they were recognized at that time. Since then the findings of Uvarov (1921), Faure (1932-33), and others have suggested that a revision of the genus is highly desirable.

Hebard (unpublished) says, "Nowhere in the present literature have these insects been satisfactorily discussed. ... In the case with obscura, however, a valid and very distinct species is represented."

Geographic Distribution

The genus Schistocerca is peculiar in its geographic distribution in that it is typically a new world group. With the exception of one species, (Schistocerca gregaria Forsk. and its phases), the genus is represented only in the Americas and adjacent islands, (Fig. 1). Scudder (1893) states that the home of the genus is in Mexico and Central America, from which various species have gradually moved into southern and northern areas. Scudder lists Mexico as having 23 species, North America north of Mexico as having 11, South America as having 20, and the West Indies as having 6 species of the genus. Kirby (1910) recognizes 73 species, a number of which are known synonyms. The recent additions of Bruner (1900), Rehn and Hebard (1938), and Hubbell and Walker (1938) do increase the total number of species, but it is thought that a thorough revision would eliminate many of the earlier descriptions.

Schistocerca obscura has a wide range of distribution, (Table 1). According to Blatchley (1920) it extends from Baltimore, Maryland, on the Atlantic Coast southward into Texas and Mexico, and as far north as Iowa and Nebraska. Scudder (1899) extends this somewhat by giving record from southeastern Colorado, New Mexico, Mexico, and Central America. From the author's records, based on correspondence and actual specimens, the species may be expected to be collected from as far north as Maryland and as far west as the Rocky Montains. Southward, there are records through all of the area to the tip of Florida and southern Mexico. All of the actual collection record is brought together and presented in Table 1. A map showing the area known to be inhabited by Schistocerca obscura is presented as Figure 2.

The earliest record in the literature concerning Schistocerca obscura in Oklahoma is that of Caudell in 1902. Morse (1907) mentions taking the species again five years later, from near Caddo. In 1927 Hubbell and Ortenburger again give this record in their list of the species of Orthoptera for the state. The latest reference to Schistocerca obscura is that of Hebard (1938), in which he lists records from Tulsa, Okmulgee, and Weatherford.

Although the species has not been taken from all the counties in Oklahoma, it may be expected to inhabit the entire state, in view of its wide distribution. The available records are widely distributed and serve as a good indication of its presence throughout the state with the exception of the northeast corner, and here a record from Missouri leads us to assume that it may be taken there. The map (Fig. 3) shows the area from which the species has been taken, and Table 2 gives the dates during which collections have been made.

Southwestern Oklahoma seems to offer more toward an optimum environment for the species in so far as Oklahoma is concerned. The largest population encountered during the course of the work was in Kiowa County, where considerable damage to wheat was done in October, 1938.

Table 1. Distribution Records of Schistocerca Obscura.

Country	State	Locality	Date	Source
United States	Arkansas	Washington Co.	8-15-38	Author's collection
United States	Colorado	Pueblo	7-30-31	Scudder (1899)
United States	Colorado	Manitou		Scudder (1899)
United States	Florida	Biscayne Bay		Scudder (1899)
United States	Florida	Green Cove Springs		Scudder (1899)
United States	Florida	Cedar Keys	Sept. 20	Scudder (1899)
United States	Georgia	Morris Island		Scudder (1899)
United States	Iowa			Scudder (1899)
United States	Mississippi		8-1915	Author's collection
United States	Mississippi		10-1915	Author's collection
United States	Mississippi	Cat Island	9-8-20	Author's collection
United States	Mississippi	Starkville	9-21-14	Author's collection
United States	Nebraska			Scudder (1899)
United States	North Car.	Wilmington	8-20-28	Author's collection
United States	North Car.	Raleigh	10-9-28	Author's collection
United States	North Car.	Raleigh	10-17-29	Author's collection
United States	North Car.	Car. Beach	8-14-32	Author's collection
United States	North Car.	Dingo Bluff	11-1915	Author's collection
United States	New Mexico	Tularosa		Scudder (1899)
United States	New Mexico	Dona Ana Co.	Aug. 25	Scudder (1899)
United States	South Car.			Scudder (1899)
United States	Texas	Dallas		Scudder (1899)
United States	Texas	Basque Co.		Scudder (1899)
United States	Texas	Eagle Pass		Scudder (1899)
United States	Texas	Corrizo Springs	Aug. 25	Scudder (1899)
Mexico	Coahuila	Matamoras		Scudder (1899)
Mexico	Sonora			Scudder (1899)
Mexico	Tepic			Scudder (1899)
Mexico	Vera Cruz			Scudder (1899)
Mexico	Durango			Scudder (1899)

Table 2. Collection Records of <u>Schistocerca Obscura</u> for Oklahoma.

Location	Date	Collector	Source	Notes
Caddo	1907	Morse	Morse (1907)	
Tulsa	7-22-37	Standish and Kaiser	Okla. A. & M.	
Okmulgee	7-18-37	Standish and Kaiser	Okla. A. & M.	
Custer Co.	8-18-37	Standish and Kaiser	Okla. A. & M.	
Hugo	7-10-37	L. G. Duck	Collection	1st-3rd Instar
Alva	7-10-38	Marie Duck	Collection	3-5 Instars Adults
Idabel	7-10-38	L. G. Duck	Collection	1st-3rd Instar
Weleetka	7-11-38	L. G. Duck	Collection	
Hughes Co.	7-11-38	L. G. Duck	Collection	
Commanche	7-10-38	Oswalt	Collection	Adults
Stillwater	7-29-38	L. G. Duck	Collection	Adults
Lincoln Co.	9-4-38	L. G. Duck	Collection	Adults
Kiowa Co.	10-16-38	L. G. Duck	Collection	Ovipositing
Woodward Co.	11-2-38	L. G. Duck	Collection	
Noble Co.	7-8-32	L. G. Duck	A. & M. Record	Adults
Kay Co.	7-11-31	L. G. Duck	A. & M. Record	Adults
Osage Co.	6-21-31	L. G. Duck	A. & M. Record	Adults
Harper Co.	8-20-31	L. G. Duck	A. & M. Record	Adults

Biology and Life History

Pairing and Copulation. Very little mention is made in literature concerning the actual activities of grasshoppers as related to pairing and copulation. With Schistocerca obscura there seems to be a definite period which might be termed the pairing period. By this, it is meant there appears to be a time at which the individuals are susceptible to sexual stimulation but not to the extent of actual copulation.

With this species, the males seem to be susceptible to sexual stimulation at a much earlier time after the last molt than do the females. That this may have a very important function in the biology of the species will be seen in the discussion of oviposition. Several times males were seen attempting to copulate within a short time after the last molt. This was noticed to be particularly true when freshly molted males and females were placed in the same cages. In accord with the work of Pospelov (1934), it is thought that females, under caged conditions, reached sexual maturity sooner than did those females living under natural conditions, where crowding did not occur. With the caged females, reared under laboratory conditions, the average length of time from the date of the last molt to the first copulation was 18 days, (Table 3).

Table 3. The Pre-Copulation Period of Schistocerca obscura females.

Cage No.	Date of First Molt	Date of First Copulation	No. of days from last molt to first copulation
3	July 24	Aug. 8	16
6	July 23	Aug. 12	21
9	July 23	Aug. 4	13
7	July 23	Aug. 4	13
10	July 19	Aug. 16	29
15	July 21	Aug. 5	16
		Average No. of Days	18

Under laboratory conditions, males showing a tendency to mate first indicate such by going through stridulatory actions. No sound is audible to the human ear, so what effect, if any, this action has on the females is unknown. It has often been suggested that the stridulatory action serves as an attraction to the female, but in no case has this been shown to be true. Very often, within a cage, while a pair were in copula, several males would group themselves around the pair and go through the stridulatory motions, which consisted of periods of spasmodic twitching of the hind legs, alternate with a slow lowering and raising of the hind legs. Sometimes the entire body was seen to twitch in the same manner as the legs. This motion was also observed in the males while in copula, and in very rare cases, in the females while copulating or while near a copulating pair.

Very often males fight over a particular female, but these fights are never of long duration nor of serious consequence. The females, however, frequently attempt to dislodge the males from their backs after copulation has begun, by scratching with their hind legs.

Due to the great difference in size between the sexes, the males often experience great difficulty in adjusting themselves to the females. In at least one case under observation, this size difference seemed responsible for the failure of the process. Blatchley (1920) gives the average size of the adults as follows: females 50-60 and the males 34-40 m.m. in length.

The actual copulation is much like that described by other authors, (Uvarov 1928, and Snodgrass 1935), and which may be summarized as follows: The male places himself well forward on the back of the female. With his forelegs he clasps the pronotum of the female, the claws holding at the notch in the anterior margin of the prothorax between the pronotum and the small exposed part of the episternum; the middle legs clasp the middle of the female's body; the hind legs are held in various positions and seem to play very little part in the act of copulation. The male lowers his abdomen along the side of the female abdomen, with the genitalia being much depressed and with the phallic organs exerted, the dorsal lobe of the aedeagus being turned upward and forward. In order to expose the spermathecal aperture of the female, which receives the end of the male organ in copulation, the male depresses the subgenital plate of the female with the hooks of the pseudosternite. The penis is then introduced between and beneath the ventral valves of the ovipositor and is inserted into the spermathecal canal.

Oviposition. Oviposition under natural conditions near Stillwater occurred in somewhat restricted situations. (Plate 1, Figs. 1 and 2). These areas where oviposition takes place represent a distinct type requirement in the environment of the species. This idea is substantiated by the fact that at late fall and early summer the insects congregate here in swarms, composed of gravid females and males. The typical habitat for oviposition consists usually of a creek bordered by elm trees or low, scrubby elm growth, with a sandy soil and an enclosed field of small grain or cotton. The eggs, as a rule, were found to be deposited in the soil around the bases of the elm scrubs, especially where they were on the slope of the creek bank. Morgan (1901) states that the egg pods of Schistocerca obscura are usually associated with those of Melanoplus differentialis Thom., although oviposition takes place much later in the season with Schistocerca obscura than with Melanoplus differentialis. There is no difficulty in distinguishing between the pods of the two species, since the eggs of Schistocerca obscura are much larger and of a brick red color.

Observations were made on females ovipositing in special cages in the laboratory and greenhouse. The temperatures for this period are given in Fig. 4. Cages first used were 12 inches square, and contained 3 inches of moist sand. These were later changed by adding up to from 5 to 6 inches of sand. Oviposition for the regular life history study was made in the pot type of cage. (Plate II, Fig. 1 and 2).

Time did not permit for a physiological study of oviposition, but in general this species seems to bear out the observations made by Pospelov (1934) on the migratory locust in Russia. In this work Pospelov found that the females did not develop eggs in the ovaries unless copulation first took place. He states that fertilization is in itself a factor which permits the maturation of the eggs in the ovaries.

In following out Slifer's (1936) plan for securing eggs from unfertilized females, the author isolated five female adult Schistocerca obscura which had freshly molted. These were kept caged without males for a period of approximately two months, at which time dissections showed that three of the individuals had not developed eggs in their ovaries. The remaining ones showed no external signs of egg development. One of the females was then placed with a male to replace a female that had died. Copulation immediately took place, and eventually one egg pod was secured. On the death of this female about ten days after oviposition of the first egg pod, dissection showed another batch of eggs well developed. These results are much the same as those secured by Pospelov (1934) in his work.

Actual oviposition was observed in two cases in the laboratory, with the aid of specially prepared oviposition jars. Glass jars were filled with sand, the surface of which was covered with cardboard, with the exception of a narrow margin around the edge. A female, ovipositing, could easily be observed through the side of the glass jar. A female ready to oviposit becomes restless and may dig several holes before the eggs are finally deposited in a suitable place. The time required for oviposition averages about 30 minutes. The bottom of the egg mass may be inserted to a depth of ten centimeters in the soil and capped with a mass of froth which extends to just below the surface of the ground. There is no egg pod proper in this species, but due to the fact that the eggs are glued together with the mucilaginous secretion of the female, particles of soil adhere to the outer surfaces, forming a somewhat stable covering for the eggs.

The ovipositing process differs little from that described for other species, except for some minor details. The female first penetrates the soil with the tip of her ovipositor, the valves being closed, and by alternately opening and closing the valves a hole is formed. Often she may enlarge the hole by twisting the abdomen around. In no case was a female observed standing against the side of the cage as described by Ballard (1931) for the desert locust. In cages where the sand was of sufficient depth, the egg mass was deposited almost perpindicular to the surface of the ground. In cages containing less sand, the pod was bent on itself at a place depending on the amount of sand. Only one egg is released at a time, and with each passage a release of the mucilaginous secretion of the female followed, until when the process was completed the entire mass was bathed in the fluid. When the last egg is released, the rest of the hole is filled with the frothy material which later dries. A female having finished oviposition may be recognized for some time due to the frothy material covering the tip of the abdomen.

A female containing around 120 eggs may oviposit approximately one half of them at one time and a few days later deposit the remaining eggs. Occasionally a female will deposit all the mature eggs she contains in one mass, and some females show records for three and four egg masses.

Two females oviposited early, within a few days after the last molt. These eggs were laid on the surface of the ground in irregular masses and covered with the frothy secretion. None of them developed embryos.

The average number of eggs per female in this study was found to be 75.4 for the first pod, 42 for the second, and 31 for the third pod. In some cases the fourth pod was secured, but counts are not available for these. It is thought, however, that a female is capable of producing around 200 eggs under favorable conditions.

At various times, females collected from the field were dissected to determine the number of eggs to be found matured at any time in ovaries. Over this period, extending from July 25 until October 16, 1938, 13 females were examined. It is not known whether these females had previously oviposited or not, but it may be assumed that in most cases they had. The following table gives the results of this study.

Table 4. Number of Eggs Found in Ovaries of *Schistocerca obscura* Females Collected from the Field.

Date of Collection	Number of Eggs
Sept. 30	110
Aug. 20	120
Aug. 20	116
Aug. 28	87
Oct. 16	167
July 26	118
Aug. 8	70
July 28	109
July 28	114
Aug. 21	116
Aug. 21	119
Oct. 16	101
July 25	93
Average Number of Eggs	108.4

It is difficult to say at what time such activities as oviposition, hatching, and copulation occur in the field under natural conditions, since these are so closely controlled by various climatic factors, and so vary from year to year. This is shown by the fact that eggs deposited in September and kept at room temperature hatched as early as the last of December. Other eggs from the same pods but stored at soil temperatures did not hatch until the last of April and the first of May. The earliest record in my notes of an adult specimen being taken is for July 6, 1938, from Woods County. Nymphs of the fifth instar were abundant at that time.

The pre-oviposition, or the period from the last molt until the time of oviposition, has been determined in this work to be 44.1 days. (Table 5). This average was taken from ovipositions of females reared in the greenhouse at the temperatures given in Fig. 4. This average approximates that given by Ballard (1932) for the desert locust of the solitary phase in Egypt. The inter-oviposition periods are given for the time between the first and second, and second and third successive pods. (Tables 6 and 7). The limited number of cases makes the latter records of much less value.

Table 5. Pre-oviposition Period for Schistocerca obscura at Stillwater, Oklahoma. 1938.

Cage No.	Date of Last Molt	Date of First Egg Pod	Duration of pre-oviposition Period (Days)
S3	July 24	Sept. 1	40
S6	July 23	Sept. 3	43
S8	July 19	Sept. 7	51
S9	July 23	Sept. 11	51
S2	July 24	Sept. 6	45
S1	Aug. 9	Sept. 1	32
S7	July 23	Sept. 1	41
S10	July 19	Sept. 5	49
S12	July 22	Sept. 13	54
S15	July 21	Sept. 1	43
S24	July 28	Sept. 5	40
S25	July 28	Sept. 5	40

Average no. of days 44.1

Table 6. First Inter-oviposition Period for Schistocerca obscura Reared at Stillwater, Oklahoma. 1938.

Cage No.	Date of First Egg Pod	Date of Second Egg Pod	Duration of First Inter-oviposition Period (Days)
S6	Sept. 3	Sept. 7	5
S8	Sept. 7	Sept. 15	9
S1	Sept. 1	Sept. 11	11
S15	Sept. 1	Sept. 7	7
		Average no. of days	8

Table 7. Second Inter-oviposition period for Schistocerca obscura reared at Stillwater, Oklahoma. 1938.

Cage No.	Date of Second Egg Pod	Date of Third Egg Pod	Duration of Second Inter-oviposition Period (Days)
S6	Sept. 7	Sept. 23	21
S15	Sept. 7	Sept. 15	9
		Average no. of days	15

Hatching. The eggs of this species, being laid in late summer and fall, normally remain inactive over the winter months and hatch in the spring. With some species of insects this overwintering at low temperatures seems to be a necessary factor in starting the development of the embryo. In the case of Schistocerca obscura there is no evidence to prove that this is so. Rather, there is much to indicate that the development of the embryo may be continuous if a sufficiently high temperature is maintained. Egg pods deposited in September were broken and the halves were stored at both room and soil temperatures. The eggs stored at room temperature started hatching in December and continued to do so up until the last of February. On examination, the eggs at soil temperature showed very little development on April 6, 1939. These eggs, however, started hatching in May. It is interesting to note, however, that much difference exists in the total percentage of eggs hatched, and between the material at the two different locations. Tables 8, 9, 10, and 11 show the relationships between the activities under the two temperature conditions. The daily record of hatching for each pod is shown in Table 12.

Table 8. Incubation Period for Eggs of *Schistocerca obscura* at Soil Temperature. Stillwater, Oklahoma, 1938-39.

Cage No.	Pod Number	Date of Oviposition	Date of First Hatch	Duration of Period (Days)
S3	First	Sept. 1, 1938	May 30, 1939	272
S24	First	Sept. 5, 1938	May 31, 1939	268
S2	First	Sept. 6, 1938	May 25, 1939	261
S8	First	Sept. 7, 1938		
S25	First	Sept. 5, 1938	May 25, 1939	262
S10	First	Sept. 7, 1938	May 30, 1939	265
S1	First	Sept. 1, 1938	May 4, 1939	246
S15	First	Sept. 1, 1938	May 3, 1939	245
S6-2	Second	Sept. 7, 1938	June 2, 1939	275
S7	First	Sept. 1, 1938	May 27, 1939	269
S6-1	First	Sept. 3, 1938	May 21, 1939	260
			Average	262.3

Table 9. Incubation Period of Schistocerca obscura for Eggs Stored at Room Temperature. Stillwater, Oklahoma, 1938-39.

Cage No.	Pod Number	Date of Oviposition	Date of First Hatch	Incubation Period (Days)
S3	First	Sept. 1, 1938	Jan. 8, 1939	99
S24	First	Sept. 5, 1938	Jan. 7, 1939	93
S2	First	Sept. 6, 1938	Jan. 11,1939	106
S8	First	Sept. 7, 1938	Jan. 8, 1939	92
S25	First	Sept. 5, 1938	Dec. 10,1938	65
S1	First	Sept. 1, 1938	Dec. 5, 1938	65
S15	First	Sept. 1, 1938	Dec. 15,1938	75
S7	First	Sept. 1, 1938	No Hatch	
S6-1	First	Sept. 3, 1938	Dec. 7, 1938	64
S6-2	Second	Sept. 7, 1938	Jan. 3, 1939	89
		Average		83.1

Table 10. Average Hatch for Schistocerca obscura Eggs Stored at Soil Temperatures. Stillwater, Oklahoma, 1938-39.

Cage No.	Number of Eggs	Number of Hatched Eggs	Percentage of Eggs Hatched
S3	15	6	40.0
S24	45	5	11.11
S2-1	52	10	19.23
S25	137	44	32.11
S10	28	22	78.57
S6-2	54	41	75.92
S7	45	38	84.44
S6-1	129	76	58.91
		Total Average	50.3

Table 11. Average Hatch for Schistocerca obscura Eggs Stored at Room Temperatures, Stillwater, Oklahoma. 1938-39.

Cage No.	Number of Eggs	Number of Hatched Eggs	Percentage of Eggs Hatched
S3	25	3	12.00
S24	17	3	17.64
S2	18	4	22.22
S8	22	2	9.09
S25	21	4	19.04
S10	29	3	10.34
S1	14	1	7.10
S15	31	1	3.20
S6-1	23	2	8.69
S7	21	1	4.76
S6-2	22	1	4.54
		Total Average	10.87

In order that the hatching process might be easily observed, a number of eggs were placed on moist sand in a tin container and allowed to stand in the sunlight until hatching activity was seen to have begun. Time records were kept in a few cases, but it soon became evident that temperature (within a constant humidity condition) was an important factor in regulating the speed of activity. In general, those individuals hatching after four o'clock in the afternoon remained in the intermediate stage until around eight o'clock the next morning. It was noticed, too, that removing the tin containers from the direct sunlight to the shade in mid-day was sufficient to decrease the speed of activity considerably.

The average hatching time was 16 minutes, as observed from ten cases at mid-day. For these same records the average length of the intermediate stage was 5 minutes. The time of hatching was considered to be from the first evidence of a rupture of the egg until the embryo was free. The intermediate stage or period of time for shedding the intermediate skin was considered as being the same, since the normal individual commences this activity immediately after leaving the egg.

On freeing itself from the egg, the embryo makes use of the pulsatile organ (cervicle ampula) which is plainly evident at this time, being located just back of the head. By alternate contractions and expansions of this organ the egg shell is burst and the nymph makes its way from the egg in a worm-like manner. According to Uvarov (1928) the movement to the surface of the ground is accomplished in much the same way. The movements of the cervicle ampula force the soil particles to one side, and on contraction the young grasshopper moves upward through the space left by the displaced soil particles.

On reaching the surface, the young nymphs present an appearance of helplessness, since their movements are greatly hampered by the enveloping membrane. The movement is entirely by worm-like contractions and expansions of the body. In our observation all the nymphs moved while on their backs, reminding one much of the locomotion activity of some of the Scarabid larvae.

Immediately on reaching the surface, the nymph begins the process of shedding the intermediate nymphal skin. That this skin is truly a nymphal skin and not the amnion or an embryonic membrane is clearly shown by Carothers (1938). The cervicle ampula seems to play the same part in this activity as in hatching and in the passage to the surface of the ground. By the alternate expansions and contractions the skin is ruptured and the nymph emerges as the first instar.

Uvarov (1928) states that light is a necessary factor in the intermediate molt and that the young grasshoppers will not hatch, move to the surface, or molt in the absence of light. With this species it was found that the young would hatch, move to the surface of the ground and complete the intermediate stage in entire absence of light. In some cases, considerable development toward the second instar was accomplished before death occurred. This indicated that starvation was responsible for the death of the hoppers rather than the absence of light. In this experiment, the eggs at the time of oviposition were confined to tin boxes with tight fitting lids. The boxes were not opened until after the insects had reached the various stages of development as stated above. Twenty-five young were hatched in this manner, of which 22 completed the intermediate molt.

Table 12. Daily Hatching Record for Schistocerca Obscura Eggs Stored at Soil Temperature. Stillwater, Oklahoma. 1939.

Date		Box Number													Daily Totals
		1	2	3	4	5	6	7	8	9	10	11	12	13	
April	26										1				1
	27														
	28														
	30														
May	1									1	3				4
	2									5					5
	3									3	5				8
	4									1	4				5
	5														
	6														
	7														
	8														
	9														
	10														
	11														
	12														
	13														
	14														
	15														
	16														
	17														
	18														
	19														
	20														
	21									1				1	2
	22													1	1
	23													31	31
	24													10	10
	25							3						10	13
	26				1			11							12
	27				4			12					20	1	37
	28				5			5					16		26
	29							5						11	16
	30		2					2	1					5	10
	31		5	4				2							11
June	1			1				4					1		6
	2											4		2	
	3											21	1	2	24
	4											5		2	7
	5								4	1		4			9
	6								6	1		5			12
	7														
	8								10						10
	9								1						1
	10											2			2
Total Eggs Per Box			7	5	10	0	0	44	22	13	13	41	38	76	269

Food Habits

With the exception of some specific experiments in food-plant preference, the principal food used in the rearing cages was American elm. Ash and other common plants were used, but it soon became evident that Schistocerca obscura had some decided preferences concerning food plants. It was then planned to study these plants on a basis of preference and availability.

Since the experiment was carried out in the greenhouse, where the rate of evaporation was very high, it seems likely that the food consumption was not normal. Some later rearing was done under conditions of extreme dryness, and it was noticed that the more succulent food was more readily taken than some of the foods of higher rating under greenhouse conditions where the humidity was kept fairly high by wetting down the soil around the cages.

Four different species of plants, at a time, were placed in a cage containing, usually, five individuals of each sex of Schistocerca obscura adults. These plants were left in the cage during the entire day, to be replaced in the morning with a new series of four more plants. At the end of a day each plant was rated on a basis of from 1 to 4 for preference. The 4 indicated the most desirable plant for food. When the entire group of 22 plants was run, the like numbers were re-run and the experiment repeated. This resulted in some of the plants being shifted to what seemed to be their more natural rating. For example, if cotton, elm, ash, persimmon, and wheat were given a rating of 4 on different days, they were all collected and offered to the insects at the same time. This usually resulted in some of the plants being shifted to a different rating.

The availability of the food was determined in a purely arbitrary manner. By taking the habits of the habits of the grasshoppers into consideration, the plants were rated on a basis of amount of leafage, number of plants, and extent of the areas having the particular plant growth. In the areas having the largest populations of Schistocerca obscura, it is noticeable that elm is a dominant plant. In the principal area studied, elm furnished an excessive amount of leafage, a large number of plants were available, and the low shrubs made it possible for the young nymphs to feed exclusively on this plant. This same condition is true in regard to the native grasses, but in no case were the nymphs or adults observed to feed on them. The availability ratings of the two species of plants is the same, but much difference exists in the preference. With the cotton, the degree of preference seems to be as high as with elm, but the cotton is nowhere as abundant as elm as a food plant. The difference here is one of availability and not preference. The food preference and availability relationships are given in Table 13.

Some interesting facts were brought to light in this experiment. For instance, with corn it seems that the degree of maturity of the corn determines whether it will be eaten or not. The insects readily ate the mature and almost mature corn, but would not eat the young corn, even under starvation conditions. Castor-bean, a plant of supposedly poisonous nature, was tried, and the grasshoppers took it readily, even in the presence of some other of the foods. Those eating this plant apparently suffered no ill results.

In the field, a more or less seasonal cycle of food plant preference was noticed. This cycle, as described below, represents the feeding habits as taking place in a typical habitat of the species. The places supporting the larger Schistocerca obscura populations were of this nature.

The nymphs hatching in the spring feed on the leaves of the low scrubby elm growth until reaching maturity. This type of habitat produces much more than just food, as readily observed when one is trying to collect specimens of the nymphs. The young grasshoppers closely resemble the elm leaves in color and in the course texture. When disturbed, they usually drop through the leaves and are lost from sight.

On reaching the adult stage the individuals move to other foods, although elm still occupies an important place in their environment.

In localities where corn and cotton fields were bordered with elm growth, it was found that the adults first moved to the corn to feed, it having almost reached maturity by this time. Later, when the corn is fully mature and commencing to dry out, the grasshoppers move to the cotton, where they may do considerable damage by feeding on the leaves. Always, however, there is almost constant movement between corn, cotton, and the elm trees.

A somewhat similar cycle occurs during the day. The grasshoppers, in the main, spend the night "roosting" in the larger elm trees along the sides of the fields and in the tall corn. Early in the morning there is a movement from the taller plants to the cotton, where feeding occurs, and then in the hot part of the day the insects return to the corn and elm again. Some feeding takes place in the evening before the grasshoppers return to the elm for the night.

In the late fall young wheat may suffer, if the field is so situated as to be near a locality suitable for oviposition. Since this species congregates at these places late in the fall for oviposition, the damage to wheat may sometimes be of considerable extent.

Table 13. Food Plant Study of Schistocerca Obscura.

Common Name	Latin Name	Family	Relative Preference	Availability
Alfalfa	Medicaga sativa	Leguminosae	2	2
American elm	Ulmus americanua	Urticaceae	4	4
Apple	Pyrus malus	Rosaceae	2	2
Ash	Fraxinus spp.	Oleaceae	1	3
Black jack oak	Quercus marilandica	Fagaceae	2	3
Black locust	Robinia pseudoacacia	Leguminosae	1	3
Black walnut	Juglans nigra	Juglandaceae	0	2
Corn (mature)	Zea mays	Gramineae	3	3
Corn (young)	Zea mays	Gramineae	0	3
Cotton	Gossypium	Malvaceae	4	3
Cotton wood	Populus deltoides	Salicaceae	0	3
Hackberry	Celtis occidentalis	Urticaceae	2	3
Mulberry	Morus spp.	Urticaceae	0	1
Peach	Prunus persica	Rosaceae	1	1
Pecan	Carya illinoensis	Juglandaceae	0	3
Persimmon	Diospyros virginiana	Eoenaceae	3	3
Red bud	Cercis canadensis	Leguminosae	1	2
Soy bean	Saja max	Leguminosae	0	3
Sumac	Rhus spp.	Anacardiaceae	2	3
Virginia creeper	Parthenocissus quinquifolia	Vitaceae	2	1
Wheat	Triticum vulgarum	Graminaceae	3	4
Grasses		Graminaceae	0	4

PART II

TECHNICAL DESCRIPTIONS

The Egg and Egg Pod

The egg when deposited has an elongate-cylindrical neck, slightly narrower than the filled portion. The entire length averages 47 mm. The eggs are arranged with much less order than is the case with most of the other local species.

The egg when freshly deposited is elongate-cylindrical, slightly bent in the middle and tapering toward the ends. The posterior cap is broadly rounded at the end and the ring is not plainly evident. The surface of the chorion is sculptured with a definite pattern of slightly raised lines. The color is brick-red, but this becomes darker with age.

The freshly deposited eggs, on drying, are so tightly bound together with the secretion of the female that they may be separated only by tearing the chorion. Later, however, when the time of hatching approaches, they shatter out so that it is with difficulty that an entire pod may be collected.

It is interesting to note that, as the time of hatching approaches, the froth extending to the surface deteriorates and leaves a partially open passage through the soil from the top of the egg mass. Considering the depth to which the eggs are deposited and the hardness of the soil in some places, this must be of great importance to the nymph on emergence from the egg to the surface of the ground.

The eggs average 6.37 mm. in length at the time of oviposition. As the embryo matures the egg enlarges, and at the time of hatching reaches the average size of 6.78 mm.

The Intermediate Nymphal Stage

On reaching the surface of the ground after hatching, the nymph presents a worm-like appearance. The body is enclosed in a transparent, membranous sac which has extended pouches for the appendages. The head is bent downward and with the antennae lying close to the frontal region. The mouth parts hang continuous with their attachments with the cranium, not being bent inward as in the later stages. The cervicle ampula is evident as a dorsal swelling just posterior to the cranial capsule. The two wing-bearing segments are to be distinguished by their lower posterior margins being rounded and slightly expanded. The genital appendages are but little developed, the cerci appearing as conical lateral extensions of the segment, and in the male specimens the ninth abdominal segment is slightly notched on the posterior margin of its sternite. The following are the average measurements of this stage:

Total Length--------------	8.0 mm.
Length of Hind Femur------	2.6 mm.
Depth of Head-------------	2.0 mm.
Length of Antennae--------	1.5 mm.
Number of Antennal Segments--------	11-13

The First Stage Nymph

The cuticle of the active young is green and rugose, closely resembling the elm leaves on which they are usually to be found. Small black dots ringed with white are regularly distributed over the body and are particularly numerous on the legs and dorsal region. This speckled appearance adds to their resemblance to the surface of the leaves. HEAD: At the beginning of the first instar the head is large in proportion to the rest of the body, but the abdomen begins to increase in size appreciably. The head is rounded above, moderately oblique in front with the vertex wide, shallow, and broadly diamond shaped. THORAX: The continuity of the median keel on the well developed pronotum is interrupted by two transverse furrows back of the middle. The posterior margin is slightly incised in the middle line and is wider than the anterior margin. GENITAL APPENDAGES: With the female of the first instar, the genital plates of both genital segments show much differentiation. The ninth sternite is much narrower than the eighth. Rudiments of the first valvulae appear as a pair of flattened lobes at the termination of the eighth sternite. No sign of the second valvulae are visible at this stage. The third valvulae have already formed conical processes, arising from the posterior part of the ninth sternite. The male genitalia is recognized by the expanded sub-genital plate with its notched posterior margin and somewhat flattened cerci. The following are the measurements of this stage:

Total Length-------------------	6.5 mm.
Length of Hind Femur-----------	5.2 mm.
Length of Pronotum-------------	1.5 mm.
Depth of Head------------------	3.0 mm.
Length of Antennae-------------	2.5 mm.
Number of Antennal Segments----	13

The Second Stage Nymph

This stage is very similar to the previous stage in general appearance. COLOR: General color green, frequently suffused, especially on the dorsal area of the abdomen, with brown shades. Eyes are yellowish brown with a dark brown apical spot or blotch. The head and prothorax are colored with a net-like pattern, with the meshes on the latter containing a central dark spot. Meso- and metanotum and abdomen are rather closely marked above with light and dark spots, the posterior portion of each abdominal segment widely ringed with an unspotted area. The hind legs have a median and marginal row of black spots. The ventral surface of the body is a dull greenish white. In some specimens a dorsal median dark line is present, extending from the anterior part of the pronotum to the genital segments. HEAD: The head is smaller in proportion to the rest of the body as compared with the previous stage, and the disk of the vertex is a little less prominent. THORAX: The pronotum is a little flattened and very definitely divided three times, once in front and twice in back of the middle. The mesonotum is nearly covered by the pronotum, leaving the elytra partly exposed from under the pronotum. The wing segments are very slightly veined. GENITAL SEGMENTS: In the females, the division of the lobes of the genital plates forming the lobes of the ovipositor is further developed. The first valvulae are seen to be plainly separated from the eighth abdominal sternite. They have increased in length to such an extent as to reach the anterior margin of the ninth sternite. Small second valvulae have appeared between the lobes of the bases of the third valvulae. The third valvulae show some sclerotization on the outer margins of their lobes. With the males, the sub-genital plate has become more expanded and the cerci more flattened. The following are the measurements of this stage:

Males:

Total Length	10.2 mm.
Length of Prothorax	2.5 mm.
Length of Hind Femur	6.0 mm.
Length of Antennae	4.0 mm.
Number of Antennal Segments	17

Females:

Total Length	11.0 mm.
Length of Prothorax	3.0 mm.
Length of Hind Femur	6.8 mm.
Length of Antennae	4.0 mm.
Number of Antennal Segments	18

The Third Stage Nymphs

COLOR: Typically green, with the dorsum and sides heavily marked with small, round black dots. Head above and cheeks much blotched, with light yellow. Eyes, yellow with light brown suffusions. Antennae with basal segment dark and gradually paler to the tip. Wing pads immaculate. HEAD: Head as before, disk of vertex a little less prominent, frontal costa straight and slightly excavate. THORAX: Wing pads bent abruptly back so that their ventral margins are almost horizontal and with the tegminal rudiments clearly differentiated from the rest of the prothorax so that only the tip of the tegminae are exposed. Prothorax distinctly cut three times. Venation plainly visible in the wing pads. GENITAL SEGMENTS: The rudiments of the ovipositor further developed, the first valvulae nearly overlapping the second. First valvulae tapering abruptly from the middle to the tips. Male genitalia clearly distinguished by the swollen sub-genital plate, deeply notched at the end, and the flattened cerci. The following are the measurements of this stage:

Male:

Total Length----------------------	15.0 mm.
Length of Hind Femur--------------	9.0 mm.
Length of Pronotum----------------	4.0 mm.
Length of Antennae----------------	5.0 mm.
Depth of Head---------------------	4.5 mm.
Number of Antennal Segments-------	19-20

Female:

Total Length----------------------	18.5 mm.
Length of Hind Femur--------------	9.0 mm.
Length of Pronotum----------------	4.0 mm.
Length of Antennae----------------	5.0 mm.
Depth of Head---------------------	5.0 mm.
Number of Antennal Segments-------	20

The Fourth Stage Nymph

Considerable difference in size between the sexes is noticed at this stage, the females being much the larger and generally more robust in their proportions. COLOR: Much as before, the pronotum with an irregular net-like pattern. Hind femur with black blotches on the upper flanges. Wing rudiments with black spots usually following the venation. HEAD: Disk of the vertex broadly or transversely diamond shaped. THORAX: Median carina divided as before but more distinctly at posterior and anterior divisions, less so between. Wing pads upturned and approximating near the tips and covering the rudiments of the elytra. GENITAL SEGMENTS: Similar to the adult stage but with less sclerotization, and the sub-genital plate of the male not so upturned or expanded as in the adult male. The following are the measurements for this stage:

Female:

Total Length	23.0 mm.
Length of Pronotum	7.0 mm.
Depth of Head	6.0 mm.
Length of Antennae	8.5 mm.
Length of Hind Femur	14.2 mm.
Number of Antennal Segments	23

Male:

Total Length	21.0 mm.
Length of Pronotum	6.0 mm.
Depth of Head	5.3 mm.
Length of Antennae	8.0 mm.
Length of Hind Femur	12.6 mm.
Number of Antennal Segments	22-23

The Fifth Stage Nymph

Given below are the detailed descriptions of the green and black color phases taken during the fifth instar of typical females for the particular coloration.

Typical green nymph fifth instar.

Head rounded, rather narrow, disk of vertex broadly diamond shaped, slightly depressed in middle; antennae with 26 segments, the color pea green and slightly darker at distal end; disk of pronotum a little arched in front, the median carina cut once in middle and twice in front of middle; surface of pronotum foveolate with irregular sized and shaped network, the raised portion usually being yellow and usually surrounding a slightly raised black dot; eyes dark brown with five lighter longitudinal lighter bands, black triangular streak extending from the eye to the mouth parts, bordered in front of eye with pale yellow streak, back margin of eye bordered with a pale yellow distinct band; wing pads light green with radiating lines of darker dots, thicker above; legs light green; outer surface of femur with three longitudinal raised lines equally spotted with slightly raised dark dots, each dot bearing a slender hair, dorsal two of the three raised lines darker green than more ventrally situated one; abdomen pale green, a median longitudinal area of dark dots becoming more thickly situated dorsalward, at posterior margin of each abdominal segment on upper half are six dark spots equally spaced beginning on either side of dorsal median line and extending ventrally, each dark spot interspaced with a light yellow blotch or indistinct line, lower margin of each upper segment bordered with light yellowish green band extending the full length of abdomen.

The following measurements were averaged from specimens which were collected from the field:

Female:

Total Length	38.5 mm.
Length of Pronotum	10.5 mm.
Length of Hind Femur	22.0 mm.
Length of Antennae	13.7 mm.
Depth of Head	9.8 mm.
Number of Antennal Segments	26

Male:

Total Length	26.0 mm.
Length of Pronotum	7.0 mm.
Length of Hind Femur	14.0 mm.
Length of Antennae	10.0 mm.
Depth of Head	7.0 mm.
Number of Antennal Segments	25-26

The Adult Stage

The following description is taken from Blatchley (1920).

Females very large, robust; males much smaller, more compressed. General color dark olive-green, usually with a narrow dorsal pale stripe as in alutacea; tegmina in fresh specimens, a handsome purplish-brown, often fading to dull brown when dried, those of the unstriped female usually with vague indistinct fuscous spots. Antennae yellowish, dusky toward tips; hind femora often with short, oblique fuscous cross-bars on upper outer face; hind tibiae purplish-black, their spines yellow, tipped with black. Valves of the ovipositor, sides of hind knees and a short of stripe on the mesopleura usually yellow. Structural characters much the same as in alutacea. Pronotum with median carina more sharply defined and slightly higher, especially on metazona, the hind margin more angulate. Cerci of male slightly narrower, their outer apical third concave and tips truncate. Notch of subgenital plate deep, V-shaped. Length of body, male, 34-40, female, 50-61; of antennae, male and female, 17-18.5; of pronotum, male, 7.5-8.7, female, 11-13; of tegmina, male, 31-36, female, 44-48; of hind femur, male, 20.5-22, female, 28-31 mm.

PART III

STUDIES ON THE NYMPHAL VARIATION OF SCHISTOCERCA OBSCURA

Introduction

In collecting nymphs for the work described in the first part of this thesis it was noticed that occasionally individuals of extremely dark coloration appeared. These, on molting to the adult stage, produced the typical *Schistocerca obscura*, which could not be distinguished from those adults reared from the green nymphs. In the field, no gradations were noticed by which this dark colored form could be connected with the typical green form.

In rearing the typical green specimens it was noticed that those individuals reared in the greenhouse gradually developed a dark coloration in the pattern. The nymphs in the field did not develop this intermediate darker form, but remained as solid green nymphs. The specimens reared in the greenhouse never reached a stage of dark coloration as complete as the few extreme cases represented in Plate III Fig. 1. A complete gradation from the extreme dark phase to the solid green phase was not found in the work of 1938. As mentioned before, the green nymphs within themselves showed considerable variation toward a darker form, but the dark purple phase seemed to be very constant.

Since the greenhouse temperatures were below those recorded for the outside, the tendency of the nymphs to change color suggested that temperature was a factor determining their color. It also seemed possible that the apparently two distinct types found might be regarded as the results of two separate physiological functions. It was decided to run experiments on freshly hatched nymphs at different temperatures the following summer to see if an explanation was available as to the relationship of the nymphal variations.

That temperature is an important factor in color variation has long been known, and Uvarov's theory of the phases of locusts has stimulated these researches in more recent times, since color is one of the characters by which the different phases of locusts are distinguished. In spite of the mass of literature published, there still remains much doubt as to the cause of color variation within a species. There is much evidence that the conditions affecting color density are different for different species of insects. Too, individual inheritance may enter in, and often in such a way as to mask the color tendencies of the phases.

There have been several theories advanced to explain the different types of color forms in a species of insect. Hudson (1913) regarded the development of dark pigmentation as a matter of adaptation to surroundings. Knight (1924) first regarded the white and colored forms of Perillus bioculatus as independent forms, but was forced to discard this idea since he was not able to establish pure lines after extensive breeding experiments. He mentions that increased metabolism produces the light colored forms. Knight further states that the metabolism of this species is increased by rearing them at 85 degrees F., or higher, at which temperatures the white bugs appear. He also found that the females were influenced in this manner at lower temperatures than were the males, and he believes that since females have to mature the eggs, metabolism goes on at a higher rate than with the males. He says that decreased metabolism or less exercise produces dark colored forms.

Faure (1932) proposes the theory of locustine production as an explanation of the dark forms. He says that as a result of high metabolism locustine, or black pigment, is produced, which leads to the black coloration in locusts. According to his theory, increased metabolism as a result of greater muscular activity at higher temperatures must produce large amounts of locustine and consequently darker pigmented forms.

Husain and Ahmad (1936) in working with the desert locust in India obtained results comparable to those of Knight (1924), but also found that increased muscular activity produced the darker forms.

Robtzov (1935), in his work with non-swarming grasshoppers, found that the solitary nymphs may exhibit the whole range of morphological and biological differences characteristic of the phases. The data presented in this paper suggests that the heritable variations inside the species following the law of homologous series,[1] and the individual phase variability, as defined by Uvarov, do not contradict each other and are probably found in all Acrididae, though to varying degrees.

In summary, we may say that the cause of color variation is not known. Some of the factors influencing color variation have been demonstrated from time to time by various workers, and as a whole these experiments give evidence that the phenomenon is not morphological but physiological in its origin. It has been shown that, to some extent, food and color of the surroundings may be of some importance in determining the color of insects. These researches, as a whole, are incomplete and need further work before their full importance may be known.

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[1]Vavilov (1922) suggests that linneons and genera more or less nearly related to each other are characterized by similar series of variations with such a degree of regularity that, knowing the succession of varieties in one genus and linneon, one can forecast the existence of similar forms and even similar genotypical differences in other genera and linneons. The similarity is more complete as the genera and linneons are more nearly allied.

Materials and Methods

The temperature experiments with Schistocerca obscura were carried out with the aid of specially constructed temperature cabinets, equipped with thermostatic controls. Since those cabinets were built with heating units only, the temperatures lower than room temperature were obtained by using the cabinets in a cooling room. Constant temperatures ranging from 89.9 to 70 degrees F. were maintained throughout the course of the experiments.

Four experiments were set up, each experiment containing one set of crowded and several isolated nymphs. By this means the influence of both crowding and temperature could be studied.

As a matter of necessity, four temperatures were maintained during the first part of the experiment. These were 89.9, 85, 85-70 and 70 degrees F. Later, the experiment fluctuating from 85-70 degrees F. was discontinued. Check experiments were carried on at outside temperatures and conditions.

Careful check was kept on all the dates of molting and development of the nymphs. Coloration was checked at one day after molting in each case, in order that equal evaluation might be given to each condition.

Food consisted of elm leaves, which was supplied each morning. The rearing cages were similar to those used in the life-history studies with the adults.

All checks on coloration and measurements were taken under a microscope at 23 magnifications.

Description of the Coloration of the Nymphs Reared at Different Temperatures

Second Stage Nymphs Reared Crowded at Outside Temperature. General coloration dark green with a very dense speckling of black dots; frons and clypeus dark green; vertex dark green with black blotches between the eyes, which are solid brown bordered with light green; genae green with white reticulations, the sub-ocular streak very black and bordered in front with white; maxillary and labial palpi green and ringed with black; cervical sclerites green; pronotum very dark green with a dark smudge on the sides; meso- and metanota black fading into green on the wing rudiments; sternal light green with light spottings of tan; first and second pairs of legs green with the tibiae and tarsi black, the third pair of legs with the femora showing black blotches on their outer sides, the tibiae black but fading out near the proximal ends; abdomen showing a very plain black longitudinal streak down its median dorsal surface, the darkened area shading off on the sides to a yellowish-green and on the ventral sides to a light green. The above description was taken from the examination of ten living specimens.

Second Stage Nymphs Reared Crowded at Temperature of 70 Degrees F. These nymphs did not reach the stage of color intensity as shown in those reared at outside temperatures. The extremes were fully as dark, but the percentage of nymphs showing the extreme condition was less. Frons and clypeus brownish-green; labrum brownish-green with a transverse row of black dots on its lower margin; vertex of a very dark brownish-green to the disk, it being dark green; genae and postgenae mottled dark green and yellow; compound eyes very dark brown; antennae with the basal segments a very dark green but darkening to the tips; mouth parts heavily spotted with black on a green ground color; the pronotum is heavily mottled with black, white and yellow, the black being most prominent; first and second pairs of legs with green femora, tibiae shading to black at the distal ends and tarsi black, hind legs with three distinct black blotches on the outer surfaces of the femora, the tibiae and tarsi being black; abdomen almost solid black, showing an absence of the usual white markings. This description was made from the examination of eleven living specimens.

Second Stage Nymphs Reared Crowded at Temperature of 85 Degrees F. In general these nymphs present a more speckled appearance than do those nymphs reared isolated at the same temperature. They do closely resemble those nymphs reared isolated at 70 degrees F. Frons green with much black speckling; clypeus dark green; the labrum green but fading out to a yellowish-green; vertex whitish with much speckling around the disk; genae with the sub-ocular streak very plainly evident as a black marking bordered in front with white; postgenae with heavy mottling of green and brown; compound eyes green with very definite brown stripes; antennae with the basal segments green but abruptly changing to black; the thorax with much black in the form of fine specks evenly distributed over the body, except for the posterior dorsal portion of the pronotum where the black condenses to form a large black blotch; the first two pairs of legs green with black markings on the tibiae and tarsi, the hind pair with conspicuous black blotches on the femora, the tibiae and tarsi with their segments margined with black; abdomen with a brownish-green ground color heavily marked with black, especially toward the dorsal median surface where a longitudinal median line of black extends from the first abdominal segment to the first genital segment. This description was taken from the examination of 16 living specimens.

Second Stage Nymphs Reared Crowded at Temperature of 89.9 Degrees F. These nymphs show a development of slightly more pigmentation than do those nymphs reared isolated under the same temperature conditions. Frons pale olive green; clypeus varying from dirty white to pale green as does the labrum; vertex pale yellowish-green; genae and postgenae mottled with green and white, the sub-ocular streak being very evident as a chalky area, in some individuals somewhat darker; compound eyes olive green with two brown stripes running the longitudinal lengths; antennae with the basal segments green but slightly darkening toward the tips; mouth parts light green spotted with black; pronotum with a heavy mottling of olive green and white, black dots being very prominent on the margins; first two pairs of legs with the tarsal segments slightly darker green, the hind pair with a slight dark blotch on the outer surface of the femora; abdomen with faint to distinct black line on the dorsal median surface, otherwise almost white. This description was taken from the examination of 12 living specimens.

Third Stage Nymphs Reared at Outside Temperatures. This stage under the above conditions is almost totally black in general appearance, the green and lighter colors being confined to very small and inconspicuous areas. Frons and clypeus pale brown, the labrum varying from this to brownish-green; the black spots of the vertex of the specimens reared at higher temperatures have with these specimens, fused so as to form a solid black slightly mottled with yellow; genae having the sub-ocular streak of a very dense black and bordered in front with yellow; postgenae black with a yellow margin around the eyes; compound eyes and antennae black; mouth parts green heavily spotted with black; pronotum black with fine reticulation of yellow; metanotum black with white and yellow reticulation; sterna light green with the sutures slightly darkened; first two pairs of legs green with black tarsi, the hind femora with the upper halves black with mottling of white and black appearing distally; abdomen with ground color of black but covered with a fine white network. The above description was taken from the examination of 50 living specimens.

Third Stage Nymphs Reared Crowded at Temperature of 70 Degrees F. These nymphs as a whole did not reach the degree of color intensity as shown by those reared crowded at outside temperatures, but the extremes, which number better than one-fourth of the total, did show as complete a development of dark coloration as any of the nymphs experimented with; the number of individuals per cage for this experiment was somewhat less than was the case for the outside experiment.

Frons brown to reddish-yellow, in some an extreme reddish coloration is developed on the frontal region; clypeus green with heavy spotting of black; labrum green; vertex with much black and dark green above but fading to green on the disk; genae with the sub-ocular streak very black and distinct and bordered in front with white; postgenae black with reticulation light green and dark green; compound eyes with dark brown stripes on a very dark green ground color; antennae black; mouth parts green with black rings on the posterior margins of each segment; pronotum with a green ground color and heavy markings of black, especially near the posterior margin; wing rudiments green; front two pairs of legs green with black tibiae and tarsi, hind legs showing heavy black blotches on the outer surfaces of the femora and with the tibiae gradually changing to black at their distal ends; the abdomen showing a definite wide longitudinal stripe on its dorsal surface, the sides being heavily marked with white. Twelve living specimens were examined for the above description.

Third Stage Nymphs Reared Crowded at Temperature of 85 Degrees F. These nymphs show a general blend of black speckling on a white background. Frons and clypeus with a whitish ground color heavily speckled with black; labrum black; heavy black blotches have appeared on the vertex as a result of the fusing of the small black spots; genae showing a heavy black sub-ocular streak, bordered in front with a white chalky area; postgenae pinkish with white mottling; compound eyes white with heavy brown stripes; antennae black; pronotum with a pinkish ground color and heavily mottled with black and white; wing rudiments pinkish-white; first two pairs of legs whitish with black on the tarsi and tibiae, the third pair having more black on the tibiae and tarsi; the abdomen with a heavy black line on its dorsal median surface, the line being broken intersegmentally with a white transverse band and divided longitudinally with a narrow white line. The above description was taken from the examination of 11 living specimens.

Third Stage Nymphs Reared Crowded at Temperature of 89.9 Degrees F. The nymphs reared under these conditions resemble closely the second stage nymphs reared under the same conditions, differing mainly in having the black more pronounced. Frons, clypeus and labrum olive green with some parts shading out to a dirty white; vertex yellowish-green with pronounced black spotting; genae and postgenae with mottling of white and pale green, the black area of the sub-ocular streak plainly evident; compound eyes olive green with three distinct brown stripes and part of a posterior fourth present; antennae with the basal segments light colored but gradually darkening to the tips; pronotum with a heavy mottling of white and olive green and with black spots very prominent on the posterior dorsal half; wing rudiments light olive green; legs light green with the tarsi margined with black, the hind femora also showing very slight indication of a dark bank; a very faint dark median line on the dorsal surface of the abdomen, otherwise almost white. This description was taken from the examination of 14 living specimens.

Fourth Stage Nymphs Reared Crowded at Outside Temperatures. These nymphs have a general appearance of black with yellow blotches on the more ventral parts of the body. Frons and clypeus brownish-yellow ground color, and with heavy black blotches between the eyes; genae with a very dense black sub-ocular streak bordered in front with white; postgenae mottled yellow and brown; compound eyes solid dark brown to black ground color, some specimens showing a faint yellow stripe; antennae black; mouth parts dark brown to black; cervical sclerites yellow; pronotum with ground color of black with blotches of yellow on the sides; wing rudiments yellow with black at the bases; first two pairs of legs yellow with black tarsi, the femora of the hind pair showing three distinct black bands running transversely on a ground color of yellow; sterna reddish-brown and faintly spotted with darker brown; the abdomen with the posterior margin of each segment lined with alternating white and black spots, the terminal segments being brown. Ten living specimens were examined for the above description.

Fourth Stage Nymphs Reared Crowded at Temperature of 70 Degrees F. In general these nymphs have an appearance of green with pronounced speckling of black on the dorsal surfaces. Frons dark green to yellowish-green with a pronounced speckling of black; clypeus and labrum varying from dark green to brown; the vertex with blotches of black between the eyes but fading to a yellowish-green color on the disk; genae with a very distinct sub-ocular streak of black bordered in front with white; postgenae mottled light green and dark green with a heavy speckling of black; compound eyes dark brown to black, in the lighter colored individuals brown stripes are present; antennae black; mouth parts green with black margins to the posterior borders of each segment; cervical sclerites dark green; pronotum green with very dense mottling of large black blotches, they being more condensed on the sides of the pronotum; wing rudiments with longitudinal rows of black dots fusing at the bases to form a black blotch, ground color dark green; first two pairs of legs very dark with black tarsi and tibiae, the hind pair with the femora almost totally black, the tibiae being black at their distal halves and the tarsi totally black; abdomen almost completely black, shading off to a grayish color on the more ventral portions, the terminal segments varying from tan to dark brown. The above description was taken from the examination of 10 living specimens.

Fourth Stage Nymphs Reared Crowded at Temperature of 85 Degrees F. The nymphs reared under these conditions differ from the ones reared crowded at 70 degrees F. mainly in a lacking of the brownish coloration and by the development of a pronounced whiteness. Frons, clypeus and labrum all similar in having a heavy speckling of black; vertex with black blotches appearing as a result of the fusion of the finer spots present in the preceding stages; genae with a heavy black sub-ocular streak, bordered in front with a chalky white area; postgenae pinkish to white with faint mottlings, very few black spots being present; compound eyes white with three heavy brown stripes and a fourth incomplete stripe diffusing downward; antennae almost totally black; mouth parts light green to white; cervical sclerites green; pronotum with a pinkish ground color and with a very heavy mottling of black and white present; wing rudiments with longitudinal rows of black spots fusing at the bases to form a black blotch; two front pairs of legs with black tibiae and tarsi, the hind pair with the proximal halves of the femora chalky white, but with the tibiae and tarsi black; abdomen with a ground color of white but heavily marked with black, on the dorsal surface a black line is present extending medially from the first abdominal segment to the first genital segment. The above description was taken from the examination of 10 living specimens.

Fourth Stage Nymphs Reared Crowded at Temperature of 89.9 Degrees F. The black pattern is a little more prominent at this stage than on the third stage at the same temperature. Frons pale olive green, the black spots showing plainly on the crests of the raised portions; clypeus light green; labrum light olive green; vertex pale yellowish-green with black dots on its margins; genae with black stripe of the sub-ocular region plainly evident and bordered in front with a faintly visible white area; postgenae mottled white and olive green; compound eyes green with longitudinal stripes of dark brown; antennae with the basal segments green but gradually shading to brown toward the tips; mouth parts green with black spots encircling the distal margin of each segment; cervical sclerites green; pronotum with a heavy mottling of green and white; the texture more rugose than in the third nymphal stage under the same conditions; wing rudiments green with a few black spots at the bases; first two pairs of legs green with black tarsi, the hind pair green with black blotches on the femora and with the tibiae and tarsi darker; abdomen with a plainly evident black line down its median dorsal surface. The above description was taken from the examination of 8 living specimens..

Fifth Stage Nymphs Reared Crowded at Temperature of 70 Degrees F. These nymphs appear much the same as those reared crowded at outside temperatures, except that there appears to be a much more red tendency to the general coloration. Frons, clypeus, and labrum deep reddish-brown heavily marked with black; vertex with the posterior half of the disk black but fading anteriorly to dark brown; genae with the sub-ocular streak consisting of a wide black band bordered in front with a dark yellow area; postgenae black mottled with yellow; compound eyes deep reddish-brown; antennae and mouth parts black; cervical sclerites deep reddish-brown; wing rudiments with the venation black on a brown ground color; first two pairs of legs brown with black tarsi and tibiae, the hind pair with the femora almost totally black, the tarsi and tibiae black; abdomen black with an irregular white network on the sides. This description was taken from the examination of 8 living specimens.

Fifth Stage Nymphs Reared Crowded at Temperature of 85 Degrees F. These nymphs have a general appearance of brown speckling on a pinkish-brown ground color. Frons, clypeus and labrum pinkish-brown; vertex with a brown spot between the eyes, the disk white and pink bordered with black; genae with a black sub-ocular streak bordered in front with white; postgenae a deep reddish-brown mottled with a lighter tan; compound eyes with a ground color of yellow, four brown stripes are plainly visible; antennae black with the basal segments bluish-green; mouth parts pink; pronotum with a pinkish-brown ground color and thickly dotted with black spots; wing rudiments with brown venation and having a light tan ground color; the first two pairs of legs pink, the hind pair dark pinkish-brown with darker blotches on the outer surfaces of the femora; abdomen brown ground color mottled with light tan. This description was taken from the examination of 10 living specimens.

Fifth Stage Nymphs Reared Crowded at Temperature of 89.9 Degrees F. In general these nymphs are much lighter in color than the nymphs reared crowded at lower temperatures. Frons light tan ground color and generously speckled with black dots; clypeus and labrum light creamy tan; vertex light tan ground color with black blotches between the eyes; genae with the sub-ocular streak consisting of a broad black stripe bordered in front with a light yellow area; postgenae mottled light cream and tan; compound eyes with a ground color of light bluish-green and with from five to six heavy brown stripes present; antennae with the basal segments light bluish-green but darkening toward the tips; cervical sclerites yellowish-green; pronotum with white ground color heavily mottled with black and chalky white; wing rudiments light greenish-yellow with the venation showing as longitudinal rows of black spots fusing at the base to form a black blotch; first two pairs of legs light greenish-yellow with black margins on the segments of the tarsi and tibiae, the hind pair with the femora heavily blotched, tibiae black and tarsi heavily margined with black; abdomen with ground color of chalky white heavily marked with black, especially on the dorsal surface. The above description was taken from the examination of 8 living specimens.

Second Stage Nymphs Reared Isolated at Outside Temperatures. Very little dark pigmentation is noticed with this stage, the general coloration being almost totally green. Frons, clypeus and labrum deep green; vertex deep green with a black blotch between the eyes; genae with the sub-ocular streak plainly evident as a black marking and being bordered in front with a yellow area; postgenae mottled dark green and white; compound eyes dark green with a brown spot at the apex of each, which diffuses downward on the anterior side; antennae green, each segment being ringed with black; mouth parts green; cervical sclerites green; pronotum dark green, also with a few dark spots on its posterior dorsal half; wing rudiments green; first two pairs of legs green with darkened tibiae, the hind pair green with darkened tibiae and tarsi, the tibiae being totally green, except for some faint black spots arranged in longitudinal rows on its length; the abdomen with a dark green ground color, but with a few black dots on its dorsal median surface, the sides white with green. The above description was made from the examination of 7 living specimens.

Second Stage Nymphs Reared Isolated at Temperature of 70 Degrees F. These nymphs present a bluish-green appearance in their general coloration. Frons, clypeus and labrum bluish-green heavily dotted with black, vertex mottled with bluish-green and dark green; genae with the sub-ocular streak consisting of an anterior bluish-green area bordered behind with a very faint dark streak; postgenae presenting a mottling of bluish-green, dark green and light green; compound eyes pale bluish-green, but with no brown stripes; antennae bluish-green, each segment being ringed with black; mouth parts bluish-green; pronotum with heavy white network on a dark green ground color, black spotting somewhat prominent; legs green with heavy speckling of black; abdomen bluish-green with large black spots present, the spots being more densely situated on the dorsal region. The above description was taken from the examination of 5 living specimens.

Second Nymphal Stage Reared Isolated at Temperature of 85 Degrees F. The nymphs reared at the above conditions show a general coloration of green, the few black spots being conspicuous in their position. Frons, clypeus and labrum solid green; vertex green with black blotches between the eyes; genae with the sub-ocular streak barely visible as a darkened area bordered in front with white; postgenae mottled dark green and white; compound eyes light green with apical brown spots; antennae green with very faint rings of black on the posterior margin of each segment; mouth parts green; pronotum strongly rugose and with a ground color of green heavily speckled with black; wing rudiments green; legs green with the tarsal segments slightly margined with black; abdomen with a very faint median dorsal streak of black, the sides being heavily mottled with white and black alternating spots. The description for this stage was taken from the examination of 3 living specimens.

Second Stage Nymphs Reared Isolated at Temperature of 89.9 Degrees F. In general these nymphs are very light green and with the body texture not so rugose as is the case with those nymphs reared under other conditions.

Frons, clypeus and labrum very light green; vertex green with very light crests on the raised portions; genae with a very faint white sub-ocular streak; compound eyes green with brown apical spots; antennae light green; mouth parts green to whitish-green; pronotum with a mottling of white over green ground color, and with a white median line extending the full length of the pronotum; legs and wing rudiments solid green; abdomen with ground color of light green, and with a white line extending longitudinally down its dorsal surface, the terminal segments being dirty whitish-green color. The description above was taken from the examination of 3 living specimens.

Third Stage Nymphs Reared Isolated at Outside Temperatures. These nymphs resemble closely those collected from the field, although more variation in color is noticed in the field specimens than in the caged individuals. Frons, clypeus and labrum deep green; vertex deep green with white on the raised portions; the genae with the sub-ocular streak plainly evident as an anterior white area bordered behind with a black streak; postgenae mottled green and yellow; compound eyes dark in color with definite brown stripes present; antennae with the basal segments green but fading almost to black at the tips; mouth parts green; pronotum with a very pronounced network of white on a dark green ground color, black speckling being also very pronounced; wing rudiments green; legs green with darkened tarsal segments; abdomen dark green with a faint black stripe down its dorsal median surface. Two living specimens were examined for the above description.

Third Stage Nymphs Reared Isolated at Temperature of 70 Degrees F. These nymphs are of a darker coloration than those reared at the other temperatures under the same population conditions, and, too, they are of a peculiar bluish color. Frons bluish-green; clypeus and labrum bluish-green with very little black spotting; vertex mottled with bluish-green and light green; genae showing the sub-ocular streak as a bluish-green area; postgenae heavily mottled with light green and dark green; compound eyes pale bluish-green with faint brown stripes; antennae green with the segments heavily ringed with black; mouth parts bluish-green; pronotum with heavy white network on a dark green ground color, a black speckling also plainly evident; wing rudiments bluish-green; legs green but heavily speckled with black; abdomen bluish-green with a dorsal condensation of black spots. The above description was taken from the examination of 3 living nymphs.

<u>Third Stage Nymphs Reared Isolated at Temperature of 85 Degrees F.</u> The nymphs reared under the above conditions show much less black coloration than do those nymphs reared isolated at 70 degrees F. Frons, clypeus and labrum green; vertex green with a black blotch between the eyes; genae and postgenae mottled with green and white, the sub-ocular streak barely visible; compound eyes light green with brown stripes; antennae green with brown to black rings on the posterior margins of each segment; mouth parts green; pronotum very rugose with ground color of deep green, some condensation of black on the dorsal half; wing rudiments green; legs with tarsal segments darkened; abdomen green with a slight indication of a black line on its dorsal median surface. The above description was taken from the examination of 2 living specimens.

<u>Third Stage Nymphs Reared Isolated at Temperature of 89.9 Degrees F.</u> These nymphs have a general appearance of very light green. The body is not rugose in texture and even in some places assumes an extreme whitish color. Frons, clypeus and labrum varying from light green to whitish-green color; vertex showing a strong development of white on the crests of its raised portions; the genae and postgenae mottled with white and

light green, the sub-ocular streak not being visible in most of the specimens; compound eyes light green ground color and usually with three light tan longitudinal stripes; antennae and mouth parts light green; pronotum with a very pronounced white mottling on the sides and with a white line extending the length of the dorsal median surface; wing rudiments and legs solid green; abdomen green with a white margin on the lower edges of the upper half. Three living specimens were examined for the above description.

Fourth Stage Nymphs Reared Isolated at Outside Temperature. The general appearance is one of deep green with no striking evidence of black markings. Frons, clypeus and labrum deep green; vertex deep green, with a small dark blotch between the eyes; genae with the sub-ocular streak plainly seen as an anterior yellow area bordered in back with a black streak; postgenae yellow immediately bordering the posterior margins of the eyes, but diffusing into green; compound eyes of a bluish-green color with four complete yellow stripes; antennae with the basal segments green but gradually shading to dark at the tips; pronotum with a sprinkling of black dots along the dorsal median carina and on the posterior lateral portions, otherwise consisting of a fine network of black on a dark green ground color; wind rudiments dark green with a very few black dots; legs solid green with black flecks on the tarsi, the hind femora with longitudinal rows of black specks; abdomen of a very dark green with a very narrow black line down the median dorsal surface.

Fourth Stage Nymphs Reared Isolated at Temperature of 70 Degrees F. These nymphs show more color development than the preceding stage. The dorsal surface is more rugose and more thickly covered with black spots.

Fourth Stage Nymphs Reared Isolated at Temperature of 85 Degrees F. The ground color of these nymphs show a decided powdery appearance, otherwise they differ little from the preceding stage reared at the same temperature.

Fourth Stage Nymphs Reared Isolated at Temperature of 89.9 Degrees F. The body is more rugose in this stage than in the preceding stage and the pronotum shows slightly more development of black pigmentation.

Fifth Stage Nymphs Reared Isolated at Outside Temperatures. These nymphs resemble those described in the first part of this work. They seem to be what may be called the typical green nymphs as collected from the field. For this description see page 35.

Fifth Stage Nymphs Reared Isolated at Temperature of 70 Degrees F. These nymphs resemble somewhat in color those reared isolated at outside temperatures. Frons, clypeus and labrum deep green with conspicuous black spots on the lower margin of the labrum; vertex green with a black blotch between the eyes; genae with the sub-ocular streak plainly evident; postgenae mottled white and dark green; compound eyes green with brown stripes; antennae with green basal segments but shading to brown at the tips; mouth parts green; pronotum with a dark green ground color and faintly speckled with black; wing rudiments green; first two pairs of legs green with black margins on the segments of the tarsi and tibiae, the hind pair with the femora showing black blotches on their outer surfaces; abdomen green with mottling of black and white. Two living specimens were examined for the above description.

Fifth Stage Nymphs Reared Isolated at Temperature of 85 Degrees F. The ground color of these nymphs is of a whitish-green color, with the black speckling and markings very prominent. Frons, clypeus and labrum pinkish white with prominent black spotting; vertex light green with two blotches between the eyes; genae with the sub-ocular streak very prominent as an anterior white area bordered behind with a black stripe; postgenae mottled with light green and chalky white; compound eyes with five brown stripes on a white ground color; antennae light green faintly darkening at the tips; mouth parts very light green; cervical sclerites white; pronotum with a whitish-green ground color heavily dotted with black and reddish-brown; wing rudiments white with venation of black fusing at the base to form a black blotch; first two pairs of legs whitish-green heavily spotted with black, the third pair with the femora showing three black blotches on their outer surfaces; abdomen with whitish-green ground color and much blotched with black, a very heavy black line extends down the dorsal median surface to the first genital segment. Four living specimens were examined for the above description.

Fifth Stage Nymphs Reared Isolated at Temperature of 89.9 Degrees F. These nymphs do not show the black coloration as seen in the specimens reared at the lower temperatures. Frons green with a row of small black dots on its lower margin; clypeus and labrum solid green; vertex green, the disk having a very few black spots; genae showing very little development of the sub-ocular streak; postgenae green with very faint light green mottling; compound eyes with five brown stripes on a ground color of light yellowish-green; antennae light green; mouth parts light green; pronotum light green ground color with very fine reticulation of white and fine speckling of black, the median carina with a white crest; wing rudiments light green with very few black spots; first two pairs of legs green with little black on the tarsi or tibiae, the hind pair almost totally green; abdomen very light green with a slight indication of a median dorsal line present, each segment encircled at its posterior margin with a band of alternating black and white spots. Four specimens were examined for the above description.

Summary

That temperature has some effect on the intensity of coloration of Schistocerca obscura nymphs is seen by comparing the cases described, where all the nymphs reared under the same population condition but under different temperature conditions, vary in their coloration. All the crowded nymphs exhibit a darker coloration than isolated nymphs, reared at the same temperatures, but within themselves the crowded nymphs show a gradation from light to dark coloration as the corresponding temperatures run from high to low.

With Schistocerca obscura nymphs, however, the most important factor contributing toward darker pigmentation, in this work, seems to be population intensity. Crowded nymphs show a far greater development of dark pigmentation than the isolated nymphs reared at the same temperatures. With this species a crowded condition seems to exist when more than two nymphs are reared together in a cylindrical cage 9 inches in length by $3\frac{1}{2}$ inches in diameter. In some cages as many as 25 to 30 nymphs were reared. These nymphs showed an extreme development of black coloration.

Movement could be observed at all times within the cages containing the crowded nymphs. As the number of nymphs was increased per cage the movement became more noticeable. That movement is a contributing factor in color arrangement has been shown by Husain (1936). This author found that nymphs could be kept moving by arrangement of a special revolving tube. The nymphs developed black coloration, regardless of the temperature and population conditions.

The isolated nymphs reared at the higher temperatures showed some black pigmentation in the presence of a fine speckled appearance on the more dorsal regions of the body. As the temperature and density of population were increased these fine specks fused together to form large areas of solid black, so noticeable in the dark extremes.

Some very definite variation was observed in the duration of the nymphal stages under the different temperatures, (Tables 14-18). As was to be expected, the stages of shorter duration occurred at the highest temperature maintained, that of 89.9 degrees F., and the stages of longer duration occurred at the lower temperatures, the lowest being that of 70 degrees F. A good deal of feeding was noticed at all the temperatures; however, those nymphs reared at outside temperatures seemed to consume the most food per individual. Records are not available, however, to show this to be true.

In conclusion, this work shows that in so far as Schistocerca obscura nymphs are concerned, crowding seems to be the most important factor contributing toward darker coloration. What this may disclose in the way of phase probability is not definitely known as yet. If the phase tendency is a phylogenetic property of a group of related insects, then we could easily expect this species to show indications of phase development under the proper environmental condition; however, it would then be expected that any Acridid would show the phase tendencies under the right environmental stimulus. Further experimentation is needed with species of typical solitary forms, before definite statements can be made as to the possibility of phase occurrence in all forms of Acrididae.

Table 14. Length of Development of the First Stage Nymph of Schistocerca obscura at Different Temperatures.

Temperature (Degrees F.)	Number of Records	Date Observations Made	Duration of Instars (Days) Max.	Min.	Mean
89.9	10	May 23-31	8	7	7.4
85.0	17	May 23-June 3	9	6	7.5
75-80	4	May 23-June 3	11	9	10.2
70.0	23	May 25-June 13	17	9	11.1
Outside Check	57	May 24-June 16	15	3	8.6
		Average	12	6.8	8.96

Table 15. Length of Development of the Second Stage Nymph of Schistocerca obscura at Different Temperatures.

Temperature (Degrees F.)	Number of Records	Date Observations Made	Duration of Instars (Days) Max.	Min.	Mean
89.9	10	May 30-June 5	6	5	5.2
85.0	17	May 29-June 14	11	3	6.0
75-80	4	June 1-June 13	10	7	8.2
70.0	15	June 4-June 16	11	10	10.2
Outside Check	48	June 4-June 16	11	5	7.02
		Average	9.08	6.0	7.32

Table 16. Length of Development of the Third Stage Nymphs of <u>Schistocerca obscura</u> at Different Temperatures.

Temperature (Degrees F.)	Number of Records	Date Observations Made	Duration of Instars (Days) Max.	Min.	Mean
89.9	8	June 4-June 23	18	7	11.25
85.0	7	June 4-June 22	17	10	13.42
70.0	17	June 14-July 10	23	10	14.11
Outside Check	45	June 10-July 1	15	5	10.09
		Average	18.02	8	12.21

Table 17. Length of Development of the Fourth Stage Nymphs of <u>Schistocerca obscura</u> at Different Temperatures.

Temperature (Degrees F.)	Number of Records	Date Observations Made	Duration of Instars (Days) Max.	Min.	Mean
89.9	5	June 14-June 30	15	8	11.9
85.0	4	June 11-June 26	12	12	12.66
70.0	9	June 23-July 12	18	16	17.71
Outside Check	47	June 11-July 9	15	7	13.11
		Average	15.0	10.75	13.06

Table 18. Length of Development of the Fifth Stage Nymphs of *Schistocerca obscura* at Different Temperatures.

Temperature (Degrees F.)	Number of Records	Date Observations Made	Duration of Instars (Days) Max.	Min.	Mean
89.9	4	June 29-July 9	13	10	10.40
85.0	4	June 23-July 2	12	8	11.55
70.0	(The experiment terminated before these specimens completed their nymphal stages.				
Outside Check	40	June 23-July 12	15	9	12.66
		Average	13.33	9.0	11.52

Table 19. Total Length of Nymphal Period of Nymphs of *Schistocerca obscura* Reared at Different Temperatures.

Temperature (Degrees F.)	Duration of Period (Days)
89.9	46.15
85.0	51.13
70.0	55.52
Outside Check	51.48
Average	51.13

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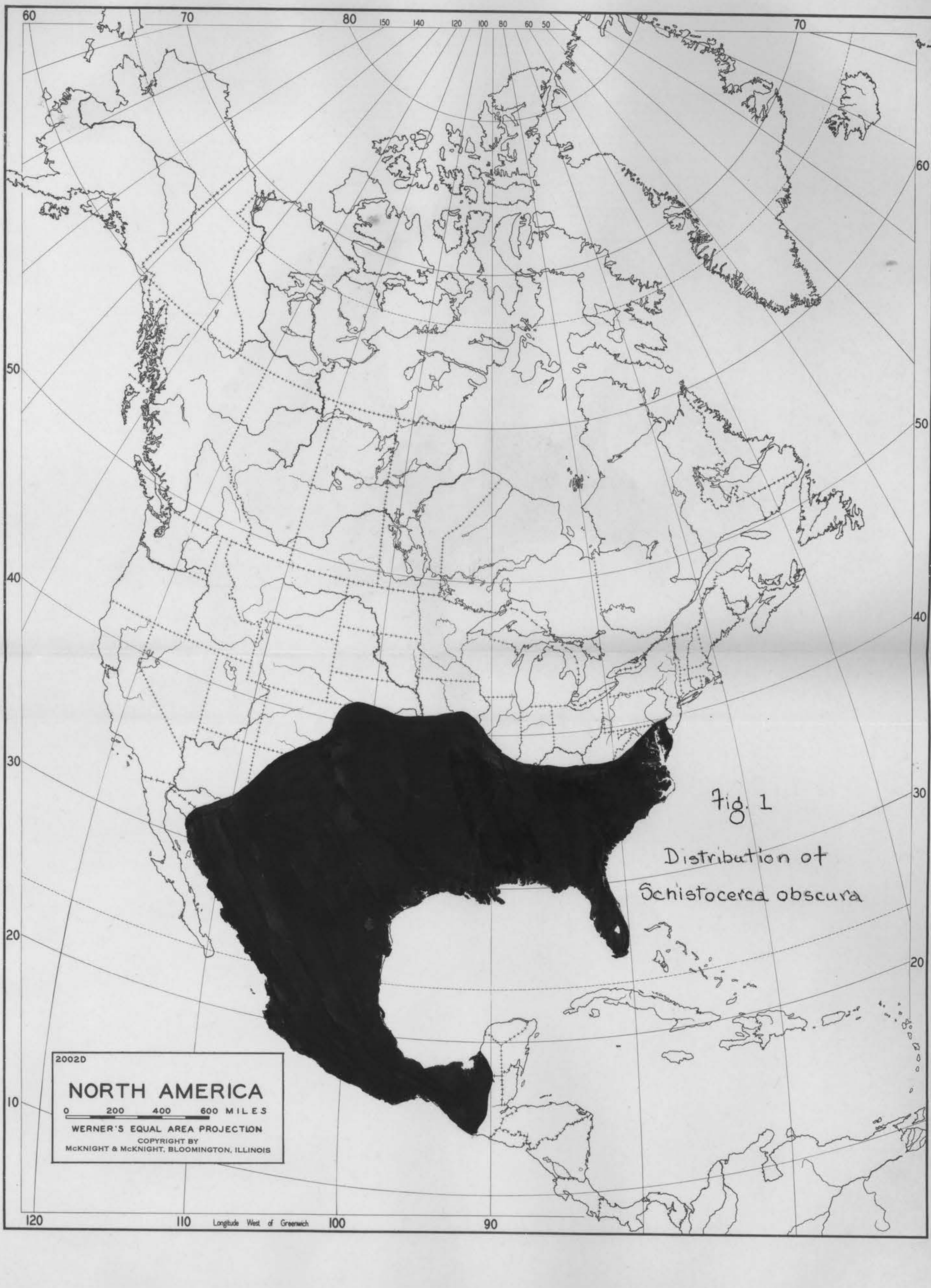
Fig. 1
Distribution of
Schistocerca obscura
2002D
NORTH AMERICA
0 200 400 600 MILES
WERNER'S EQUAL AREA PROJECTION
COPYRIGHT BY
McKNIGHT & McKNIGHT, BLOOMINGTON, ILLINOIS
Longitude West of Greenwich

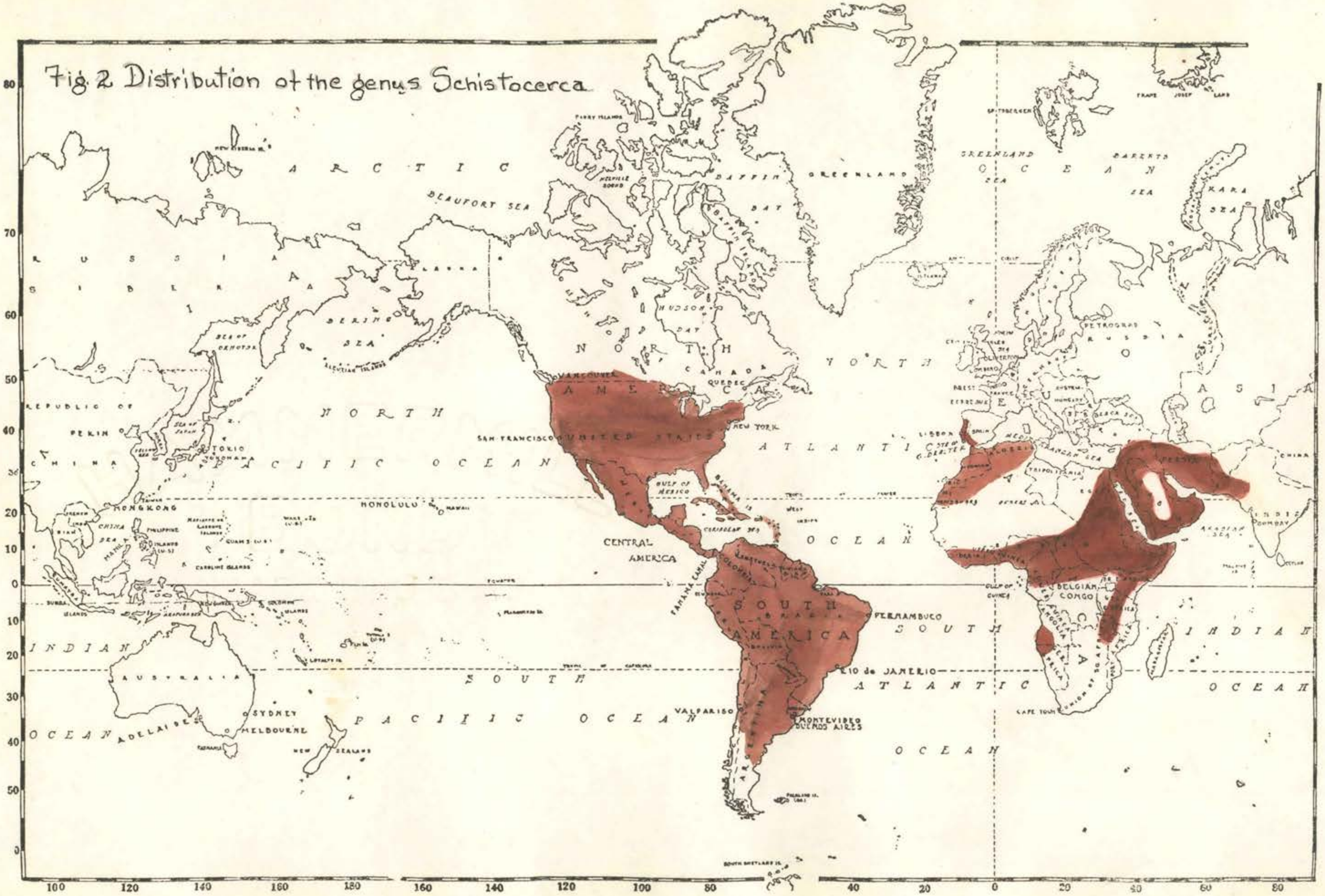

Fig. 2 Distribution of the genus Schistocerca

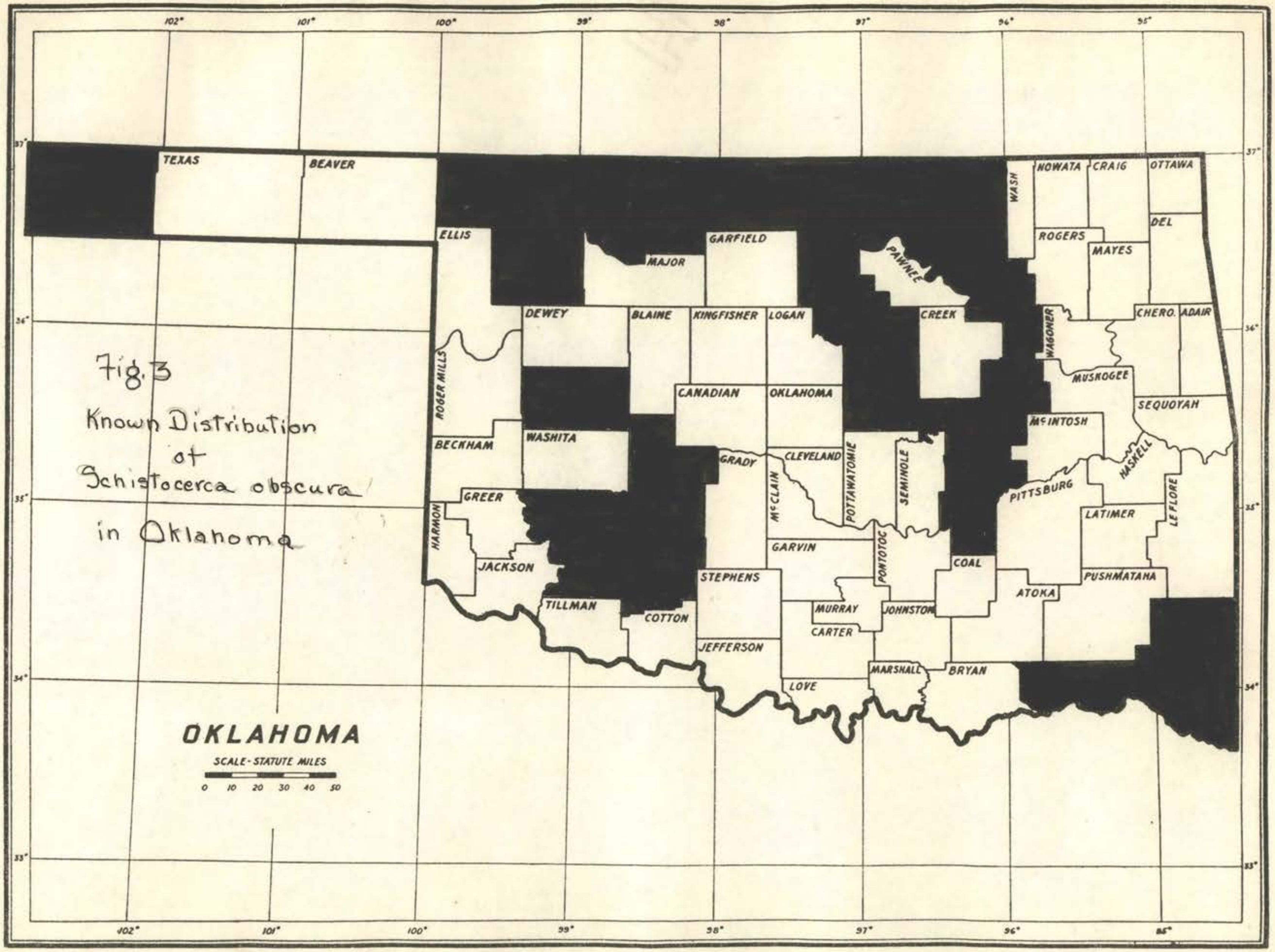

Fig. 3
Known Distribution
of
Schistocerca obscura
in Oklahoma

Fig. 4 Temperature of Greenhouse Stillwater, Oklahoma July 6 — Oct. 17, 1939

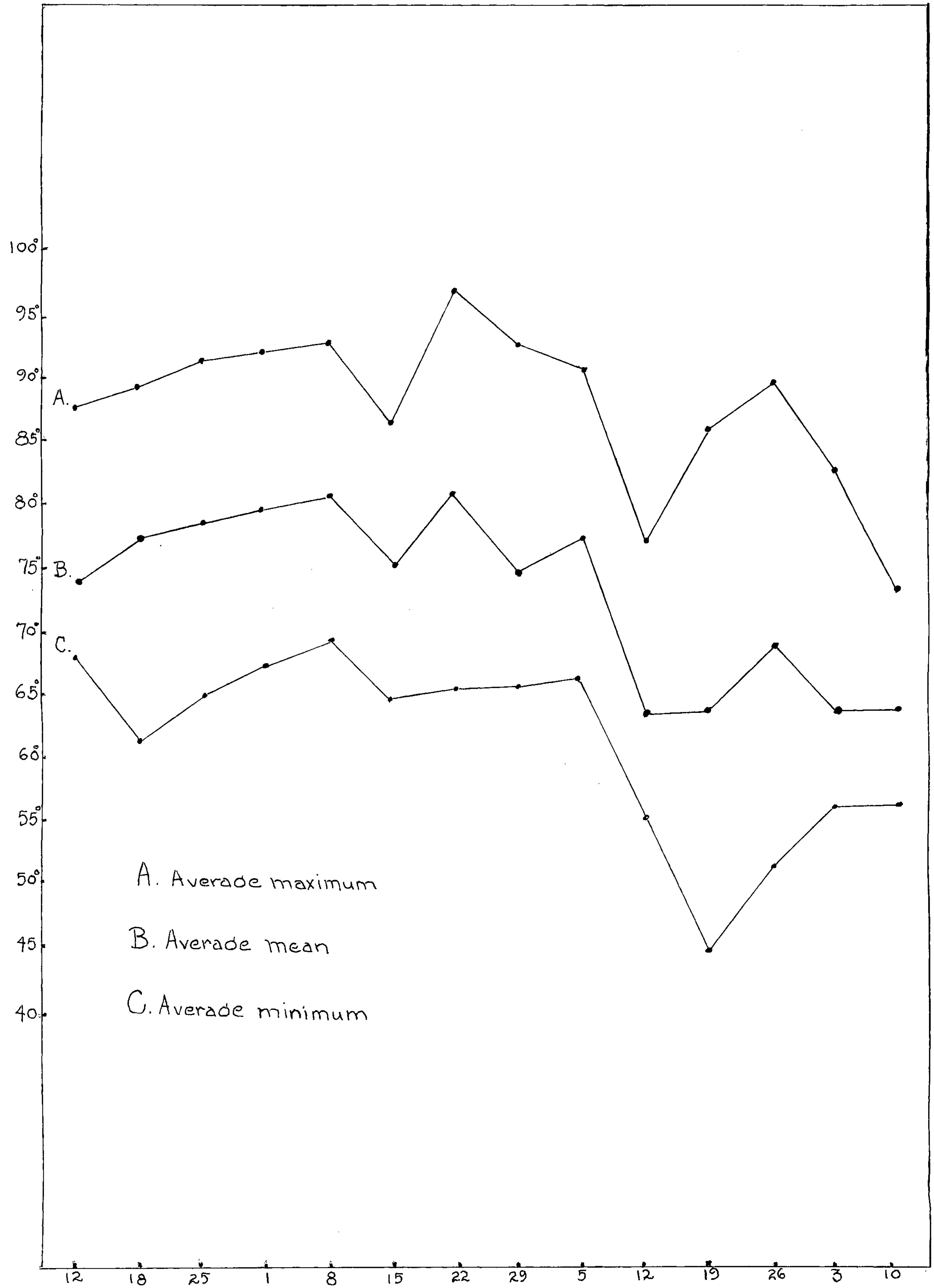

Plate I.

Fig. 1. Typical habitat for oviposition.

Fig. 2. Typical habitat for oviposition.

Plate II.

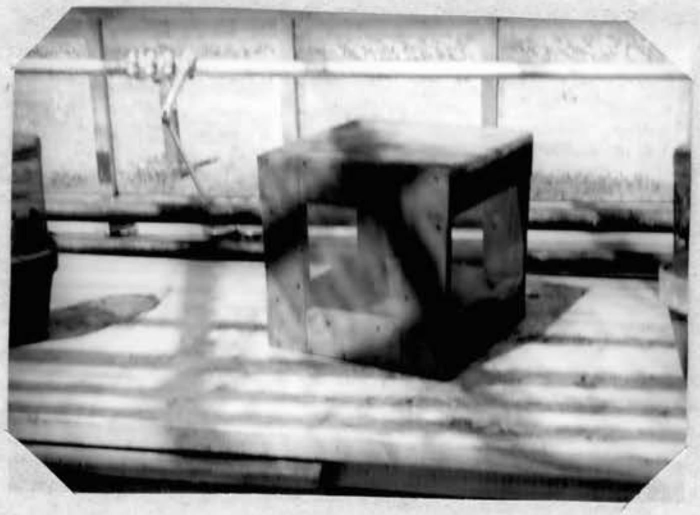

Fig. 1. Rearing cage for adults.

Fig. 2. Rearing cage for nymphs.

PLATE III.

Fig. 1. Typical coloration of crowded fifth stage nymph.

PLATE IV.

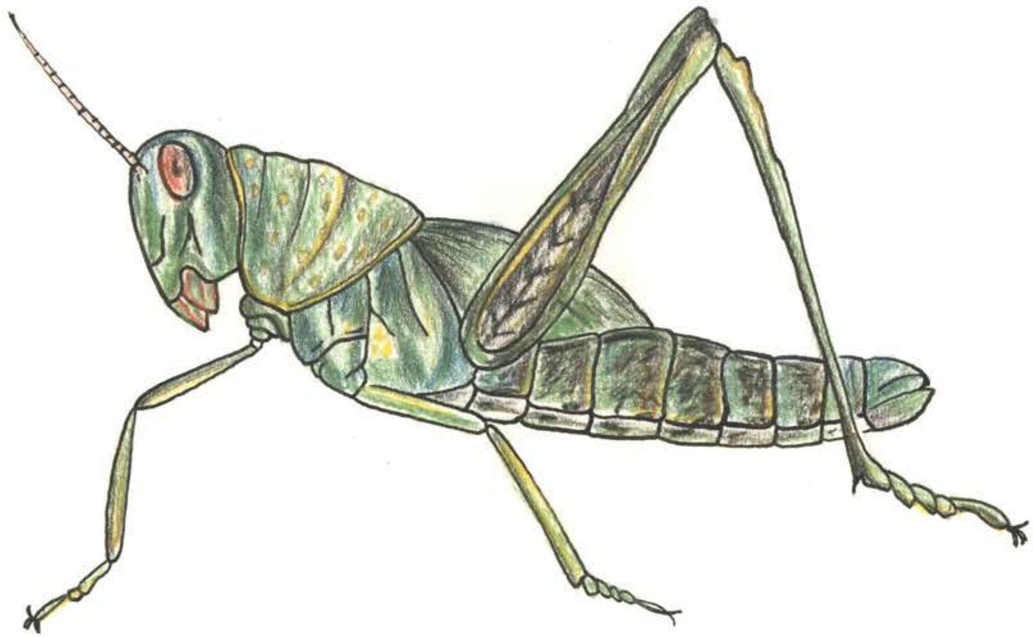

Fig. 1. Typical coloration of isolated fifth stage nymph.

Typist--Lucille Philips