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# The biology and control of certain species of crustacea of the families Oniscidae and Armadillidiidae.

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# THE BIOLOGY AND CONTROL OF CERTAIN SPECIES OF CRUSTACEA OF THE FAMILIES ONISCIDAE AND ARMADILLIDIIDAE

HATHAWAY 1947

# THE BIOLOGY AND CONTROL OF CERTAIN SPECIES OF CRUSTACEA OF THE FAMILIES ONISCIDAE AND ARMADILLIDIIDAE

By

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# THE BIOLOGY AND CONTROL OF CERTAIN SPECIES OF CRUSTACEA OF THE FAMILIES ONISCIDAE AND ARMADILLIDIIDAE

## Introduction

For the past sixty-seven years certain crustacean species of the families Oniscidae and Armadillidiidae, or woodlice, sowbugs and pillbugs as they are commonly called, have been known as pests by gardeners, greenhouse and mushroom house proprietors alike. The role of a minor pest is usually awarded them because of their depredations, but occasionally the damage they cause places them in the category of a major pest. An instance of the latter role focused the attention of the author upon these crustaceans.

Some preliminary literature research indicated that inadequate studies concerning the biology and control of these creatures had been conducted. Thus, for more than a year the author has sought to gain information on various fields of terrestrial isopod biology and control. The work has been divided into four phases or sections:

1. life history studies
2. temperature and humidity studies
3. distribution studies
4. control studies

Each of the four phases has been given separate treatment, and in order to preserve unity every phase includes a literature review, the investigational work of the author, a discussion of results, and conclusions. Lastly, the conclusions presented in each section have been brought together in a final summation of the thesis work.

The author believes that there has been a need for a compilation of the mass of literature pertaining to the land isopods of the families Oniscidae, Armadillidiidae and Cubaridae. For this reason the bibliography was compiled with the intention of making it as complete as resources available to the author would allow.

## Life History Studies

Research in the literature reveals the fact that other than for the outstanding contributions of a few authors, the life histories of terrestrial isopods have not been recounted frequently. Numerous other authors discuss various phases of the life history, but a need for organization of the information is apparent. The literature review as well as the investigational work will be confined chiefly to a discussion of one species of terrestrial isopod, Armadillidium vulgare (Latreille), although other species will be mentioned for purposes of comparison. Armadillidium vulgare (Latreille) is illustrated in plate 1.

### Literature review

In an early paper by Schöbl, 1879, observations on the breeding of Oniscidae are reported. The large number of specimens kept in confinement for the period of the observations consisted largely of Porcellio scaber Latreille. Schöbl notes that after fecundation the female becomes very inactive, losing the female orifices and receptacula seminis at the next moult. The fecundated eggs penetrate from the oviducts into the abdominal cavity and from this, by a median cleft in front of the sixth segment, into the incubatory cavity or marsupium formed by chitinous processes at the

Plate 1.

Armadillidium vulgare (Latreille)

under surface of the body. During incubation another set of ovula is ripened in the ovaries and fecundated by the spermatozoids which have remained in the oviducts or at the ovary entrance. A second brood is produced by the same female without copulation. A new moult follows afterwards by which the female orifices are again opened and new fecundation becomes possible. It is also mentioned that the spermatozoids are moveable to a certain degree.

De La Valette, 1883, largely confirms the views of Schöbl, 1879, but adds that the so-called oviduct discussed by other authors does not eject the eggs. Rather De La Valette states that the eggs become free by the spontaneous destruction of that part of the ovary which contains the mature eggs.

Pierce, 1907, provides a detailed account of the life history of <u>Armadillidium</u> <u>vulgare</u> (Latreille). He states that during April or May copulation is frequently noted out of doors. In this species the period of incubation is long and somewhere between 56 and 93 days. The exact period, however, could not be learned from the data because no individuals were secured in copula. The development of the eggs, the young embryos, and the little white young within the marsupium is easily watched from the exterior.

When young isopods leave the marsupium, they are pure white and have six pairs of legs. The first moult occurs within twenty-four hours after birth and the young still have only six pairs of legs. Between the fourteenth and eighteenth days another moult takes place and seven pairs of legs are present in the resulting third instar. Growth and moulting continue in the young, observations of moulting having been made on the 28th, 36th, 58th, and 68th days. After the first moult there is no regularity as to times of moulting in the brood, all depending upon the food supply. A slight darkening of the intestines is noted after the first moult, and by the 21st day the sowbugs are of a gray color throughout and under three millimeters in length. Their length does not exceed four millimeters in 58 days. No adult over fifteen millimeters in length was ever found and the specimen of this length was probably several years old. Reproduction is possible in females seven millimeters or more in length.

The process of moulting is described by Pierce in this same paper. He notes that the body of all sowbugs becomes a very dirty gray color before moulting. During the act of moulting a white border indicating the loosening of the old skin appears at the front edge of the fifth free thoracic segment, then another is observed on the sixth, and still another on the seventh. Finally the entire posterior half of the skin is free and the isopod is able to step out of it. About twenty-four hours is consumed in the process, and when completed the posterior half of the body is of a fresh slate color. The old anterior portion appears very dull. After the casting of the posterior portion, the anterior segments commence to loosen and are slid forward. The dorsum of the third and fourth thoracic segments is loosened before the legs of these segments are released. In order to hold the animal in position during the moulting of the anterior portion of the body, the last two pairs of legs are used in the very young and the last three pairs of legs in later stages. The anterior legs cannot be used for some time after they become free. The antennae are the last to be withdrawn.

Regeneration of parts was observed in the antennae and legs. Several times, individuals with aborted members were noticed, and these latter would gradually attain normal length. In each individual, budding of the succeeding segment would be observed and finally the member would be normal, the regenerated part remaining white for some time.

Although Aubin, 1914, did not work with either <u>Armadillidium</u> <u>vulgare</u> (Latreille) or <u>Porcellio</u> <u>scaber</u>

Latreille in his moulting studies, he does present an excellent description of ecdysis in Porcellio laevis Latreille and Porcellio dilatatus Brandt. The process is first noted when the creature becomes generally listless and may in some cases, but not in the majority, try to hide. Within twenty to twenty-four hours the posterior tergal joints are distinctly gaping, the connecting integument is of glass-like brilliancy, and a faint white line is visible at the extreme edge of pleura and along the posterior edge of terga. After five hours the three posterior thoracic and all the abdominal segments have become quite white, the last three pairs of legs are not used but are dragged uselessly along the ground, the front of the fifth segment is beginning to show at the fracture of the old shell, droplets of liquid exude at the fracture, and a careful examination reveals that there is a film of liquid interposed between the old shell and the underlying cuticle. The rhythmical elongation and contraction of the body, noticeable more especially between the fourth and fifth segments, marks the constant effort that the animal makes to free itself. These contractions continue throughout the process of moulting and for some time after. The whole of the fifth segment is exposed an hour later except for the points of the pleura which are folded back and still held by the edge of the old shell.

Ten minutes later half of the sixth tergum is showing, and the points of the fifth pleura are free; the tail-appendages are entirely withdrawn so that extremities occupy the center of the carpopodite of the old shell. The portions already moulted participate in the contractions, and the worm-like undulations distinctly show that the new cuticle is soft. In another five minutes the thorax is free as well as the pleura of the third abdominal segment, and in five minutes more the animal crawls free. The increase in size of the animal takes place gradually in the short period between the moment of ecdysis and the solidification of the new shell. During this period of growth the contractions continue at the rate of about two per minute, and in the course of about half an hour the soft posterior half of the body has become wider than the anterior half. The animal crawls about slowly using only the anterior legs, and the cuticle has now lost its glossy appearance and become smoky.

After casting the posterior portion of the skin, the animal remains quiescent for two or three hours before beginning to use the posterior legs. The strength of these legs is then tested by efforts to support the body on them.

It can be observed through the shell that the tail appendages play a distinct part in ecdysis. At each contraction of the body the tail appendages move forward with their upturned points resting against the interior surface of the old shell, and with the elongation that follows they retain their position and the shell is moved backward.

Concerning the cast skin, Aubin notes that it is frequently examined but not eaten by the moulting specimen. However, it is often eaten by other individuals.

The animal becomes inactive in some two to four days after the moult of the posterior half is completed, and preliminary whitening of parts of the anterior portion of the body is then observed. The flagellae are the first parts to whiten. Gaping of the carapace joints occurs, and the glossy connecting integument is seen. Expansion and contraction of the body begins within twenty-four hours, and each contraction is accompanied by a strong downward bending of the posterior half of the body. The eyes and lobes lose their color and become transparent shortly after the contractions begin. Uselessness of the limbs and antennae becomes apparent.

If the moulting specimen is examined under a strong light about an hour after the contractions begin, it is observed that the antennae and legs have withdrawn from the skin to some extent. After a period of variable length the edge of the fourth tergum appears beneath the old shell, and the same phases are gone through as in the case of the posterior half of the body. When the free edge of the old shell reaches the level of the eyes, all of the legs are liberated nearly simultaneously.

Concerning the remainder of the moulting process, Aubin states that "after the feet are free the shell is still pushed forward with the antennae; the first joints of the peduncle being in contact along their whole length and resting against the inside of the old shell in the median line, the more proximal joints are used after the fashion of lazy-tongs; as soon as the peduncles are entirely clear of the cast shell the flagellae are freed by a sudden separation of the antennae, which are at once folded back so that the flagellae rest, along their whole length, against the head and first tergum with the points directed upwards. Except for the contractions of the body, the animal remains motionless for some minutes, and then begins to walk with a peculiar gait-the anterior four pairs of legs being still soft it uses only the fifth, sixth and seventh pairs, with the result that it overbalances at every step and falls forward so that the metastoma strikes the ground."

Aubin emphasizes the point that throughout the whole ecdysis there is no such thing as "crawling out of the shell". In fact with the exception of the moment when the last abdominal pleura are freed and a slight forward movement is made to free the tail-appendages, the animal remains stationary, casting of the shell being accomplished by the contractions of the body.

No joints properly so-called exist between the terga at the moment of ecdysis. Rather it can be observed that the connecting integument is continuous from the posterior edge of one tergum to the anterior edge of the succeeding one, the infolding of the integument to form the normal joint not being entire until half an hour after complete ecdysis. The joints appear to infold in the order of their emergence from the old shell.

Aubin, 1914, notes in his account that "in some cases, at the period when the legs and antennae are withdrawn within the old shell before the terga have moved, the extremities are eaten by other woodlice and the individual so attacked dies, being unable to complete ecdysis. This is due to the soft extremities being injured, and the coagulation of the exuded blood, by fastening the limb to the shell, prevents further withdrawal."

Several writers observed attempts by other individuals to eat the soft parts of a newly moulted specimen, but Aubin didn't make observations that confirmed the statement. He does mention, however, that a newly moulted specimen objects to the soft parts being touched.

Blake, 1929a, records that the terrestrial isopods feed largely on living or dead vegetable matter. They will not refuse animal food, even weaker members of their own group.

Miller, 1938, states that laboratory maintained specimens of terrestrial Isopoda consumed carrot and potato slices with avidity.

That woodlice under laboratory conditions will eat potato slices sprinkled with water is attested by Taylor, 1938.

Metcalf and Flint, 1939, present a survey of the life history of woodlice. They note that woodlice "reproduce by means of eggs which are retained in the marsupium of the females for about two months. Young sowbugs, on hatching, do not leave the marsupium of the female for some time; twenty-five to seventy-five constitute a brood. The young are similar to adults except in size. About one year is required for the young bugs to reach full growth. All stages of the bugs will be found in infested greenhouses at the same time."

Howard, 1940, provides an interesting paper that is concerned with the genetics of Armadillidium vulgare (Latreille). He states that this species is easy to breed and matures at one year. Females carry the eggs about in a brood pouch and produce broods of 50-150 young per year. Few broods show a 1:1 sex ratio. Many broods consist entirely or predominantly of males or females only. The type of brood depends upon the female parent, since a single male may produce any sort of brood when mated to different females. In populations around Cambridge, England there is a marked excess of females over males (28.2 per cent), and a preponderance of female-producing females.

Imai and Sajiro, 1940, make a comparison of the number of chromosomes in the secondary spermatocyte of Porcellio scaber Latreille shows twenty-eight V-shaped chromosomes, while the more primitive isopods such as Asellus and Trichoniscus have only seven or eight. The chromosome number is twenty-seven or twenty-eight in more specialized forms like Armadillidium and Porcellio.

An account of the oniscoid moult is given by Verhoeff, 1940b. In this paper it is stated that the members of the family moult in two stages. First the posterior half moults and this is followed one and one-half through four or five days later by a moulting of the anterior half. An adhesive fluid exudes from the whole surface of the body during the moult, and this fluid also dissolves the calcium carbonate in the exuviae. The fluid accumulates between the old and the thin chitinous surface of the newly forming exoskeleton and is a medium for absorption of much of the material of the old exoskeleton back into the body fluids for use in making the new skin. The exuviae are also devoured so that not much material is lost at a moult. Adhesive forces of the fluid between the new and old armor, however, hinder the moulting process and are the chief cause of the frequent deaths from inability to complete the moult. The cause of the pause between the moulting of the two body halves is said to be the necessity for the posterior half to harden sufficiently so that its peristaltic contractions can assist the moulting of the anterior half.

Land isopods have three larval moults, one pre-adult moult, and ten or more moults in the adult stage.

Heeley, 1941a, in an excellent presentation of the life histories of some terrestrial isopods includes much data on <u>Armadillidium</u> <u>vulgare</u> (Latreille). Heeley states that under laboratory conditions Armadillidium vulgare (Latreille) can be kept almost indefinitely if a little chalk is provided in addition to the regular food. Concerning the feeding of woodlice, it is noted that the creatures will consume an enormous amount of food if it is available and yet an extremely small amount has been found to keep them alive for long periods of time.

Heeley gives a number of definitions that are of value when discussing isopod life history data. The time between the moult forming the maternal brood pouch and the bursting of the egg membranes within the pouch is termed the "embryonic period". The"larval period" is designated as the time between the bursting of the egg membranes and the liberation of the brood from the brood pouch. That moult of the female which is the first in the year to give rise to the brood pouch is regarded as the "first maternal moult". The "second maternal moult" is the moult which occurs a short time after the liberation of the brood.

These definitions were used in a discussion of Armadillidium vulgare (Latreille), and the following average of results was obtained. The date of the moult forming the brood pouch occurs from mid May to early July. The embryonic period in the brood pouch is thirty-three days, while the larval period in the brood pouch is eight days. One hundred and thirteen is the number of larvae liberated, and the period between the first and second maternal moults is seventy-two days.

Heeley noted that the young of *Armadillidium vulgare* (Latreille) require more moisture than do the adults of the same species. Since the young of this species require a different environment from the adults, a high percentage of the young of *Armadillidium vulgare* (Latreille) do not survive. This fact is stated by Heeley to be the reason why *Armadillidium vulgare* (Latreille) has such large broods.

Heeley, 1941, assembled data concerning the average age of the young after liberation from the marsupium at the time of the first eight moults. The average age at each of the first eight moults was observed to be 1, 22, 41, 60½, 87, 117, 138, and 160 days respectively. As regards moulting Heeley also states that "unlike the adult, the young continue to moult regularly throughout the winter, and increase in size at a constant rate. Observations upon the successive moults beyond the age of six months have not been carried out on a large scale, but the behaviour of isolated specimens showed that moults continue to occur in regular succession at about monthly intervals up to the commencement of the breeding season of the next year, when they fall into line with the moults of adults." Females also appear to moult at regular intervals during and immediately subsequent to the breeding period of life.

A well-marked seasonal periodicity of the phases of breeding activity was recorded for many species of terrestrial isopods including Armadillidium vulgare (Latreille). The latter species was observed to have one brood during the short breeding season.

In this same paper Heeley records the features of the moulting process that are common to all species studied in his experiments. His discussion coincides with that of Aubin, 1914, and Verhoeff, 1940. He agrees with Aubin, 1914, that "crawling out of the shell" does not occur at any time during the moulting process.

Howard, 1942, presents data on the genetics of Armadillidium vulgare (Latreille). He states that three types of female occur in this species of woodlouse. Amphogenics produce broods with a 1:1 sex ratio, while monogenics produce broods almost wholly of one sex. Female broods are produced by thelygenics, and male broods by arrhenogenics. The genetic ratios for autosomal characters show normal segregation and no parthenogenesis. Armadillidium populations usually show an excess of females that is often considerable. Of the females about half are amphogenic and half thelygenic. Howard stresses the significance of monogeny as a mechanism enforcing out-breeding.

Vandel, 1942, points out that in addition to certain coaptations, rolling of isopods necessitates modification of the marsupium. He also notes that females cease feeding when brood development inhibits food uptake.

Howard , 1943, mentions that the sperms of *Armadillidium vulgare* (Latreille) may remain in a viable condition within the female more than one year.

Collinge, 1944c, records that sexes in woodlice are distinguishable soon after the fifth moult, but occasionally maturity is reached more rapidly.

## Investigational work of the author

For over a year the author has maintained cultures of *Armadillidium vulgare* (Latreille), and in the course of that time has made many observations concerning the life history of the species. However, much of the information has already been recorded carefully by other authors, and repetition here would be useless. The author has accumulated much data concerning the moulting process, but this merely serves to corroborate the excellent work of Aubin, 1914; Pierce, 1907; Verhoeff, 1940b; and Heeley, 1941a. In spite of the completeness of the work of the above authors, the writer has obtained some data that should be of value. This data includes information on culture methods, the time of the first moult, the size of the broods at the time of liberation from the marsupium, and regeneration.

## Culture methods

For the most part, cultures of *Armadillidium vulgare* (Latreille) were kept in glass jars of one gallon capacity to which sufficient cow manure and water had been added to furnish the need for food and moisture. When, during the moulting and regeneration studies, it was desired to observe a few specimens, small cultures were found to be feasible if maintained in Petri dishes to which cow manure and a little water were added. Two or three drops of water from an eye dropper were usually supplied every day or so to the manure in the Petri dishes. The manure retained the water well, and this ability was essential because of the moisture requirements of isopod specimens.

Since the author usually maintained four isopods in each Petri dish, it was often desirable to differentiate between specimens. The problem of identification was found to be easily solved if each specimen was marked with a different spot of colored paint on the dorsal surface. Early experiments indicated that various dyes would not adhere to the isopod dorsal surface or remain sufficiently visible. Concerning the paint it was learned that only aluminum and gold would adhere well, but every other color applied would not remain. Because of this fact, a spot of aluminum or gold paint was always placed on the dorsal surface of the specimen first, and then any other desired color was applied readily over these paints.

In the moulting studies the painting of specimens proved to be particularly valuable, since a quick glance at any specimen revealed whether or not a moult had occurred. It was known that the posterior portion of the body had moulted if the paint spot terminated with the fourth thoracic segement, and it was readily discernible that a complete moult had taken place if the paint spot disappeared. The presence of the paint did not appear to injure the specimen or interfere with the moulting process.

It was determined that Armadillidium vulgare (Latreille) ate beet pulp readily. The fact that mould formed quickly on the beet pulp if excessive moisture was present, however, proved to be a disadvantage in the use of the material as a culture medium.

Armadillidium vulgare (Latreille) also was found to feed on ground oats or soy bean flour but not to the extent that the species fed on manure or beet pulp.

### Moulting process

Results of January 20 and January 21, 1947 observations on young of <u>Armadillidium vulgare</u> (Latreille) to determine the length of the first instar.

| specimen number | time of emergence | time of moulting of posterior portion of body | time of moulting of anterior portion of body | number of hours necessary to complete first moult |
|---|---|---|---|---|
| 1 | 8:00-9:00 A. M. | 4:30-5:00 P. M. | 1:05-1:35 A. M. | 16 hrs., 35 mins. |
| 2 | " " " | 4:30-5:00 P. M. | 1:00-1:30 A. M. | 16 hrs., 30 mins. |
| 3 | " " " | 2:30-3:00 P. M. | 11:30 P.M.-12:00 M | 15 hrs. |
| 4 | " " " | 6:00-7:00 P. M. | 2:05-2:35 A. M. | 17 hrs., 35 mins. |
| 5 | " " " | 6:00-7:00 P. M. | 3:30-4:00 A. M. | 19 hrs. |
| 6 | " " " | 2:30-3:00 P. M. | 11:30 P.M.-12:00 M | 15 hrs. |
| 7 | " " " | 6:00-7:00 P. M. | 3:30-4:00 A. M. | 19 hrs. |
| 8 | " " " | 2:00-2:30 P. M. | 11:15-11:45 P. M. | 14 hrs., 45 mins. |
| 9 | " " " | 2:00-2:30 P. M. | 11:30 PM.-12:15 AM | 15 hrs., 15 mins. |
| 10 | " " " | 4:30-5:00 P. M. | 1:00-1:30 A. M. | 16 hrs., 30 mins. |
| 11 | " " " | 6:00-7:00 P. M. | 3:30-4:00 A. M. | 19 hrs. |
| 12 | " " " | 6:00-7:00 P. M. | 3:00-3:30 A. M. | 18 hrs., 30 mins. |
| 13 | " " " | 4:30-5:00 P. M. | 12:05-12:35 A. M. | 15 hrs., 35 mins. |
| 14 | " " " | 4:30-5:30 P. M. | 12:05-12:35 A. M. | 15 hrs., 35 mins. |

Table 1.

## Studies of moulting and first and second instars

Although Pierce, 1907, and Heeley, 1941a, state that the first moult occurs within twenty-four hours after the young are released from the marsupium, the author found no record of detailed studies concerning this moult. Studies of the time of the first moult were therefore made by the author, and most of the results of these studies are in table 1.

## Discussion of results

The observations were made on young from one female. Each young from this female was placed, for purposes of observation, in a tin salve box cover to which a small amount of moistened cow manure was added. A square of glass was placed over each cover and numbered for identification purposes. All observations were taken hourly and with the aid of a binocular microscope.

Using the data presented in table 1 it is learned that slightly over eight hours from the time of emergence from the marsupium is the average time required to complete the casting of the skin from the posterior portion of the body. The average number of hours needed to cast the entire skin is found to be nearly seventeen. It is interesting to note that in two cases moulting of the posterior portion was accomplished in five and one half hours.

Although data on all forty-nine of the young from the one female are not given, it is known that four and one half hours were taken for the complete emergence of the young from the marsupium.

In two instances the author recorded the time that the rhythmical worm-like movements to cast the skin, mentioned by Aubin, 1941, and Heeley, 1941a, continued after the skin was cast. The time recorded was twenty minutes in the first case, and in the second case slightly over twenty minutes. Heeley, 1941a, notes that the rhythmical elongation and contraction of the body occurs every five seconds. The writer noted, however, that after the casting of the skin these movements although rapid at first gradually became slower until they ceased in the time previously indicated.

Seven pairs of legs appear in the young after the second moult. Because of this interesting occurence, the author made observations to determine whether or not the second moult takes place at a regular interval after the young are released from the marsupium. The author's observations were based on thirty-nine young from seven different females of the species Armadillidium vulgare (Latreille).

Pierce, 1907, states that the second moult occurs between fourteen and eighteen days after the first

Age of various numbers of young of
*Armadillidium vulgare* (Latreille)
at the time of the second moult.

| family number | age in days | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| 1 | | 1 | 1 | | | | | | | 1 |
| 2 | | | | | | | | | | 1 |
| 3 | | | | | 5 | | | | | |
| 4 | | | 12 | | | | | | | |
| 5 | 3 | | 1 | | | | | | | |
| 6 | | | 5 | 3 | | | | | | |
| 7 | | | | | 6 | | | | | |

TABLE 2.

moult, while Heeley, 1941a, observed the second moult to occur when the young were from fifteen to twenty-seven days old. Heeley records twenty-two days as the average.

Table 2 records the results of the author's studies. From this table it is observed that all young moulted for the second time in twenty-one through thirty-one days, the average number of days being nearly twenty-five.

At no time during the studies of the moulting process was a female seen to moult while young were in the marsupium.

Aubin, 1914, in studies of Porcellio scaber Latreille and Porcellio dilatatus Brandt makes the statement that "specimens frequently examine the cast shell, but make no attempt to eat it, though it is often eaten by other individuals." The author throughout the thesis studies, however, however, has observed many cases where the moulting specimen of Armadillidium vulgare (Latreille) ate its cast skin. In fact the skin appeared to be eaten by the moulting specimen in the majority of cases.

Both Aubin, 1914, and Heeley, 1941a, state that after the skin of either half is cast the legs involved in the casting of the skin drag uselessly and cannot be

Number of young (larvae) liberated by
females of *Armadillidium vulgare* (Latreille).

| date | specimen number | number of young | length of female at time of brood emergence | date | specimen number | number of young | length of female at time of brood emergence |
|---|---|---|---|---|---|---|---|
| 9/17/46 | 1 | 34 | - | 1/27/47 | 23 | 45 | 8.5 mm. |
| 9/21/46 | 2 | 39 | - | 1/11/47 | 24 | 58 | - |
| 10/3/46 | 3 | 19 | 7 mm. | 1/28/47 | 25 | 47 | 10 mm. |
| 9/16/46 | 4 | 101 | - | 1/31/47 | 26 | 71 | 10 mm. |
| 10/11/46 | 5 | 33 | - | 1/27/47 | 27 | 26 | 8.5 mm. |
| 9/10/46 | 6 | 25 | - | 1/31/47 | 28 | 31 | 9 mm. |
| 10/12/46 | 7 | 50 | - | 1/24/47 | 29 | 31 | 8.5 mm. |
| 8/31/46 | 8 | 76 | - | 1/16/47 | 30 | 30 | 8 mm. |
| 9/4/46 | 9 | 24 | - | AVERAGE | | 47.8 | 9.6 mm. |
| 9/1/46 | 10 | 31 | - | | | | |
| 9/9/46 | 11 | 46 | - | | | | |
| 1/29/47 | 12 | 64 | 9 mm. | | | | |
| 1/26/47 | 13 | 48 | 9.5 mm. | | | | |
| 1/16/47 | 14 | 44 | 9 mm. | | | | |
| 1/26/47 | 15 | 47 | 9.5 mm. | | | | |
| 1/30/47 | 16 | 37 | 9.5 mm. | | | | |
| 1/20/47 | 17 | 49 | 11 mm. | | | | |
| 1/28/47 | 18 | 76 | 11.5 mm. | | | | |
| 1/25/47 | 19 | 68 | 10 mm. | | | | |
| 1/21/47 | 20 | 57 | 10 mm. | | | | |
| 1/23/47 | 21 | 60 | 11 mm. | | | | |
| 1/25/47 | 22 | 66 | 12 mm. | | | | |

Table 3.

used. They gradually return to normalcy. The author noted that the legs remained useless for a considerable period, and from numerous observations it was determined that after the moulting of the posterior half, the anterior half could not be cast until the posterior three pairs of legs were capable of clinging to the surface on which the isopod rested. In one instance the legs required somewhat over fifteen hours after the moulting of the posterior half before they could aid in propulsion.

As reported by many authors, the isopod young have but six pairs of legs until after the second moult when the seventh pair is acquired. The author observed that after the second moult the newly acquired seventh pair of legs is much weaker than the fifth and sixth pairs which cast their skin at the same time. This weakness continues until after the fifth and sixth pairs of legs have regained usefulness.

### Size of the broods

In numerous instances gravid female specimens of *Armadillidium vulgare* (Latreille) were maintained separately and the young counted as they emerged from the marsupium of each individual. Table 3 records data on the size of the broods and in many cases the length of the female at the time of brood emergence.

## Discussion of results

A study of the data given on table 3 reveals that the average number of the larvae at the time of emergence is 47.8. Heeley, 1941a, gives 113 as the average brood number in Armadillidium vulgare (Latreille) for young liberated from the middle of May to early July. From the author's table 3 it is observed that specimens 1-11 liberated larvae from August 31, 1946 through October 12, 1946. In the case of specimens 12-30, the larvae were liberated from January 11 to January 31, 1947. Heeley's studies were conducted in the British Isles and for that region he states that the breeding season is only from the middle of May to early July. Since the broods maintained by the author were observed at a much later date than those observed by Heeley, 1941a, this fact may explain the difference in the data concerning average brood size.

Because it was believed that the length of the female might have some bearing on the number of larvae, data on the length of the female at the time of liberation from the marsupium are given in table 3. A study of the data indicates that little correlation exists between the length of the female and the number of the larvae liberated. It can be observed, though, that the smallest number of young recorded was liberated by a

Results of regeneration studies.

| specimen number | date of appendage removal | appendage removed | point at which appendage was cut | date of first moult after appendage was removed | remarks |
|---|---|---|---|---|---|
| 1 | 8/23/46 | right antenna | lower fourth of fifth segment | 9/11/46 | antenna regenerated of nearly normal length |
| 2 | 8/23/46 | right antenna | middle of fourth segment | 9/18/46 | antenna regenerated of nearly normal length |
| 3 | 8/23/46 | right antenna | base of first segment | 9/19/46 | antenna regenerated of nearly normal length |
| 4 | 10/29/46 | right antenna | tip of first segment | 11/2/46 | no regeneration |
| 5 | 10/29/46 | right antenna | lower fourth of fifth segment | 11/9/46 | very small regenerated bud present |
| 6 | 10/29/46 | right antenna | base of sixth segment | 11/22/46 | antenna regenerated of nearly normal length |
| 7 | 10/29/46 | left antenna | tip of fourth segment | 11/28/46 | antenna regenerated of nearly normal length |
| 8 | 10/29/46 | right antenna | tip of first segment | 11/29/46 | antenna regenerated of nearly normal length |
| 9 | 10/29/46 | left antenna | tip of first segment | 12/6/46 | antenna regenerated of nearly normal length |
| 10 | 10/29/46 | left leg fourth pair | lower third of second segment | 12/4/46 | leg regenerated of nearly normal length |
| 11 | 10/29/46 | right leg second pair | lower third of second segment | 12/6/46 | leg regenerated of nearly normal length |
| 12 | 10/29/46 | left leg, fifth pair | base of third segment | 12/6/46 | leg regenerated of nearly normal length |
| 13 | 10/29/46 | left leg, sixth pair | base of first segment | 12/9/46 | leg regenerated of nearly Normal length |

Table 4.

female only seven millimeters in length. A longer series of records might provide more indicative results.

## Regeneration

Although numerous authors have mentioned the occurrence of regeneration in terrestrial isopods, the author conducted a few tests on *Armadillidium vulgare* (Latreille) with the intention of obtaining answers to two questions believed to be unanswered. The two questions follow.

1. Is the length of a regenerated antenna directly proportional to the number of segments removed from the original antenna?

2. How quickly can an antenna or a leg be regenerated?

In order to gain information concerning regeneration, the author removed various lengths of antennae or legs. Removal of the parts was accomplished by cutting with scissors or tying off with thread. Each specimen was spotted with paint, as indicated in the author's discussion of culture methods, and placed in a separate Petri dish containing moistened manure. Table 4 records the data obtained in the regeneration studies.

## Discussion of results

A study of table 4 indicates that all regenerated antennae or legs were nearly normal in length after the first moult following the removal of the particular appendage. This was found to be true even when the number of segments removed from the original appendages varied greatly.

In the case of specimens 4 and 5, it is seen that not sufficient time elapsed for regeneration to occur between removal of the appendage and the first moult after removal. Specimen 5, however, revealed some evidence of regeneration, and this was visible eleven days after removal of the antenna. Specimen 1, which moulted nineteen days after antenna removal, had regenerated an appendage of nearly normal length. It can be assumed, therefore, that the regeneration of an antenna of nearly normal size requires a length of time between eleven and nineteen days. More than one moult is required to produce an antenna of normal size.

## Conclusions

Numerous conclusions can be drawn from the life history studies of the author. These conclusions follow:

1. Small cultures of *Armadillidium vulgare* (Latreille) are easily maintained in Petri dishes containing moistened cow manure to supply the need for moisture and food.

2. Beet pulp is a good culture medium for Armadillidium vulgare (Latreille) but mould forms readily on the material if too much moisture is present.

3. During the first moult in Armadillidium vulgare (Latreille), slightly over eight hours is the average time required to complete the casting of the skin from the posterior portion of the body.

4. The first moult in Armadillidium vulgare (Latreille) requires an average of seventeen hours for completion.

5. Moulting of the posterior portion of the body may take place in five and one half hours during the first moult in Armadillidium vulgare (Latreille).

6. The rhythmical movements that assist in casting the skin of Armadillidium vulgare (Latreille) may continue for slightly over twenty minutes after the moulting of a body portion.

7. Based on the thesis studies, an average of twenty-five days is required for Armadillidium vulgare (Latreille) to undergo the second moult.

8. Armadillidium vulgare (Latreille) usually eats the cast skin after moulting.

9. Armadillidium vulgare (Latreille) cannot cast the skin of the anterior portion of the body until the

legs of the posterior portion have regained the usefulness lost during the first part of the moulting process.

10. Fifteen hours may be required before the legs regain normal functions after a moult.

11. Studies indicated that the average number of the young liberated by *Armadillidium vulgare* (Latreille) from September to February is 47.8.

12. Regenerated antennae or legs are nearly normal in length after the first moult following the removal of the particular appendage even though the number of segments removed from the original appendage varies greatly.

13. The length of time required to regenerate an antenna of nearly normal size in the case of *Armadillidium vulgare* (Latreille) is between eleven and nineteen days.

## EFFECT OF TEMPERATURE AND HUMIDITY

### Literature Review

The number of references concerning the effect of temperature and humidity on species of Oniscidae and Armadillidiidae is very small. This may seem somewhat surprising when it is considered that specimens are readily collected, easily maintained under laboratory conditions and large enough to permit ease of studying. Although literature on the precise subject is extremely limited, much work has been done in the field of temperature and humidity effect on insects. Because many of the observations made concerning insects undoubtedly apply also to the Oniscidae and Armadillidiidae, it is proposed to present some of the fundamental concepts of the former studies in order that the experimental work of this portion of the thesis may be clarified.

The author will first consider the effect of temperature and humidity separately and finally will present material on the combined effects of the two ecological factors. Uvarov, 1931, in his valuable paper correlates the work of many authors and it is to this work and that of Chapman, 1931, that the writer is greatly indebted.

## Temperature or heat

Chapman, 1931, states that there are two types of animals as far as their relationship to temperature is concerned; 1. poikilothermic or cold-blooded animals, 2. homoiothermic or warm-blooded animals. The poikilothermic animals, of which the insects and isopods are members, have no particular mechanism for regulating body temperature. The homoiothermic animals, on the other hand, represented by the mammals and birds have a definite means of regulating the temperatures of their bodies. In these latter animals, body temperature is maintained more or less constant regardless of external temperature while in the former the body temperature is largely determined by the temperature of the environment.

It is well known that the activity of poikilothermic animals is confined to certain limits of temperature above and below which they become inactive. Shelford, 1927, used the term "temperature threshold" to express the minimum effective temperature at the lower limit of activity and the maximum effective temperature at the high point of activity. Chapman, 1931, states that below the minimum effective temperature there is a dormancy zone and at a still lower point death occurs. The low temperature at which death occurs may be termed the absolute minimum temperature. At high temperatures there is another zone of dormancy and also a death point above this zone. Death at the high temperature point occurs at what may be called the absolute maximum temperature. Chapman, 1931, further notes that between the limits of the minimum and maximum effective temperatures, there is a zone of activity for poikilothermic animals. The same author also states that there is a point within this zone which may be termed the optimum temperature and at this point life of the animal is at an optimum but "not necessarily with respect to rates of processes but at which conditions are generally most favorable for the organism." According to Janisch, 1930, every departure from this optimum point, however slight, is injurious to the organism. Uvarov, 1931, notes the serious objections to the existence of an optimum point in contrast to an optimum zone. He claims that the idea of the invariably injurious effect of deviations from an optimum point is based largely on theoretical considerations and that data against it is too numerous to be ignored. In the same work Uvarov points out the well known fact that within the favorable range of temperature the life of an individual insect becomes longer at lower temperatures.

Concerning the rates of biological processes

Chapman, 1931, states that as temperatures approach either a high or a low extreme, processes are slowed. The slowing of biological processes is much more noticeable and gradual as the low temperature is neared, and at the high temperature it is so rapid as to frequently go unnoticed. To avoid high temperature the animal usually reacts quickly because of its rapidity of activity. At low temperatures, however, the animal is usually sluggish and the reaction to avoid the low temperature is hence much less rapid and very indefinite.

It is mentioned by Chapman, 1931, that the high range of temperature which can be endured by insects is between 48 and 52° C. This range appears to be rather constant. Uvarov, 1931, states that "the upper fatal limit is fairly uniform for various insects, and lies on the average at about 50° C." A chart that Uvarov includes in his paper shows, however, numerous recorded instances of much higher fatal temperatures. This same writer points out that several authors have noted that there may be considerable variation in resistance to high temperatures among specimens of the same species. The ability of insects to withstand low and high temperature seems to be related to the amount of moisture present. Depending on the animal, long or short periods of dormancy may cause death. Others may survive in low temperatures for a long time if freezing does not occur. Still others may live but a short time under the same conditions. Some animals can endure freezing conditions for varying lengths of time while others cannot. Uvarov, 1931, and Payne, 1927a, support these statements on the ability of insects to withstand low temperatures. In connection with this thesis it will be interesting to mention that Payne, 1927b, noted that cold hardiness could be induced in insects by partial dehydration. Cold resistance, according to the same author, is increased by starvation but decreased if abundant moist food material is present. Uvarov, 1931, suggests that these facts indicate the relationship of cold hardiness to the total water content of the insect and to the amount of reserve substances. Another interesting fact noted by Uvarov, 1931, is that while a frozen insect may often be revived, heat produces a stupor that is invariably fatal. According to Matisse, 1919, therefore, the action of heat is irreversible.

The following phases of general activity were suggested by Bodenheimer, 1930. These phases follow the ascending or descending scale of temperatures.

Phase 1. Beginning of cold stupor.
Phase 2. Very slight movements of antennae and extremities.
Phase 3. The intermittant crawling of the insects.
Phase 4. Normal activity.

Phase 5. Strong activity.
Phase 6. Strong excitement.
Phase 7. Beginning of heat stupor.
Phase 8. Death from heat.

That the activity range and the limits of each phase vary greatly in different insects was shown by Chapman, Mickel, Parker, Miller, and Kelly, 1926.

Uvarov, 1931, specially points out that external temperature does not directly influence the activities of insects but rather acts through their body temperature. It is important to note that Uvarov in the same work stresses the importance of recognizing the evidence that points toward the probability of insects not being absolutely dependent on the external temperatures. According to him "the study of body temperatures as affected by external conditions will, no doubt, explain many difficult points in the problem of the relation of development to temperature." Some of the factors affecting body temperature as listed by the same author are movements of the insect, humidity of the air, evaporation and all factors influencing its rate.

## Moisture or humidity of the air

Without water it is not possible for a living organism to exist or accomplish vital processes. This statement of Uvarov, 1931, demonstrates clearly the importance of water to the living creature.

Relative humidity is the expression of the state of moisture in the air. Chapman, 1931, defines relative humidity as "the amount of moisture present in a space as compared with the amount required to produce a condition of saturation at the same temperature and atmospheric pressure. It is expressed as per cent of saturation, and is an important expression because it represents the state of equilibrium of the atmosphere in the moisture cycle."

There are several methods of maintaining constant moisture conditions. Two of these methods that will enter into the thesis discussion are of concern here. Chapman, 1931, describes both methods; 1. use of sulphuric acid solutions, 2. use of saturated salt solutions. The former is of use in small chambers for certain types of experiments. One should always make certain that the air comes into equilibrium with the sulphuric acid. An objection to employing the method exists because of the difficulty in checking the action of the solutions and keeping the sulphuric acid standardized as to specific gravity. Saturated salt solutions were used by Headlee, 1917, as a substitute for the sulphuric acid solutions. Many salt solutions are convenient to use in this way. Precaution must be taken that the solution comes into equilibrium with the air and that the salts used are chemically pure. An advantage of this method lies in the fact that a standard solution can be readily maintained if there is water in the container above some precipitated salt.

It is learned from Uvarov, 1931, that the insect usually obtains the necessary moisture from its food. Hence it can be seen that the water content of the food is of great importance. Chapman, 1931, states in a generalization that if the moisture content of the food is sufficient to maintain the moisture content of the insect body, the insect is relatively independent of the surrounding medium. However, there is a direct relationship between the moisture content of the surrounding medium and the moisture in the food. Thus an indirect effect of the surrounding medium upon the insect always exists. This indirect effect is further substantiated by Uvarov, 1931, He notes that "the rate of loss of water from the tissues must be connected with the relative humidity of the air as well as with the temperature."

Several other statements of Uvarov, 1931, are interesting. He states that although very little work has been done on the fatal limit of dessication, this limit cannot be the same in different insects. Uvarov states further that no experiments up to the time of the writing of his paper could even suggest that vital limits of relative air humidity exist in either direction from the optimum. This is true because no definite cases of insect injury by high air humidity have been recorded.

Temperature and humidity acting together

A prime consideration when measuring effects of either temperature or moisture upon animals is the maintenance of all other factors constant. Chapman, 1931, emphasizes this point and further states that when one factor varies other factors may vary likewise.

When a multiplicity of factors is present and only one of these factors is near the limit of toleration, this one factor would be the controlling one. "Liebig's law" is the name that has been given to this generalization.

Among other facts presented by Chapman, 1931, it is learned that "since the water content of an aqueous solution varies the boiling and freezing points so much, it may be expected that the water content of a complicated organism will greatly affect the behavior of the organism in respect to temperature. "Likewise, Uvarov, 1931, states that temperature "may affect an insect in a different way according to the relative humidity of the air, which in itself depends on the temperature."

It is also noted by Chapman, 1931, that an organism cools rapidly in a moist cool atmosphere.

This is true because the moist atmosphere causes the rapid conduction of heat from the body. As a result, the metabolism of poikilothermic organisms is decreased greatly under these conditions. Heat loss is less rapid in a cold but dry atmosphere because heat conduction is less. This condition causes poikilothermic animals to lose heat less rapidly. Evaporation on the body surface will be rapid in a dry, warm atmosphere and this results in a cooling effect because of the heat of evaporation lost by the animal. Regulation of body temperature is thus possible at high temperatures. Evaporation, on the other hand, is not permitted in a moist, warm atmosphere and hence there is no means of lowering body temperature. Bachmetjew, 1901, arrived at about the same conclusions.

Concerning the intensity of cold which the insects can endure, Payne, 1929, stresses the importance as a factor of absolute humidity expressed in millimeters of mercury. (The definition of absolute humidity given by Chapman, 1931, "is the amount of moisture by weight in a given solume of space.") That the proportion of water bound on the surface of body colloids may be extremely important in the case of insects which are able to withstand freezing of their free water is pointed out by Chapman, 1931.

A few excellent papers have been written concerning the effect of temperature and humidity on terrestrial isopods. The most important of these appear to be the work of Allee, 1926; Gunn, 1937; Miller, 1938; and Waloff, 1941.

Allee, 1926, made studies in animal aggregations dealing with the causes and effects of bunching in land isopods. He states that land isopods (*Armadillidium vulgare*, *Oniscus asellus*, *Tracheoniscus rathkei*, *Cylisticus convexus*, *Porcellio scaber*) form aggregations readily when exposed to drying conditions and much less readily when the substratum is moist. The bunching reaction is also affected by temperature, illumination, positive thigmotropism and chemotropism, the latter two factors with only slight evidence of mutual attraction. Bunching is exhibited in both hibernation and aestivation. Allee notes that homotypic aggregations form more readily than heterotypic ones and that normally bunching occurs in the least stimulating part of the container, this area being reached by random movements. Under uniform conditions the aggregation usually forms about one of the most quiet isopods. No sexual significance has been attached to the bunching habit. Bunched land isopods take up or lose water less rapidly than isolated individuals when they are out of moisture equilibrium with their environment. Tests on rate of respiration with Tashiro's biometer and with Krajnik's respirometer show that recently formed bunches respire less rapidly per unit of weight than recently isolated isopods. After both have stood for some time, the conditions are reversed. The bunching behavior is thus advantageous to the individual and probably represents a very early stage in social development. From his results and from a review of literature Allee indicates that the first step toward social life in lower animals is the appearance of tolerance for other animals in a limited space. The second step is reached when the aggregation comes to serve the individual members. Isopods have reached this stage.

Gunn, 1937, is solely concerned with the humidity reactions of _Porcellio scaber_. It is stated that if _Porcellio scaber_ is kept in dry air at $20^{\circ}$ C. the weight loss (largely water) is at the rate of four per cent an hour. This species dies in a few hours if kept under these conditions. The following summary of the experimental data is made.

1. _Porcellio scaber_ exhibits hygrokinesis, being very active in dry air and almost motionless in nearly saturated air. With rising humidity a steadily increasing proportion of a batch of specimens is found

to be inactive at any one moment.

2. Porcellio acaber also shows hygrophobotactic behavior.

3. The effect of both reactions is to collect the animals into moist air.

4. In a humidity gradient of given steepness, the intensity of the humidity preference varies at different parts of the humidity range. There is no reaction at all if the gradient does not include a region below 65% relative humidity. There is definite reaction to a difference of 6% relative humidity in approximately half-saturated air.

5. The humidity receptors, if they are confined to one area, apparently do not lie on the abdomen or head region.

Miller, 1938, conducted experimental studies that apply, in part, directly to the experiments conducted by the author. The experimental studies of Miller were of two types; 1. humidity gradient experiments, 2. survival experiments. Miller's experiments of the first type were intended to test the discrimination ability of several species of terrestrial isopods when a choice of humidities in a humidity gradient was offered. The second type of experiments were designed to learn the survival time of eight species under various combinations of constant temperature and humidity.

According to Miller, 1938, "the following conclusions may be drawn from the gradient experiments.

1. The results definitely show that the four species of isopods tested reacted to the gradients, always aggregating in greater numbers in the chambers with the highest humidity in the gradient used; whereas in the controls there were no preferences for any chamber.

2. They also indicate that the preferences were progressively less marked in gradients with shorter range and at the dry end of the scale. For instance, the preferences of <u>Armadillidium vulgare</u> for the 100 per cent relative humidity chambers in three difference combinations were 81.8, 71,6, and 66.6 per cent, whereas the preferences when the moistest chambers were 75 and 50 per cent were 47.7 and 39.3 (and 44.0) per cent respectively. By decreasing the range of the gradients, it might be possible to determine a limen, or threshold value, for ability to discriminate.

3. The reactions of <u>Porcellio spinicornis occidentalis</u> to the gradients were much less marked than in the other three species.

4. Sensitivity to moisture in <u>Armadillidium vulgare</u>, at least, is not exclusively dependent on receptors in the antennae, since specimens with antennae removed

reacted practically the same as uninjured specimens.

5. It seems probable that the aggregation of the animals in the moistest chamber was brought about by conditions set up internally by loss of water and or drying of the respiratory membranes, resulting in greater random activity, eventually bringing the animal into regions of greater comfort -- specifically, the moister chamber."

The survival experiments of Miller, 1938, were conducted at four temperatures; 20° ± 1° C., 25°, 30°, and 35° C. Using sulphuric acid solutions, the following relative humidities were maintained at each temperature:

20° C. -- 95, 90, 75, 60, 45, 30, 21.5, 15, 10.5 and 0%.

25° C. -- 50 and 0%.

30° C. -- 75, 45, and 0%.

35° C. -- 75, 50, and 0%.

With one exception (Ligia pallasii) twenty adult specimens of each species of isopod were used for every unit of the experiment, a unit of the experiment being a given combination of humidity and temperature. In the case of Ligia pallasii, fifteen individuals of each sex were used in order to determine whether or not previously noted sexual dimorphism had any differential survival value. Since each unit of the experiment was usually repeated at least once, calculations of the mean survival time for each species was based in the majority of cases upon samples of forty and sixty individuals. However, at 25° C. the samples contained only 20 individuals, and at 30° and 35° C. only two of the six constant humidities maintained employed as many as forty specimens.

Dessicators were used for experimental and control chambers. At high temperatures a small air-tight constant temperature box was converted into a dessicator by the placing of a large acid container on the floor of the box. Determination of the isopod death point was accomplished by the use of wire probers which could be operated from the outside of the chambers without permitting the entrance of air. Death of an isopod was assumed to have taken place when no movement was evidenced, especially of the antennae, upon probing.

The isopods were placed into the chamber at the beginning of an experiment by dropping them through a glass tube. The conditions within the chamber were thus very little disturbed.

Miller made no attempt to determine exact survival times of the isopods kept in the saturated control chambers. He states that the control animals far outlived the experimentals. No food was supplied during the experiments for any of the specimens.

Miller, 1938, deduced the following conclusions from the survival experiments.

1. The optimum relative humidity for survival is close to 100 per cent, or a saturation deficit of zero.

2. Survival times for each species become progressively shorter as humidity decreases. Survival is only a matter of a few hours even at moderate humidities.

3. Survival is not inversely proportional to saturation deficit, as noted by other authors working with arthropods, but rather there exists a quite precise relationship between the two variables.

4. Shorter survival times resulted from an increase in temperature within the range used.

5. The divergences of the survival curves plotted from the experimental data show the differences in ability of species to survive under the same humidity conditions.

6. The "bunching" reaction reported by Allee, 1926, is stated to be another factor relating to the viability of the isopods under conditions of low humidity.

An interesting point that Miller notes in this same paper is that in the microhumidity conditions under boards, rocks, and other objects, the terrestrial isopod finds optimum conditions in the nearly saturated atmosphere. He further states that the isopods may emerge and feed at night when the general atmosphere humidity is more favorable. This circumvents in nature the lethal effects that even moderately high humidities have been demonstrated to produce under experimental conditions.

In a comparison of the various phases of his paper, Miller, 1936, shows that humidity is considered to be the dominant and limiting factor in the isopod environment. His general conclusions follow.

"1. Optimum humidity for survival is a saturation deficit of zero, and the species cannot long endure lower humidities. There is a precise relationship between survival and saturation deficit capable of expression in simple equations.

2. The isopods are predominantly found in places of high or optimum microhumidity, and it is shown to be highly improbable that any species can maintain itself without access to such places.

3. There is a triple correlation between the species in moisture of their habitats, degree of evolution of their respiratory systems and associated water-conserving devices, and their respective abilities to survive experimentally produced low humidities.

4. There is a seasonal periodicity in breeding and other activity correlated with the incidence of rainfall.

5. The taxonomic poverty of species in California and their spotty distribution are associated with the long dry season and the small amount of rainfall characteristic of the State.

Temperature is considered to be of little ecological importance except as it influences humidity. Increase in temperature from 20° to 35° C., with saturation deficit constant, has very littleeffect on survival of animals in laboratory experiments in comparison with changes in humidity.

The isopods studied show several stages in the transition between aquatic and terrestrial life. The Oniscoidea cannot be considered to be successful invaders of the land, because they have not solved satisfactorily the related problems of water conservation and aerial respiration."

Waloff, 1941, added considerably to the information presented by Miller, 1938. In studies on the mechanisms of humidity reactions of terrestrial isopods, Waloff states that <u>Porcellio scaber</u> did not orient to slow air currents in a tube. Thigmokinesis (percent of time spent next to glass wall) increased from 79-82% at 20-25% relative humidity to 92.6% at 90-95% relative humidity.

As studied in a modified Gunn's circular glass humidity apparatus (Gunn, 1937) at various constant relative humidities there was a decrease in speed and activity (hygrokinesis) in Oniscus asellus, Porcellio scaber and Armadillidium vulgare from 45-65% relative humidity upward. Periods of rest increased at high humidities with Oniscus and Porcellio, but less and not beyond 60% relative humidity with Armadillidium. Turnings (90° equals one unit) decreased from 75% relative humidity in Oniscus, consistently in Porcellio, and indefinitely from 90% in Armadillidium. Distance between turnings decreased rapidly from 70-75% in Porcellio, and less rapidly to a higher value (from 40-45%) in Armadillidium. In humidity gradients Porcellio spent more time in the damp half, where speed was less and periods or rest greater. In 75-95%, 65-85%, and 55-75% gradients, distance and time between turns were less in the damp half. In 20-73% and 42-60% gradients, turns were greater. Oniscus survived least well and Armadillidium best to desiccation at various relative humidities. The rate of water loss in Oniscus was 9.9%, 6.3% and 3.6% of the body weight per hour in relative humidities of 0%, 50% and 75% respectively. Water loss was progressive with time. In a gradient of 50-90% relative humidity with the dry half darkened, the majority of specimens tended initially to the dark dry half. Eventually, however, they settled in the light damp half. Thus *Oniscus*, *Porcellio* and *Armadillidium* range from moist to least moist natural habitat and from least to greatest resistance to desiccation. Humidity reactions with correlated thigmokinesis and negative phototaxis (except at very low humidities) combine to retain the animals in damp, dark habitats.

Other authors provide miscellaneous facts on the subject at hand. Pierce, 1907, notes the necessity of moisture presence when sowbugs are kept in captivity.

Blake, 1930, conducted experiments to determine how long *Armadillidium vulgare* could live in sea water and in fresh water. Twelve specimens lived eighteen days when placed in sea water while sixteen specimens remained alive about 22 hours when placed in fresh water.

Herold, 1932, conducted similar experiments with terrestrial isopods. *Armadillidium zenckeri* Brandt, a boreal-alpine species, lived ten and three quarters to sixty hours in water when the temperature was 15.5-17.5° C. *Armadillidium opacum* at the same temperatures lived ten and three quarters to sixteen hours. *Porcellium conspersum* at 14-16° C. lived six hours, and *Tracheoniscus rathkei* twenty-four through thirty hours.

At 4-10° C., however, *Tracheoniscus rathkei* lived over sixty-six days. Herold also mentions that the temperatures listed above are close to the limits of tolerance.

Numanoi, 1934, deals with the relation between atmospheric humidity and evaporation of water in *Ligia exotica*. The author has not been able to see this paper, however.

Heeley, 1941a, notes that choice of habitat by terrestrial isopods is largely determined by humidity. He mentions that when isopods are kept in captivity excessive moisture is just as fatal as insufficient moisture, the excessive moisture causing death by clogging the pleopods. Moisture is of chief importance and food is only of second importance. He states that "relative humidity of the atmosphere does not appear to be sufficient for any of the species except *Armadillidium vulgare* since they are unable to survive exposure for a considerable length of time. This accounts for their tendency to hide beneath stones, among roots, under bark, etc., where there is less loss of moisture by evaporation." An atmosphere hardly more moist than the air appears to be best for Armadillidium vulgare. In fact this species was often found during the day-time on a dry, chalky slope exposed to the full glare of the sun. It should be mentioned, however, that under such conditions the animals are usually found curled up, no doubt conserving the moisture in their respiratory organs until the evening when the relative humidity of the air becomes higher and the dew falls.

Woodlice show no appreciable response to small temperature changes within the range of approximately 10° C. either in the field or in captivity. They are, however, influenced by profound seasonal temperature changes.

Except in so far as they influenced humidity other ecological factors (light, temperature and oxygen content of the air) were found to be of little importance when the woodlice were kept in captivity.

Collings, 1944a, made an interesting observation. Two live specimens of Trichoniscus pusillus were seen to emerge from an empty space or cell in dried soil recovered from a Petri dish where they had lived for just over two months.

## Experimental Work Of The Author

The data included in this section of the thesis was acquired from two series of laboratory tests conducted to determine the survival time of *Armadillidium vulgare* (Latreille) at various constant temperatures and humidities. A small amount of data of this nature was also obtained for *Armadillidium nasatum* Budde-Lund.

As noted in the literature review Miller, 1938, assembled data on the survival abilities of eight species of terrestrial isopods at various constant temperatures and humidities. It is believed by the writer, however, that Miller's work did not employ a sufficiently wide range of constant humidities and temperatures. In fact although Miller conducted his experiments at four constant temperatures (20° C., 25° C., 30° C. and 35° C.), in only one instance did he use relative humidities over 75%. This seems to be a rather serious omission in view of the fact that terrestrial isopods require a high relative humidity for existence. Moreover, Miller did not utilize any temperature below 20° C. The experimental procedure of the author also differs considerably from that of Miller, most notably in the fact that while the latter used sulphuric acid solutions in dessicators and a small constant-temperature box to maintain the constant humidities, the author for the same purpose utilized various salt solutions in smaller closed containers. Thus it was with the purpose of adding to the data presented by Miller, 1938, that the following experimental procedure was developed.

Procedure

All experiments were conducted in the constant temperature cabinets of the insect ecology laboratory at Fernald Hall, University of Massachusetts. Five cabinets were maintained at the following temperatures throughout the experiments:

7° ± 2° C.
22° ± 2° C.
27° ± 2° C.
33° ± 2° C.
37° ± 2° C.

The cabinets are illustrated in plates 2 - 3.

Constant relative humidities within closed containers were obtained by the use of saturated salt solutions placed in sealed pint preserving jars. An illustration of the jar may be seen on plate 4. The relative humidities that the various saturated salt solutions maintain were determined by reference to the International Critical Tables of the National Research Council, 1926, and Sweetman, 1933. A list of the saturated salt solutions used and the various approximate relative humidities they maintain at the constant temperatures of the experiments follows:

Plate 2.

Constant temperature cabinets in ecology laboratory of the University of Massachusetts.

Plate 3.

Typical arrangement of experimental equipment
in constant temperature cabinet.

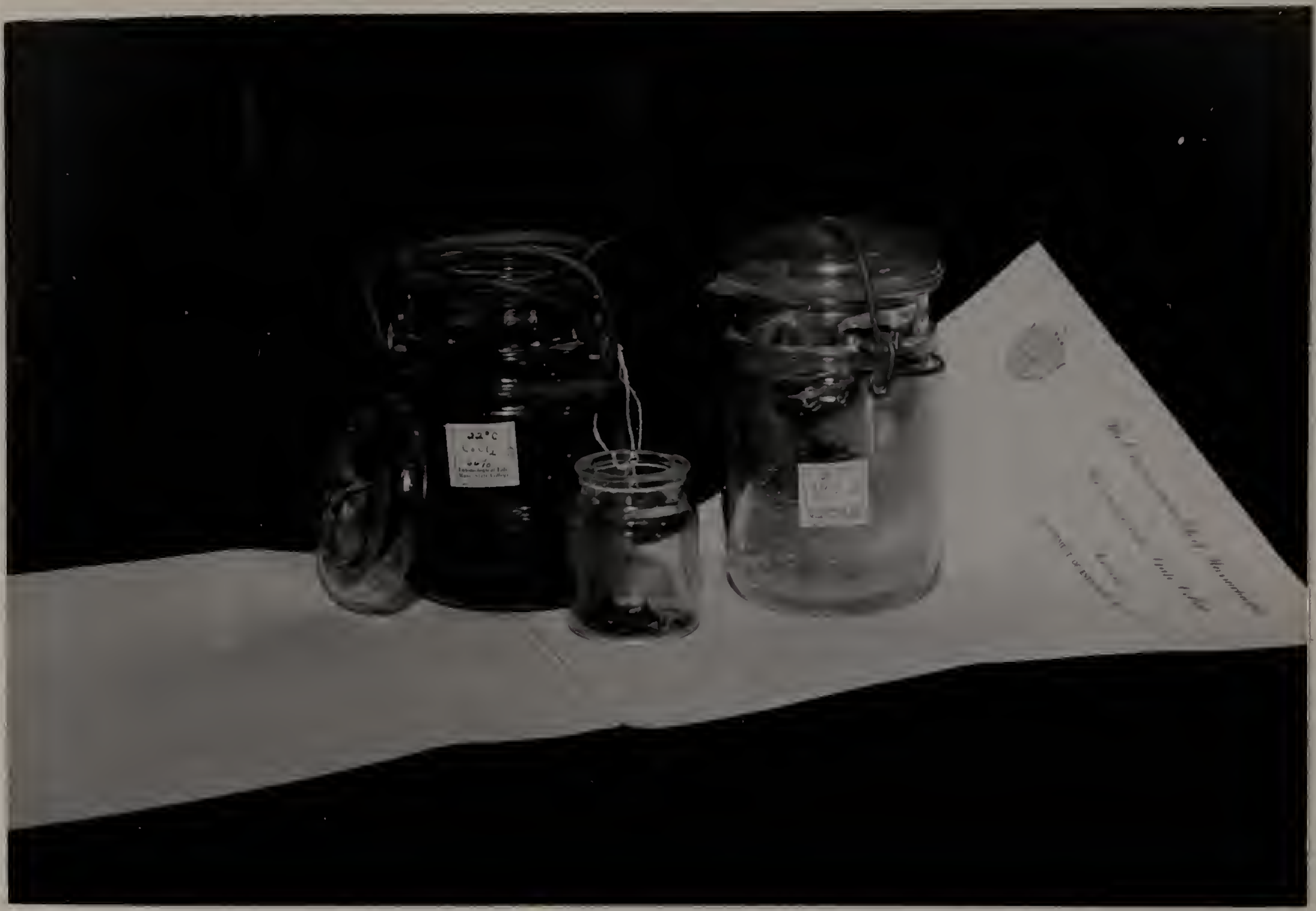


Plate 4.

Illustration of method of maintenance of specimens under constant humidity conditions.

7° ± 2° C.

| | | | | |
|---|---|---|---|---|
| $NH_4NO_3$ | yields | 68% | relative | humidity. |
| NaCl | " | 78% | " | " . |
| KCl | " | 88% | " | " . |
| $KNO_3$ | " | 97% | " | " . |

22° ± 2° C.

| | | | | |
|---|---|---|---|---|
| $Na_2Cr_2O_7$ | yields | 51% | relative | humidity. |
| NaCl | " | 77% | " | " . |
| KBr | " | 84% | " | " . |
| $K_2CrO_4$ | " | 87% | " | " . |
| $K_2HPO_4$ | " | 91% | " | " . |
| $KNO_3$ | " | 94% | " | " . |
| $K_2SO_4$ | " | 97% | " | " . |

27° ± 2° C.

| | | | | |
|---|---|---|---|---|
| NaBr | yields | 56% | relative | humidity. |
| NaCl | " | 77% | " | " . |
| KBr | " | 83% | " | " . |
| $KNO_3$ | " | 93% | " | " . |
| $K_2SO_4$ | " | 97% | " | " . |

33° ± 2° C.

| | | | | |
|---|---|---|---|---|
| $CoCl_2$ | yields | 58% | relative | humidity. |
| NaCl | " | 77% | " | " . |
| KCl | " | 84% | " | " . |
| $KNO_3$ | " | 92% | " | " . |
| $K_2SO_4$ | " | 97% | " | " . |

37° ± 2° C.

| | | | | |
|---|---|---|---|---|
| $CoCl_2$ | yields | 57% | relative | humidity. |
| KCl | " | 83% | " | " . |
| $KNO_3$ | " | 91% | " | " . |
| $K_2SO_4$ | " | 97% | " | " . |

At each temperature listed, 100% relative humidity was obtained by the use of distilled water.

It should be emphasized that the humidities maintained by the different salts are only approximate. That discrepancies exist may be seen by comparing the data given in the International Critical Tables of the

National Research Council, 1926, and Sweetman, 1933. Moreover, the variation present in the temperatures maintained by the constant temperature cabinets undoubtedly serves to cause changes in the relative humidities obtained by the use of the various saturated salt solutions.

A small uncapped bottle 2¼ inches deep with an opening at the top 1 1/8 inches in diameter was suspended within each pint preserving jar containing a salt solution. The bottle is illustrated in plate 4. Each preserving jar was sealed with a jar rubber and was opened only during the interval of a few seconds when the suspended bottle was removed and replaced during the periods of observation.

With the exception of two instances in which tests were made with Armadillidium nasatum Budde-Lund, five specimens of Armadillidium vulgare (Latreille) of both sexes were placed in each suspended bottle. No food was supplied for the crustaceans in the preliminary tests to be described later, but in all other tests small pieces of cow manure were placed in each suspended bottle to serve as food for the five crustaceans.

In order to assure the reaching of moisture equilibrium between the air in the preserving jar, suspended bottle and food, the crustaceans were not added to the suspended bottle until the prepared test jar had remained at the desired temperature and humidity for five days. For the duration of each test, two prepared jars containing five crustaceans per jar were maintained at the selected temperature and humidity. Thus the result of every test is based on the survival time of each of ten crustaceans and in all but two instances (only one test conducted at 97% relative humidity; 27°± 2° C. and 33°± 2° C.) the author's conclusions are derived from two tests made at the same constant temperature and humidity. The maximum period of a test was eighty days although in most instances the crustaceans did not survive for the entire period. To serve as a control a culture of Armadillidium vulgare (Latreille) was kept at room temperature for the duration of each test in a jar containing moistened cow manure. The specimens in the control jar were living at the end of each eighty day test period.

In making an observation each preserving jar was taken from the temperature cabinet briefly, the suspended bottle containing the five crustaceans removed from the preserving jar and the preserving jar recapped during the short interval required for obtaining the daily data. Each specimen was noted to be alive or dead. It was learned that death could be ascertained when probing failed to evoke any movement of the antennae. All

All data was recorded on specially prepared data sheets. At each daily observation the following information was recorded:

1. date
2. hour or observation
3. number of specimens alive or dead in every jar at each constant temperature and humidity

In order to ascertain whether planned experimental procedure was satisfactory, preliminary tests were made at 22°C., a temperature that by casual observation seemed to be within the optimum range for the isopod species, *Armadillidium vulgare* (Latreille), employed. The following salt solutions and the constant humidities they maintain were used in the preliminary experiments.

$22^{\circ} \pm 2^{\circ}C$.

$Na_2Cr_2O_7$ yields 51% relative humidity.
NaCl " 77% " " .
KBr " 84% " " .
$K_2SO_4$ " 97% " " .

Test procedure was identical to that used in the main body of the experiments with the exception of the fact that no food was placed in the suspended jar to serve as food for the crustaceans. Since food was not used, a shorter but unrecorded period was allowed to establish an equilibrium of the relative humidity. After examination of the data from the preliminary tests, it was decided to introduce food to the suspended jars in order that the factor of starvation would not influence the

Survival ability in days of <u>Armadillidium</u> <u>vulgare</u> (Latr.)
at various constant temperatures and relative humidities. *

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 68% R.H. | 78% R.H. | 88% R.H. | 95% R.H. | 97% R.H. | 100% R.H. | | |
| | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | | |
| 7°±2°C. | 17 : 15 | 9 : 5 | 14 : 7 | 80+ : 80+ | 80+ : 80+ | 80+ : 80+ | | |
| | average | average | average | average | average | average | | |
| | 16 | 7 | 10.5 | 80+ | 80+ | 80+ | | |
| | 51% R.H. | 77% R.H. | 84% R.H. | 87% R.H. | 91% R.H. | 94% R.H. | 97% R.H. | 100% R.H. |
| | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 |
| 22°±2°C | 3 : 2 | 4 : 2 | 9 : 2 | 22 : 10 | 2 : 2 | 45 : 45 | 80+ : 80+ | 80+ : 80+ |
| | average | average | average | average | average | average | average | average |
| | 2.5 | 3 | 5.5 | 16 | 2 | 45 | 80+ | 80+ |
| | 56% R.H. | 77% R.H. | 83% R.H. | 93% R.H. | 97% R.H. | 100% R.H. | | |
| | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | | |
| 27°±2°C | 2 : 2 | 2 : 2 | 2 : 6 | 9 : 12 | 66 : - | 61 : 64 | | |
| | average | average | average | average | average | average | | |
| | 2 | 2 | 4 | 10.5 | 66 | 62.5 | | |
| | 58% R.H. | 77% R.H. | 84% R.H. | 92% R.H. | 97% R.H. | 100% R.H. | | |
| | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | | |
| 33°±2°C | 1 : 2 | 1 : 2 | 2 : 2 | 7 : 4 | 21 : - | 19 : 15 | | |
| | average | average | average | average | average | average | | |
| | 1.5 | 1.5 | 2 | 5.5 | 21 | 17 | | |
| | 57% R.H. | 83% R.H. | 91% R.H. | 97% R.H. | 100% R.H. | | | |
| | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | T.1:T.2 | | | |
| 37°±2°C | 2 : 2 | 1 : 2 | 2 : 2 | 2 : 1 | 2 : 2 | | | |
| | average | average | average | average | average | | | |
| | 2 | 1.5 | 2 | 1.5 | 2 | | | |

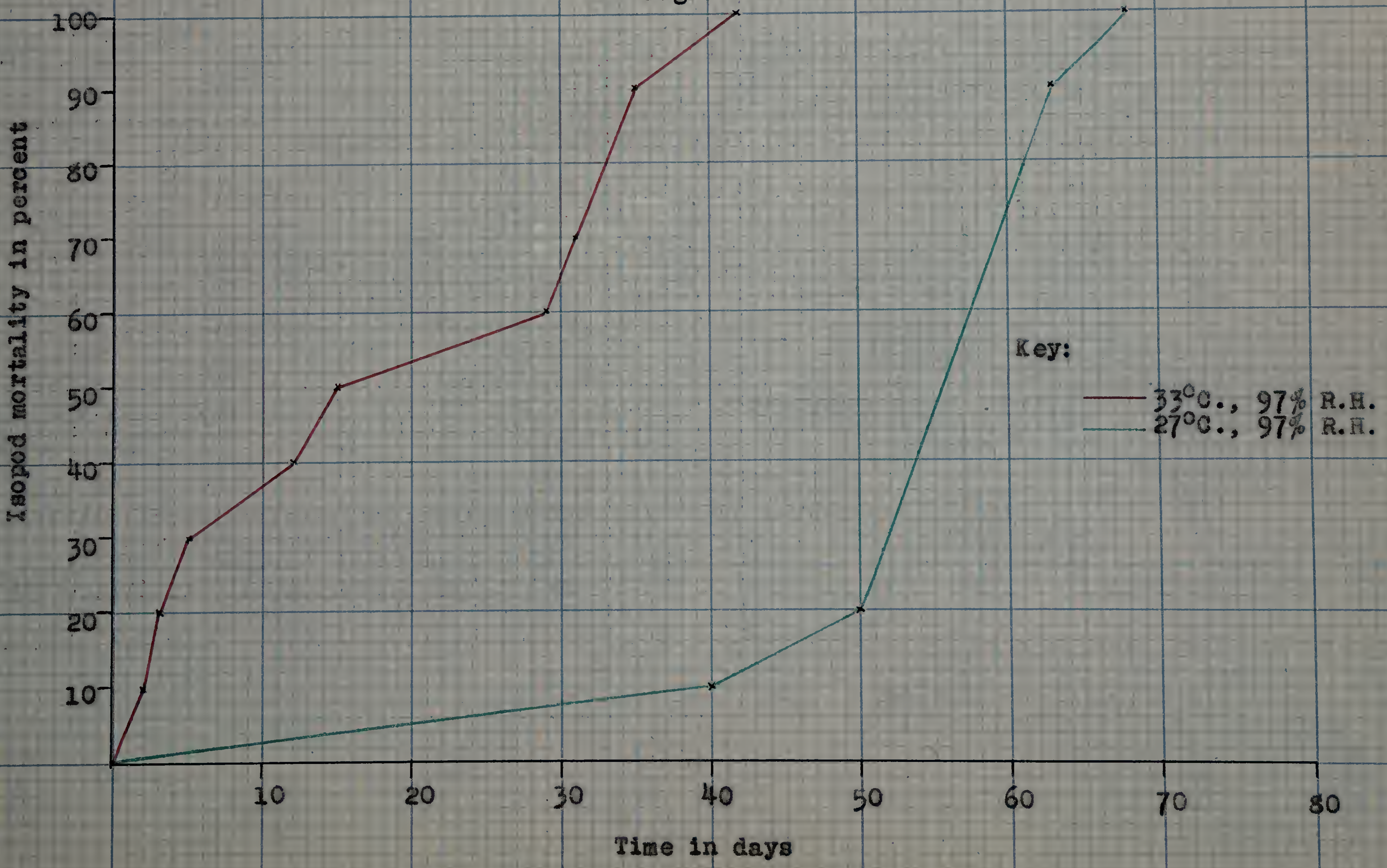
*10 specimens used in each test.

T.1 equals Test 1.
T.2 equals Test 2.

Table 5.

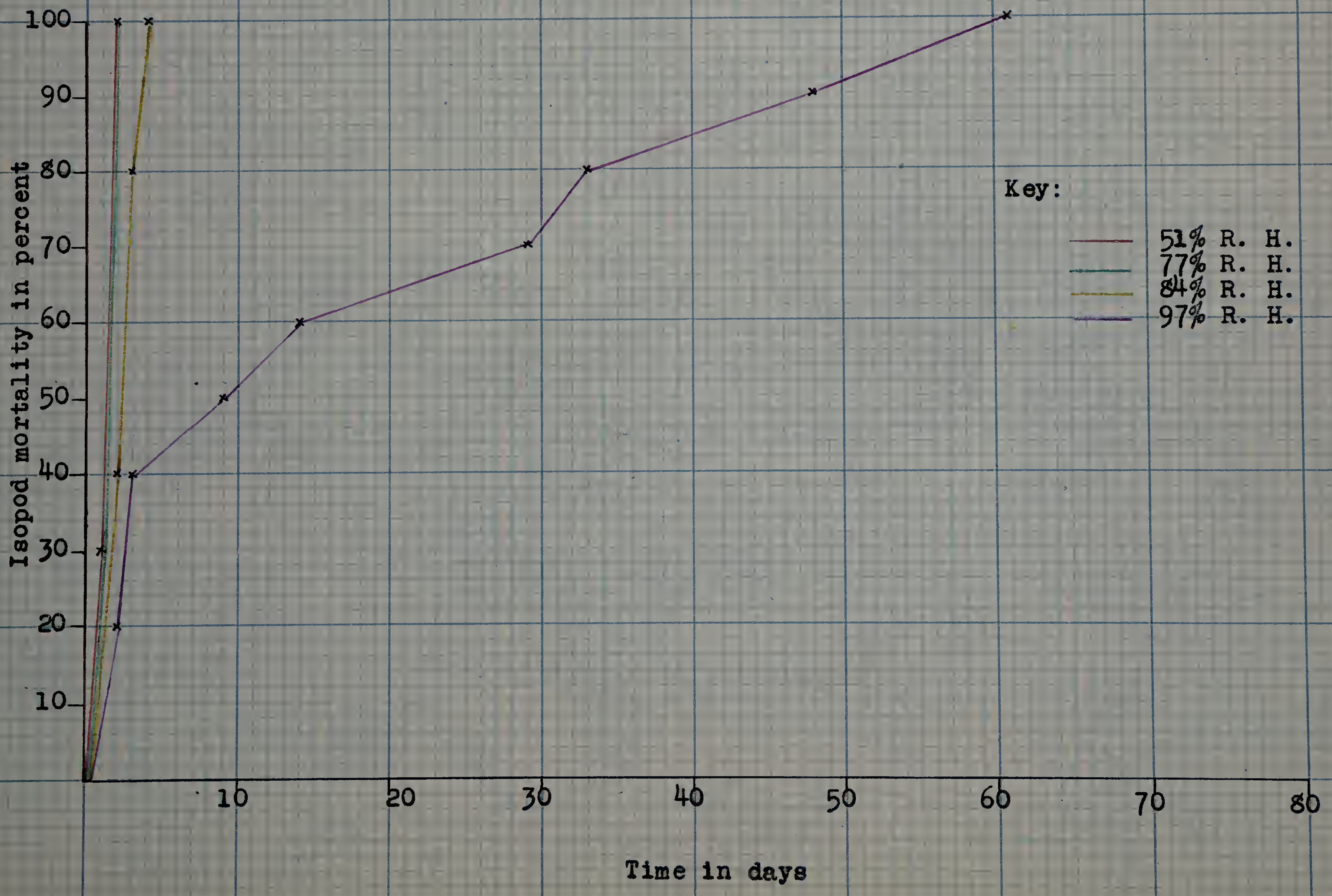
Influence of 97% relative humidity on
*Armadillidium nasatum* Budde-Lund, at 27°±2°C. and 33°±2°C.

Fig. 1



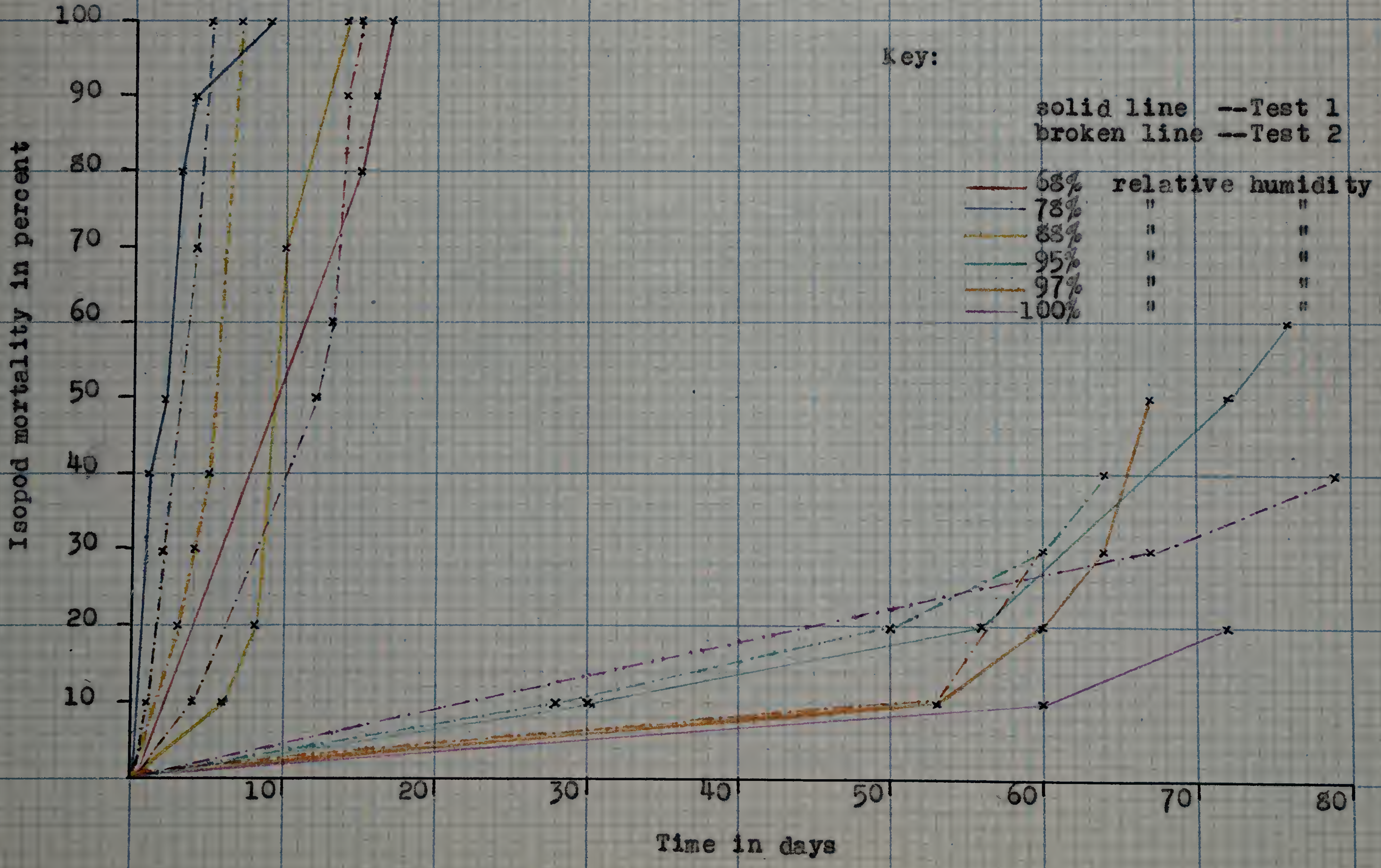
Preliminary tests of the effect of various relative humidities on *Armadillidium vulgare* (Latreille) at $22^\circ \pm 2^\circ$ C.

Fig. 2



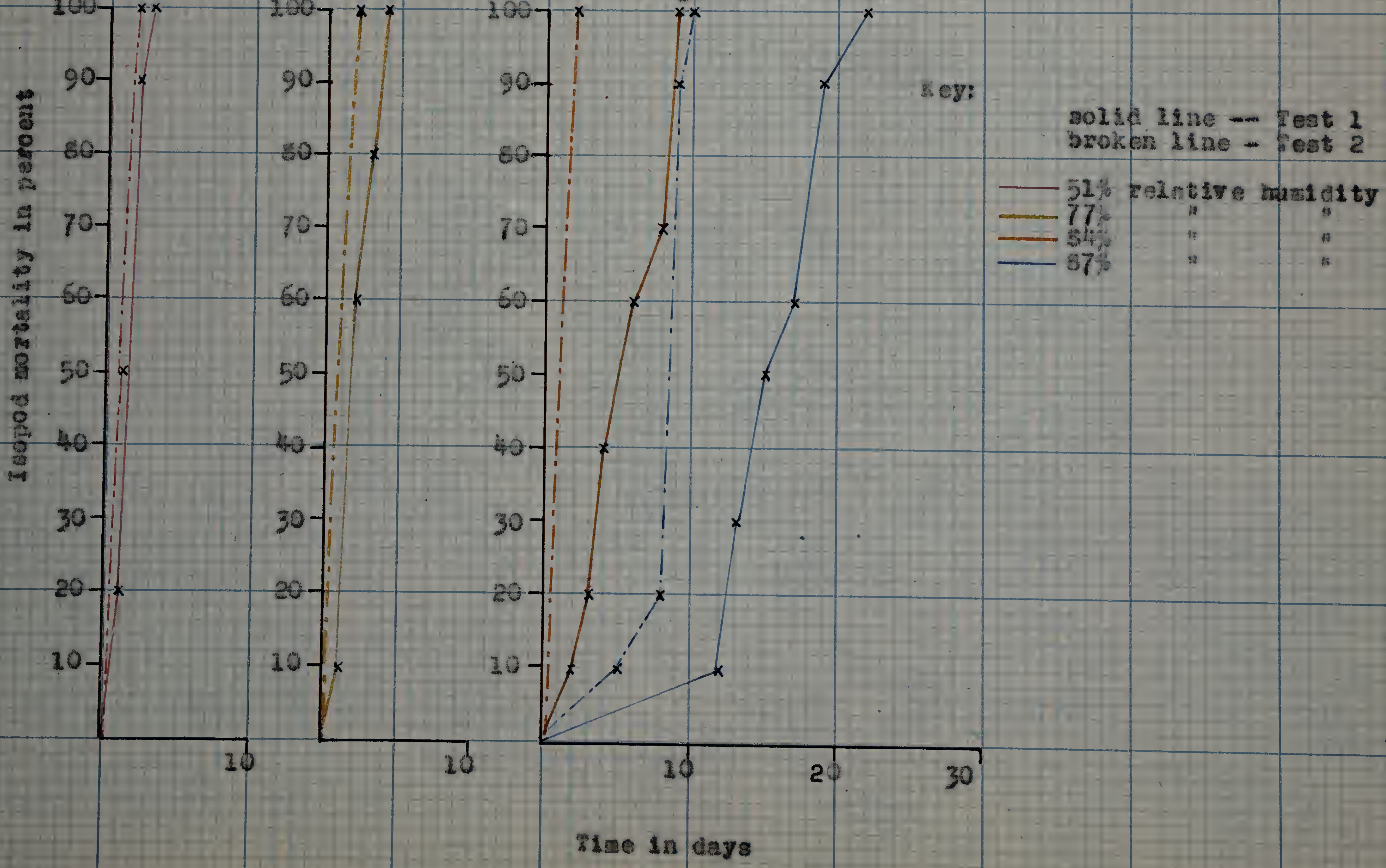
Influence of various relative humidities on
**Armadillidium vulgare** (Latreille) at 7°±2° C.

Fig. 3



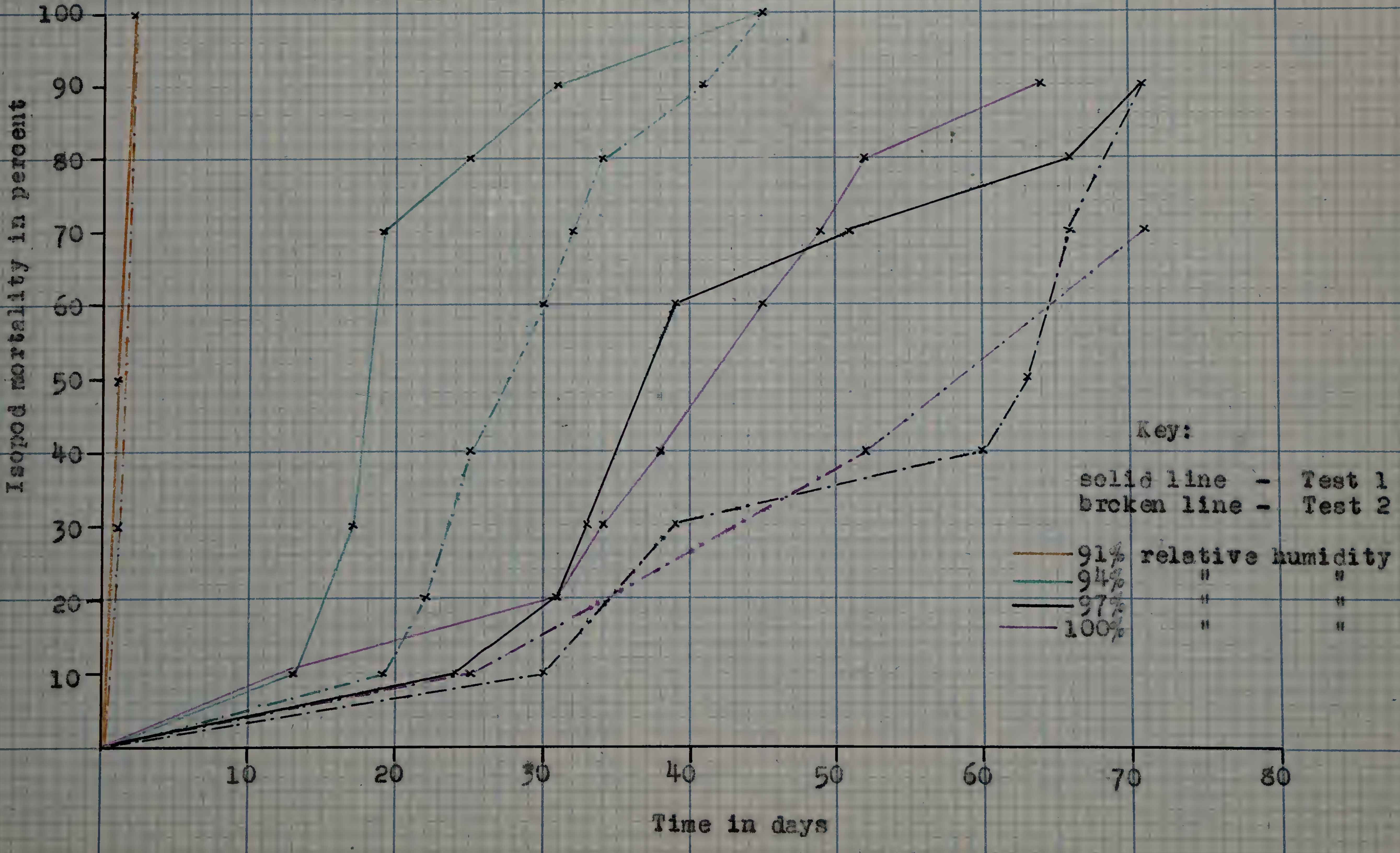
Influence of various relative humidities on
Armadillidium vulgare (Latreille) at 22°±2° C.

Fig. 4



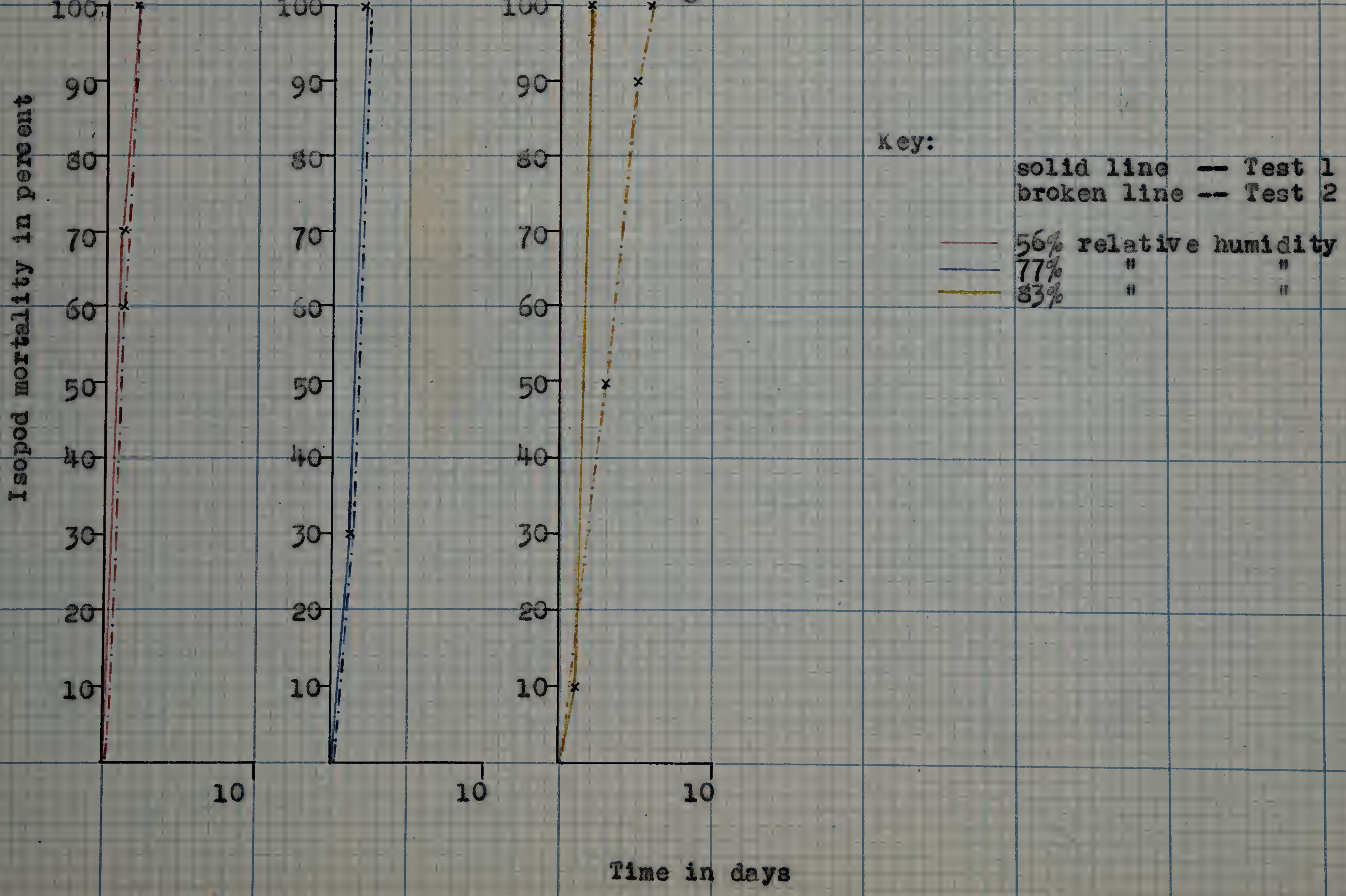
Influence of various relative humidities on *Armadillidium vulgare* (Latreille) at 22°±2° C.

Fig. 5



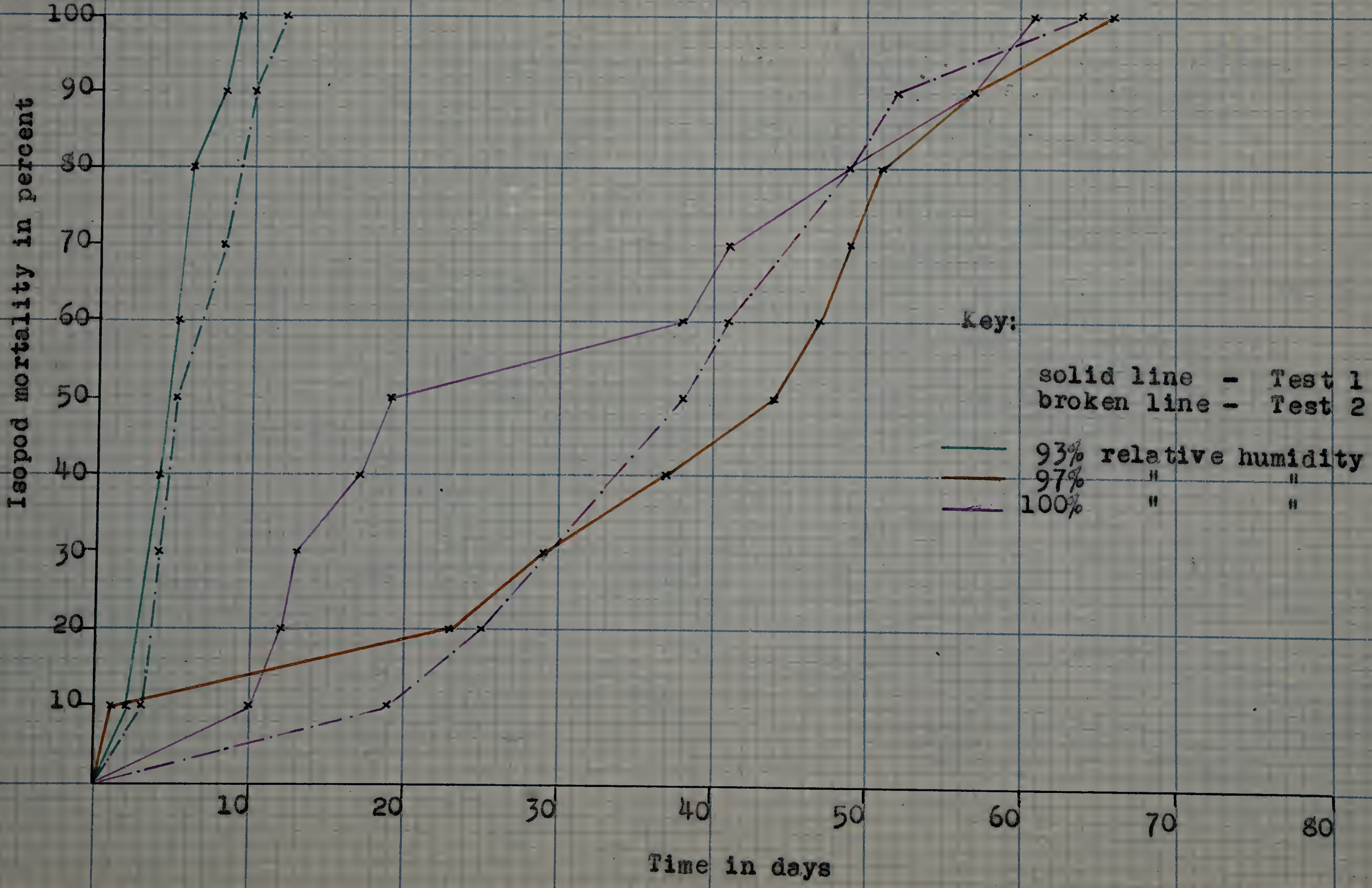
Influence of various relative humidities on
<u>Armadillidium</u> <u>vulgare</u> (Latreille) at 27°±2° C.

Fig. 6



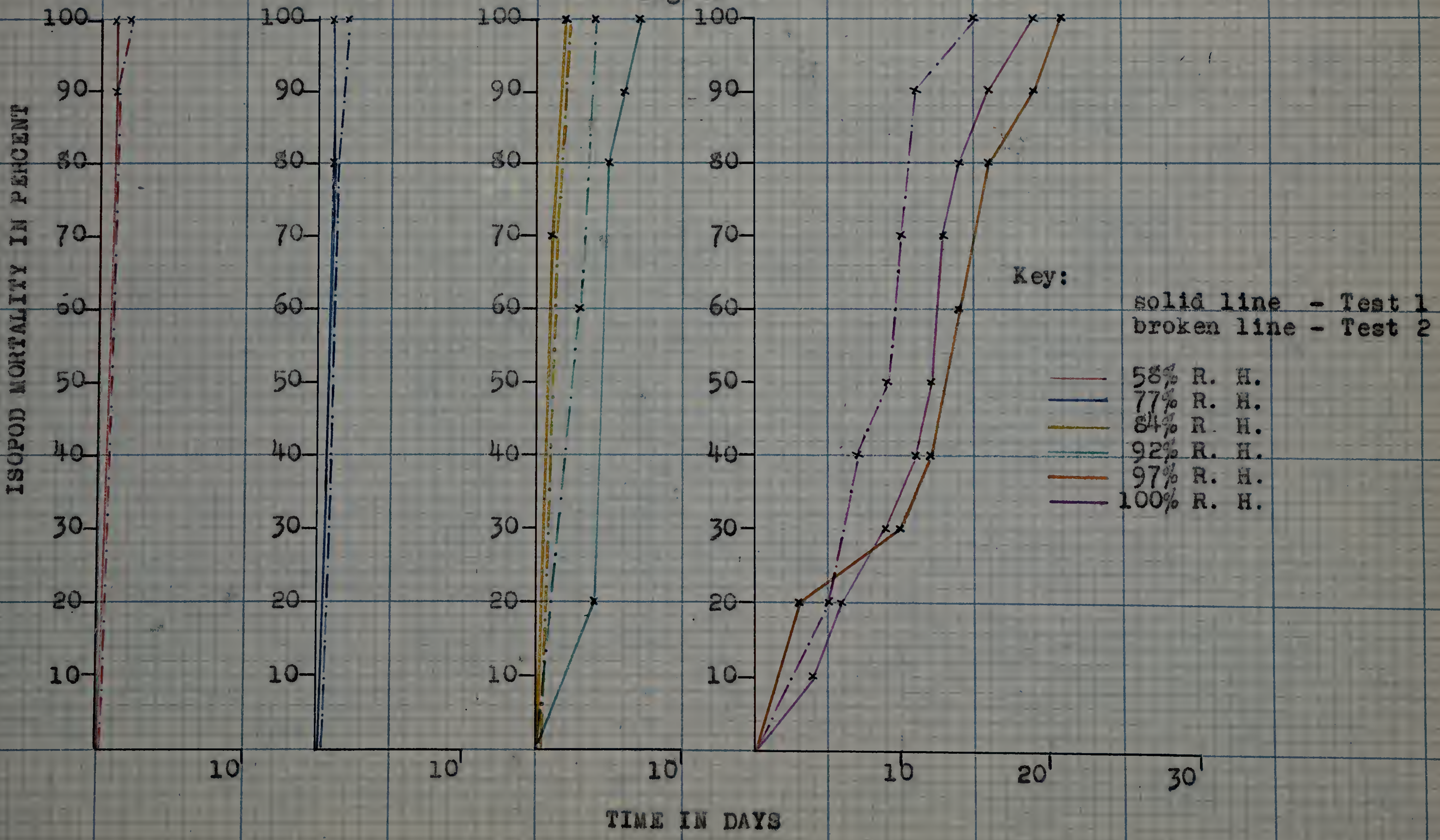
Influence of various relative humidities on
<u>Armadillidium vulgare</u> (Latreille) at 27°±2° C.

Fig. 7



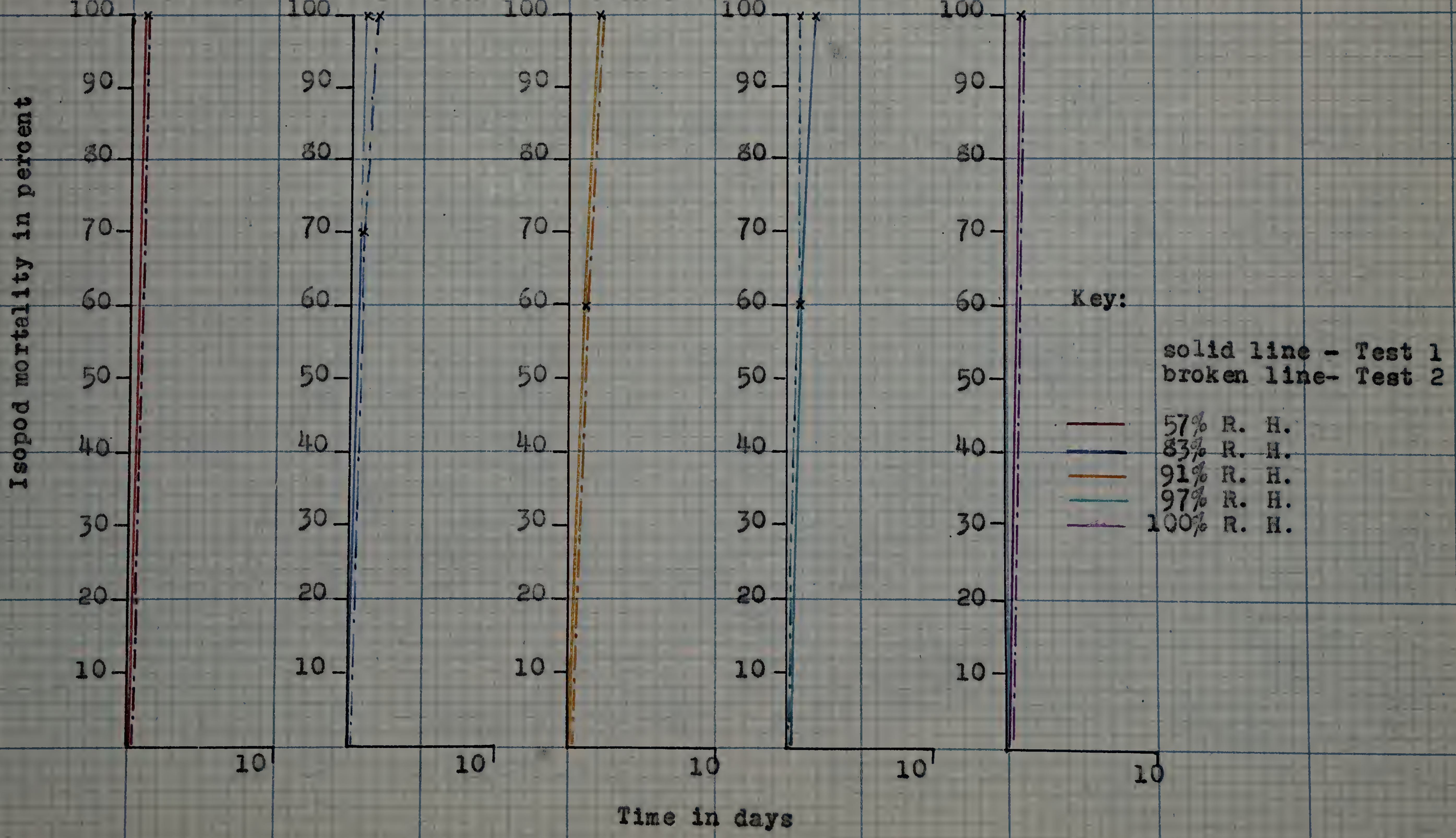
Influence of various relative humidities on
Armadillidium vulgare (Latreille) at 33°±2° C.

Fig. 8



Influence of various relative humidities on
*Armadillidium vulgare* (Latreille) at 37°±2° C.

Fig. 9



survival time of the crustaceans.

It is not believed that the final results of the experiments were altered by the temporary changes of conditions that resulted during the periods of observation. Sweetman, 1933, provides information that tends to support the validity of the author's experimental method. He states that "the humidities obtained with chemical compounds did not change during a period of six months under the conditions tested. The established moisture equilibrium was changed very rapidly in the containers when they were exposed to external humidities greatly different from the internal humidity. The moisture equilibrium was quickly reestablished after the containers were closed at 22°, 27° , and 32° C."

## Discussion of results

The results of the survival experiments are summarized in table 5 and figures 1 - 9. Figures 1 - 9 present in the form of graphs the results of all the survival experiments. Table 5, on the other hand, does not tabulate the results of the preliminary tests or the two tests with *Armadillidium nasatum* Budde-Lund.

It would be well to first consider the results obtained at each constant temperature and finally to make any correlations that can reasonably be made.

The results of the preliminary tests (figure 2) demonstrate points that should be mentioned. Armadillidium vulgare (Latreille) at 22°C. cannot exist under conditions of low humidity. The fact that no food was given the crustaceans in the preliminary tests probably explains why the specimens at 97% relative humidity died more rapidly than did those in later experiments that were supplied with food but maintained at the same temperature and humidity of the preliminary tests. It was found in the preliminary tests at the high humidities, however, that bits of paper toweling inserted in the jar to serve as shelter for the crustaceans were partly eaten.

Some interesting observations should be mentioned in connection with the tests carried out at 7° C. Once again it is seen that a high relative humidity is necessary for survival. Even specimens kept at a relative humidity of 88% did not survive over fourteen days. The writer, however, cannot explain why the specimens survived longer at 68% relative humidity than at 88% relative humidity. It is possible that the discrepancy exists because of faulty experimental procedure.

It was noted that within a few hours after the specimens were introduced to the various humidities at 7° C. they became dormant, a condition that continued for the duration of the tests at this temperature.

While dormant it was observed that the crustaceans usually remained curled up, did very little feeding, and never moulted. Although frequent cases of cannibalism have been recorded at most of the other constant temperatures employed, no cannibalism occurred at 7° C. No young were ever found at 7° C. and hence it is possible that reproduction doesn't occur at this temperature.

In two tests at 7° C. and high humidity, the results of which were later discarded, it was noted that when because of failure of the temperature cabinet unit the cabinet temperature rose to about room temperature the crustaceans soon became active, feeding took place, and one instance of moulting and two cases of cannibalism occurred.

Since some of the life functions of the crustaceans seem to cease at 7° C., the temperature is obviously not optimum. It is true, however, that after eighty days a greater percentage of the crustaceans maintained at high humidities were alive than at any other higher temperature. It is known that below the minimum effective temperature a dormancy zone exists and that within the favourable range of temperature the life of an individual insect becomes longer at lower temperatures. The author does not know whether this fact would likewise apply at a temperature such as 7° C. after some life functions cease to occur and the conditions are seemingly unfavourable. In the literature review, statements by Chapman, 1931, are recorded. He notes that an organism cools rapidly in a moist cool atmosphere. As a result, the metabolism of poikilothermic organisms is decreased greatly under these conditions. It seems possible that the decreased metabolism might tend to lengthen the life of the crustaceans if there is a high relative humidity to provide adequate moisture.

At 22° C. the fact is again evident that a high relative humidity is necessary to maintain the crustaceans. No crustaceans, it is seen, outlived the eighty day test period except those kept at 97% and 100% relative humidity. As high a relative humidity as 94% was still insufficient to permit survival over forty-five days under test conditions. Faulty technique may have caused the extremely short survival period at 91% relative humidity since the author can determine no other reason why the instance should have occurred.

Moulting was observed to take place at 22° C. as was also feeding and cannibalism. At this temperature moulting was recorded at 97% and 100% relative humidity while cannibalism was noted at 84%, 94%, 97% and 100% relative humidity. Feeding took place at least under conditions of high relative humidity. Young appeared at this temperature but copulation may well have taken place before the specimens were introduced to the test bottles.

27° C. provides still further evidence that a high humidity is essential for the survival of Armadillidium vulgare (Latreille). However, no specimens lived longer than sixty-six days even at 97% and 100% relative humidity. Specimens at 97% relative humidity are seen to have survived for a longer period than those at 100% relative humidity. This evidence indicates that the temperature is thus too high for optimum conditions to exist.

Moulting occurred at this temperature under conditions provided by 97% and 100% relative humidity. Cannibalism likewise was recorded, it being found at 77%, 93%, 97% and 100% relative humidity. Feeding was recorded at 97% and 100% relative humidity although it may also have taken place at lower humidities. Young were observed at 27° C. under conditions of 97% relative humidity.

Even at high humidities Armadillidium vulgare (Latreille) had a relatively short survival time at 33° C. although again the survival ability of the species was greatest at the highest humidities. It should be observed that at 27° C. and 33° C. the specimens survived for a slightly longer period at 97% relative humidity than at 100% relative humidity. This could be explained because of the facts presented in the book by Chapman, 1931, that at high temperatures regulation of the body temperature in poikilothermic animals is possible because of the cooling effect caused by evaporation of water from the body. In a very moist atmosphere, therefore, the animal is unable to regulate body temperature since evaporation is not permitted in a very moist atmosphere of high temperature. More cooling effect is undoubtedly permitted at 97% than at 100% relative humidity.

Moulting was observed at 33° C. when the relative humidity was 97% and 100% and was recorded as occurring four times at 97% and only once at 100% relative humidity. Data indicates that feeding existed at 97% and 100% relative humidity although it may also have taken place at lower humidities.

At 37° C. the inability of Armadillidium vulgare (Latreille) to survive even at high humidities is obvious since all the specimens died within a two day period. Therefore it is evident that a high temperature such as 37° C. plays a more important role in determining the survival ability of specimens of Armadillidium vulgare (Latreille) than does moisture.

In the two tests conducted at 27° C. and 33° C. with Armadillidium nasatum Budde-Lund it is readily observed that under conditions of 97% relative humidity the species has a longer survival period at 27° C. than at 33° C. This agrees with the data recorded for Armadillidium vulgare (Latreille). The survival period is also long at this humidity and thus it is concluded that like Armadillidium vulgare (Latreille), A. nasatum Budde-Lund requires a high humidity for existence.

A correlation of the data for individual constant temperatures and humidities permits the forming of a number of generalizations. Perhaps the most obvious is that relative humidity determines the survival time of Armadillidium vulgare (Latreille) to a much greater extent than does temperature. A wide range of temperature exists between 5° and 33° centigrade, but throughout this range no specimen of Armadillidium vulgare (Latreille) lived for longer than twenty-two days at a relative humidity below 87%. In fact, at constant temperatures of 5°, and 27° centigrade, no specimens of Armadillidium vulgare (Latreille) survived a period of sixty-one days under conditions less than 95% relative humidity. A still further limitation can be made by stating that only at 5° and 22° C. did specimens of Armadillidium vulgare (Latreille) live beyond the eighty day limit of each test and even then this long survival period was confined to relative humidities between 95 and 100%. Thus humidity is the determinant of survival time at all the constant temperatures maintained in the experiments from 7° through 33° C.

The decreasing dominance of relative humidity as the determining factor in survival is noted at 27° C. At 33° C. the role of relative humidity is even less prominent, while at 37° C. temperature assumes the position of dominant factor in the survival time of Armadillidium vulgare (Latreille) under experimental conditions. At the latter temperature no specimen lived beyond a period of forty-eight hours at any relative humidity.

Since dormancy exists at 7° C. this temperature cannot be within the optimum zone for survival. The long survival period and the fact that all normal life functions seem to occur at 22° C. under conditions of high humidity indicates that this temperature is within the optimum zone for Armadillidium vulgare (Latreille). 27° C. cannot be within the optimum zone because a definite limiting of the survival period by temperature is noted.

In comparing the records of cannibalism at the various constant temperatures, it is found that no cannibalism occurred at 7° or 37° C. At 7° C. cannibalism probably did not take place because of the existing conditions of dormancy, while at 37° C. it may have been prohibited by the short length of life of the specimens. It is interesting to record that cannibalism occurred while a specimen was moulting. Three definite instances of this were recorded. One case of attack upon an injured specimen was observed, and it is believed, but not recorded, that numerous other cases of cannibalism took place when a specimen was injured or dying. A total of thirty-seven certain instances of cannibalism were presented in the data.

Moulting did not occur at either 7° or 37° C. It could not have taken place at 37° C., however, because of the short length of life of the specimens at this temperature. At 7° C. dormancy appears to prohibit the functioning of some life processes.

## Conclusions

Several conclusions based upon the data recorded can safely be enumerated.

1. Over a wide range of temperature, humidity determines the length of the survival period of *Armadillidium vulgare* (Latreille) to a much greater extent than does temperature.

2. In the experiments, *Armadillidium vulgare* (Latreille) required a humidity close to the saturation point in order to survive for an extended period of time.

3. 22° C. is within the optimum temperature zone

for the survival of *Armadillidium vulgare* (Latreille).

4. 7° C., 27° C. and higher temperatures do not provide optimum conditions for the survival of *Armadillidium vulgare* (Latreille) even at high relative humidities.

5. At. temperatures of 27° and 33° C., a relative humidity of 100% was not as favorable as one of 97% probably because under conditions of a saturated atmosphere evaporation of water from the crustacean and the resultant cooling effect could not take place.

6. 7° C. permitted a long survival period for *Armadillidium vulgare* (Latreille) under conditions of high humidity.

7. Temperature is the controlling factor in survival time at 37° C.

8. Dormancy is present at 7° C. and this condition results in the ceasing of certain normal functions such as feeding, moulting and reproduction.

9. Cannibalism does not occur either at 7° or 37° C.

## DISTRIBUTION AND TAXONOMY

### Literature Review

Authors of many countries have contributed to our knowledge of the distribution of the land isopods. In the United States the outstanding work has been accomplished by Van Name, Mrs. Harriet Richardson Searle, Stafford, Boone and Blake. Although in the bibliography the author has included what is believed to be a nearly complete list pertaining to the distribution of three families of the Isopoda (Oniscidae, Armadillidiidae and Cubaridae), it is not the author's plan to utilize all of this literature in the discussion. In this paper the author will confine himself to a consideration of the species reported in New England of the three families mentioned above, although to provide clarity general statements will be made concerning the larger groupings. As a corollary to the presentation of material on distribution, considerable attention will be given to taxonomic relationships within the Isopoda.

Today, the Oniscidae, Armadillidiidae and

Cubaridae are generally placed as families within the superfamily Pleurotracheata created by Verhoeff, 1917b and 1920c, for these families and the family Scyphacidae. This is likewise the classification used by Van Name, 1936, in his great monograph. The Pleurotracheata are placed in the suborder Oniscoidea, which suborder is contained in the Isopoda, a group now usually ranked as an order of the Malacostraca. The Malocostraca, in turn, are the highest subclass of the class Crustacea. Van Name, 1936, states that the Isopoda "together with the Amphipoda . . . are often grouped as a super-order called Arthrostraca (from the segmented condition of the thorax) or Eriopthalmata (from the fact that the eyes are sessile instead of being raised on stalks), which forms one of the lower divisions of the Malacostraca." Although both the Isopoda and the Amphipoda include terrestrial species, the Amphipoda, according to Van Name, 1936, has one family which has acquired terrestrial habits to some extent. The Isopoda, on the other hand, as pointed out by Richardson, 1905, and Van Name, 1936, possesses one entire suborder, the Oniscoidea, which contains all terrestrial forms. The Isopoda can be separated readily from the Amphipoda. A key character is provided by the appendages of the abdomen. The abdominal appendages of the Isopoda are usually reduced to flattened plates that with the exception of the last or sixth pair are modified for respiratory purposes. In the Amphipoda short swimming feet are found on the first three abdominal segments while short processes for jumping or sudden propulsion are located on the last three abdominal segments. According to Van Name, 1936, the body of Isopoda "is usually of a somewhat flattened, dorsoventrally compressed form; in the Amphipoda it is compressed from side to side." The heart is in the anterior part of the body in the Amphipoda but in the posterior part in the Isopoda.

Several older classifications are interesting and illustrate the evolution of isopod taxonomy. Lack of uniformity is noted in the designation of rank given the various groupings. An early classification is that of Lilljeborg, 1864. The arrangement of the isopod families by this author is given.

Suborder Isopoda

| | |
|---|---|
| Family 1. | Oniscidae |
| Family 2. | Asellidae |
| Family 3. | Munnopsidae |
| Family 4. | Tanaidae |
| Family 5. | Arcturidae |
| Family 6. | Idotheidae |
| Family 7. | Anthuridae |

Family 8. Sphaeromidae
Family 9. Cymothoidae
Family 10. Bopyridae
Family 11. Anceidae

Müller, 1870, gave the Isopoda the rank of an order and arranged the various families within the order in the following manner:

Suborder 1. "Scheerenasseln" (Isopods with hands).
 Family 1. Tanaidae (equals Asselotes heteropodes of Milne-Edwards).

Suborder 2. Isopoda proper

- A. Walking isopods (Isopoda marcheurs of Milne-Edwards)
    - a. Ligioids: Family 2. Bopyridae
        Family 3. Oniscidae
    - b. Aselloids: Family 4. Asellidae (equals Asellotes homopodes of Milne-Edwards)
        Family 5. Idoteidae
- B. Swimming isopods (Isopoda nageurs of Milne-Edwards)
    - Family 6. Cymothoidae
    - Family 7. Sphaeromidae
    - Family 8. Pranzidae

Budde-Lund, 1893, presents a classification of the terrestrial Isopoda and places them in two subfamilies ("tribes"). The genera included in each subfamily are also given.

1. Ligiae: Ligia, Ligidium, Trichoniscus and Haplopthalmus

2. Onisci: Philoscia, Oniscus, Platyarthrus, Porcellio and Armadillidium

Gerstächer, 1882, arranges the Isopoda as follows:

Section 1. Isopoda anomala
  Family 1. Anceidae

Section 2. Isopoda genuina
  Family 1. Oniscoidea
  Family 2. Serolidea
  Family 3. Asellina
  Family 4. Munnopsidae
  Family 5. Idotheidea
  Family 6. Anthuridae
  Family 7. Sphaeromidae
  Family 8. Aegidae
  Family 9. Cymothoidae
  Family 10. Bopyridae
  Family 11. Cryptoniscidae

Budde-Lund, 1885, in a still later classification divides the terrestrial Isopoda into four tribes:

Tribe 1. Onisci (contains Armadilloidea and Oniscoidea)
Tribe 2. Ligiae
Tribe 3. Tylides
Tribe 4. Syspasti

Richardson, 1905, in her monumental work presents a classification which represents a considerable advance over the other classifications that the writer has listed. The orders and families that she lists are as follows:

Order 1. Tanaioidea or Chelifera

Family 1. Tanaidae
Family 2. Apseudidae

Order 2. Cymothoidea or Flabellifera

Family 3. Gnathiidae
Family 4. Anthuridae
Family 5. Cyrolanidae
Family 6. Exocorallanidae
Family 7. Corallanidae
Family 8. Aegidae
Family 9. Cymothoidae
Family 10. Limnoriidae
Family 11. Sphaeromidae
Family 12. Serolidae

Order 3. Idotheoidea or Valvifera

Family 13. Arcturidae
Family 14. Idotheidae

Order 4. Aselloidea or Asellota

Family 15. Asellidae
Family 16. Stenetriidae
Family 17. Janiridae
Family 18. Munnidae
Family 19. Munnopsidae

Order 5. Bopyroidea or Epicaridea

Family 20. Bopyridae
Family 21. Dajidae
Family 22. Cryptoniscidae

Order 6. Oniscoidea

Family 23. Tylidae
Family 24. Eubelidae
Family 25. Oniscidae
Family 26. Armadillidiidae

Family 27. Scyphaciidae
Family 28. Ligydidae
Family 29. Trichoniscidae

In this monograph Richardson appears to be contradictory concerning the rank given the orders listed above. Her analytic key, slightly modified from that of Sars, 1899, terms the above orders, tribes or superfamilies. This contradiction seems important as Richardson places several families in the "order Oniscoidea", for example, which are not included by Van Name, 1936, in the "suborder Oniscoidea".

Throughout the thesis the author is basing all taxonomic work on the monograph by Van Name, 1936, and his classification of the American land and fresh-water Isopoda is as follows:

- Suborder: Oniscoidea
  - Superfamily: Atracheata
    - Family: Ligiidae
    - Family: Trichoniscidae
  - Superfamily: Pleurotracheata
    - Family: Scyphacidae
    - Family: Oniscidae
    - Family: Armadillidiidae
    - Family: Cubaridae
  - Superfamily: Hypotracheata
    - Family: Tylidae

Suborder or Order Chelifera

Family: Tanaidae

Suborder: Flabellifera

Family: Cirolanidae
Family: Excorallanidae
Family: Cymothoidae
Family: Sphaeromidae

Suborder: Valvifera

Family: Idotheidae

Suborder: Asellota

Family: Asellidae

Suborder: Epicaridea

Family: Bopyridae

Van Name, 1936, presents a comprehensive statement on the distribution of land isopods. He states that land isopods may be divided into two groups; 1. the littoral or sea coast forms, 2. those forms that are not littoral. This division can be utilized to point out the difference in distribution of the two groups. The littoral species, many of which can stand considerable immersion in salt water, are more widely distributed than species of the non-littoral group. This is probably true because littoral species are very likely to be transported even to widely separated coasts on floating logs or other debris. It appears that a large part of the American non-littoral forms did not originate on this continent. Rather Van Name, 1936, states his belief that they reached American from the Old World at various times and in various ways. In support of this belief it can be noted that land isopods are very scarce in temperate North America with the exception of a few littoral forms and some originally from Europe and Asia that have been introduced, probably accidentally, through human agency. The forms in this latter category have, according to Van Name, 1936, "adapted themselves to life under the conditions of human occupation of the land, and have become so abundant that they constitute by far the greater part of the land isopod population of temperate North America." As an illustration of these forms found in the United States the following are listed: *Porcellio scaber*, *Porcellio laevis*, *Porcellio spinicornis*, *Porcellionides pruinosus*, *Tracheoniscus rathkei*, *Cylisticus convexus*, *Oniscus asellus* and *Armadillidium vulgare*.

Blake, 1929, writing on New England Oniscoidea, notes that not more than five species are indigenous to the region. He believes that the other species were probably brought from Europe on imported plants and in ship ballast along with many of our introduced insects and weeds. In this same work Blake states that some species have, in like manner, been distributed almost all over the world. He mentions as examples *Armadillidium vulgare*, *Oniscus asellus*, *Porcellio scaber*, *Porcellionides pruinosus*, and *Tracheoniscus rathkei*. Concerning the Oniscoidea Van Name, 1936, states that a number of the larger groups are very probably from the Old World. By way of illustration he mentions the Armadillidiidae and many genera centering about *Porcellio* and *Cubaris*.

In tropical and warm-temperate regions land isopods, according to Van Name, 1936, seem to be much more numerous, only a few extending northward to or over the United States-Canadian border. Reasons for believing in extensive migrations over a former land connection across Behring Strait thus seem insufficient. It seems most likely that American forms of foreign origin crossed the ocean in the region of warmer latitudes.

Van Name, 1936, lists 254 species of land Isopoda for all of America. Of this number, 22 are known also from Europe, Asia, or Africa. Nearly 75 per cent of the American land isopods are found in tropical America or areas that are close to the tropics, including the West Indies as well as the continental masses. Thus Van Name, 1936 has reason for stating that "the scarcity of land isopods in North America is remarkable".

A survey of the literature concerning the families Oniscidae, Armadillidiidae and Cubaridae showed that adequate distributional data for New England is lacking. In fact Blake, 1931b, states that "the records in the literature pertaining to the Oniscoida of New England are so few as to be of little assistance in determining their distribution." From the work of Gould, 1841; Stuxberg, 1875; Harger, 1880; Rathbun, 1905; Richardson, 1901 and 1905; Kunkel, 1819; Blake, 1929 and 1931b, most of the information has been supplied concerning previous distribution records of the New England Oniscoidea and Armadillidiidae. To the best of the author's knowledge there is no record of any species of Cubaridae occurring in New England.

Blake, 1931b, has presented a complete listing of the distributional records concerning the New England species of the families Oniscidae and Armadillidiidae. In this same paper Blake supplements his work of 1929 and provides many new records of distribution. A report on collecting trips to the White Mountain area and various other regions of New England, chiefly eastern Massachusetts and Rhode Island, is made by Blake, 1931b. He states that no woodlice are found in the White Mountains above an altitude of 650-700 feet. As his collecting was not very detailed in the Berkshire and Green Mountains region, he mentions that in these areas "similar lacunae have not yet revealed themselves." *Armadillidium vulgare*, according to Blake, 1931b, provides an example of a few forms that are coastal or southern in distribution.

The following is a list of the New England species of Oniscidae and Armadillidiidae and all records of distribution that the author has been able to find in the literature:

Family Oniscidae

*Oniscus asellus* Linn.

distribution records:
Maine: Freeport (Rathbun, 1905); Jonesport, Mt. Desert Island (Blake, 1g2gb.); Blue Hill, Farmington, (Blake, 1931b).

New Hampshire: Center Harbor (Blake, 1931b).

Massachusetts: Woods Hole (Rathbun, 1905); Salem, Beverly (Richardson, 1905); Bridgewater (Coll. Boston Society of Natural History); Prides Crossing, Nahant, Middlesex Falls, Cambridge, Boston, Roxbury, Sudbury, Needham, Blue Hills, Sharon, Nantucket (Blake, 1931b).

Rhode Island: Providence (Rathbun, 1905); Barrington (Coll. Boston Society of Natural History).

Connecticut: New Haven (Kunkel, 1819).

Blake, 1931b, states that "the distribution of this species is still very imperfectly known. It appears to be rather generally distributed, at least near the coast, from New Haven to Boston. The only inland records are Farmington, Maine; Center Harbor, New Hampshire and Sudbury, Massachusetts. North of Boston it seems to be definitely synanthropic."

*Philoscia* (*Philoscia*) *muscorum* (Scopoli), var. *sylvestris* (Fab.)

distribution records:

Maine: Mt. Desert Island (Blake, 1929b.); Blue Hill (Blake, 1931b).

Massachusetts: Barnstable, Woods Hole (Harger, 1880); Salem (Richardson, 1905); East Braintree (Coll. Boston Society of Natural History); Nahant, Roxbury, Sharon, Duxbury, Wellfleet, Edgartown, Nantucket (Blake, 1931b).

Rhode Island: Riverview, Newport (Blake, 1931b).

Connecticut: Stony Creek (Harger, 1880).

Herold, 1929c, states that this species is definitely associated with soils that are markedly saline. Blake, 1931b, notes that this is also apparently true in New England with the only exception being Sharon, Massachusetts.

*Philoscia culebrae* Moore

distribution records:

Massachusetts: Woods Hole (Van Name, 1936)

*Porcellio scaber* Latreille

distribution records:

Maine: Freeport (Rathbun, 1905); Mt. Desert Island, Jonesport, Beals Island (Blake, 1929b.); Quahog Bay (Coll. Boston Society of Natural History); Blue Hill (Blake, 1931b).

Massachusetts: Lawrence, Woods Hole (Rathbun, 1905; Salem, Beverly, Penikese Island (Richardson, 1905); Bridgewater, North Wrentham (Coll. Boston Society of Natural History); Prides Crossing, Boston, Roxbury, Blue Hills, Sudbury, Wellesley, Needham, Duxbury, Cedarville, Dennis, Wellfleet, Mashpee, Edgartown, Nantucket (Blake, 1931b).

Rhode Island: Wickford (Blake, 1931b).

Connecticut: West Haven (Rathbun, 1905); New Haven (Kunkel, 1918).

According to Blake, 1931b, "this species . . . is strongly hygrophilous and hence, more coastal in distribution. It is very sharply localized in its inland occurences. Toward the north it is somewhat synanthropic."

*Porcellio spinicornis* Say

distribution records:

Maine: Hampden (Blake, 1931b).

Vermont: Larrabees Point (Blake, 1931b).

Massachusetts: Dover, Sudbury (Blake, 1931b).

Rhode Island: Wickford (Blake, 1931b).

Connecticut: Goshen (Rathbun, 1905); New Haven (Kunkel, 1918).

Blake, 1931b, notes that "the highly discontinuous distribution of this species as known at present is doubtless due to its usually xerophilous habits and the corresponding paucity of suitable locations."

*Porcellionides pruinosus* (Brandt)

distribution records:

Massachusetts: Beverly, Salem (Richardson, 1905); Boston (Blake, 1931b).

Blake, 1931b, comments that "this form is definitely synanthropic in New England."

Cylisticus convexus (DeGeer)

distribution records:

Maine: Mt. Desert Island, Jonesport (Blake, 1929b.); Blue Hill, Strong, Gilead (Blake, 1931b).

Massachusetts: Mt. Lebanon (Stuxberg, 1875); Warwick (Richardson, 1905); Prides Crossing, Roxbury, Needham, Dennis, Woods Hole (Blake, 1931b).

Connecticut: New Haven (Kunkel, 1918).

According to Blake, 1931b, "a general statement of the distribution of this species cannot yet be made. In Maine it is evidently synanthropic."

Tracheoniscus rathkei (Brandt)

distribution records:

Maine: Freeport (Rathbun, 1905); Portland, Westbrook, Washington Junction (Norton, 1909); Mt. Desert Island, Jonesport, Beals Island (Blake, 1929b.); Blue Hill, Brooklin, Hampden, Newport, Farmington, Strong, Dixfield, Gilead (Blake, 1931b).

New Hampshire: Lancaster, Glen, North Woodstock, Center Harbor (Blake, 1931b.)

Vermont: Guildhall, Walcott, Charlotte (Blake, 1931b).

Massachusetts: Lawrence, Lanesboro (Rathbun, 1905); Salem, Beverly (Richardson, 1905); Middlesex Fells, Cambridge, Boston, Roxbury, Needham, Sudbury, Sharon, Williamstown (Blake, 1931b).

Rhode Island: Providence (Rathbun, 1905); Riverview, Smithfield Blake, 1931b).

Connecticut: New Haven (Kunkel, 1918); Kent (Blake, 1931b).

This species is not present in southeastern Massachusetts. Blake, 1931b, states that in this region "it is replaced by *Porcellio scaber* even in the less moist places."

### Family Armadillidiidae

*Armadillidium vulgare* (Latreille)

distribution records:

Massachusetts: (Gould, 1841, states that the species occurs in Massachusetts); Salem (Richardson, 1905); Nahant, Cambridge, Boston, Brookline, Roxbury, Mattapoisett, Wellfleet, Mashpee, Woods Hole, Edgartown (Blake, 1931b).

Rhode Island: Providence (Rathbun, 1905); Riverview, Wickford (Blake, 1931b).

Connecticut: New Haven (Kunkel, 1918).

Blake, 1931b, notes that "this species is distinctly southern in distribution, occurring as far north as

Salem, Massachusetts, and only near the coast. I have not found it even at Sharon where Philoscia muscorum occurs."

Armadillidium nasatum Budde-Lund

distribution records:

Massachusetts: Cambridge (Blake, 1929).

Connecticut: Middletown (Blake, 1931b).

According to Blake, 1931b, "this is a hothouse species".

## Investigational Work Of The Author

### Distribution

In an effort to contribute to the distributional data of the species of Oniscidae and Armadillidiidae found in New England, the author visited all commercial greenhouses within two selected areas of Massachusetts. Area I includes all commercial greenhouses within a twenty mile radius of Amherst, Massachusetts, while Area II embraces all commercial greenhouses on Cape Cod from the Cape Cod Canal to the tip of the Cape. One greenhouse in Middleboro, Massachusetts is also included. Plates 5 and 6 present maps of the precise areas visited. The areas were selected for two reasons. 1. They represent widely separated Massachusetts

<u>Area I</u>

Map showing the localities included in the survey of commercial greenhouses.

Plate 5

## Area II

Map showing the localities included in the survey of commercial greenhouses.

Plate 6

# DISTRIBUTION OF
# CERTAIN SPECIES OF
# ONISCIDAE AND ARMADILLIDIIDAE
# IN COMMERCIAL GREENHOUSES
# WITHIN A TWENTY MILE RADIUS OF
# AMHERST, MASS.

Table 6

| GREENHOUSE VISITED | ADDRESS | REMARKS |
|---|---|---|
| Abbe Ave. Greenhouse | Springfield, Mass. | Isopods occasionally found. |
| Allen Street Greenhouse | Springfield, Mass. | Isopods occasionally found. |
| Chas. A. Anderson | Easthampton, Mass. | Isopods have eaten wood of benches and tops of plants. |
| Babcock Greenhouses | Ware, Mass. | Isopods found in rotten wood and debris under benches. No damage. |
| Baker Greenhouse | Farley, Mass. | Isopods found on benches beneath flower pots. No damage noted. |
| Cleo D. Bourgeois | Springfield, Mass. | Infestation in past but not at present. |
| M. L. Brown & Sons | West Springfield, Mass. | Vegetable houses only; not operating in winter. Isopods found under boxes. |
| Buckley's Little Flower Shoppe and Greenhouse | Springfield, Mass. | No isopods found. |
| Butler & Ullman Inc. | Northampton, Mass. | Infestation in past in houses with wooden benches. Isopods uncommon at present. |
| Butler & Ullman Inc. | Hadley, Mass. | Heavy infestation in one rose house. Lighter infestation in another house. |
| Paul A. Cantin | Easthampton, Mass. | No isopods found. |
| R. S. Carey | So. Hadley Center, Mass. | No isopods found. Infestations in past. |
| Demaio's Greenhouse | Springfield, Mass. | No isopods found. House only two years old. |
| Joseph Dietrich | Willimansett, Mass. | No isopods found. Owner has found a few specimens in past. |

Table 6 cont.

SPECIES OF ONISCIDAE AND ARMADILLIDIIDAE PRESENT IN GREENHOUSES VISITED

| Oniscus asellus Linn. | Porcellio scaber Latr. | Porcellionides pruinosus (Brandt) | Armadillidium vulgare (Latr.) | Armadillidium nasatum Budde-Lund |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 5 | 0 | 0 | 17 |
| 0 | 63 | 0 | 0 | 0 |
| 0 | 0 | 0 | 21 | 4 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 8 | 18 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 2 | 0 |
| 0 | 0 | 0 | Several thousand obtained for experiments | Several hundred obtained for experiments |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |

Table 7

| GREENHOUSE VISITED | ADDRESS | REMARKS |
|---|---|---|
| Vernon A. Doty Gardens | West Springfield, Mass. | Isopods occasionally found. |
| Wm. E. Dressel | South Hadley Falls, Mass. | Isopods occasionally found. |
| Alfred E. Dunlop | Chicopee Falls, Mass. | St. James Ave.:<br>No isopods found. Infestation in past.<br>Grape St.:<br>Isopods found. Damage to base of plants. |
| Dupont the Florist | Granby, Mass. | Isopods prevalent. Feeding on roots protruding from flats. |
| East Springfield Flower Shop | Springfield, Mass. | Isopods found under pots. |
| Edgewood Conservatories | Springfield, Mass. | No isopods found. |
| Glendale Gardens | Easthampton, Mass. | No isopods found. Owner has found a few in past. |
| E. W. Goman | South Amherst, Mass. | No isopods found. |
| Beulah M. Hanley | Fairview, Mass. | Isopods occasionally found. |
| Harackwiewicz | Holyoke, Mass. (Smith's Ferry) | Isopods prevalent, under flats and boxes beneath benches. |
| Charles H. Henry | Chicopee Falls, Mass. | No isopods found. |
| Harold L. Hindle | South Hadley, Mass. | Isopods occasionally found under pots. |
| Indian Mound Greenhouses | Orange, Mass. | Isopods prevalent, under pots and boxes beneath benches. |
| John O. Jones | Haydenville, Mass. | No isopods found. |

Table 7 cont.

SPECIES OF ONISCIDAE AND ARMADILLIDIIDAE PRESENT IN GREENHOUSES VISITED

| Oniscus asellus Linn. | Porcellio scaber Latr. | Porcellionides pruinosus (Brandt) | Armadillidium vulgare (Latr.) | Armadillidium nasatum Budde-Lund |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 2 |
| 0 | 13 | 0 | 0 | 4 |
| 0 | 0 | 0 | 0 | 5 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 |
| 0 | 2 | 0 | 28 | 2 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 4 | 0 | 0 | 0 |
| 0 | 40 | 19 | 0 | 1 |
| 0 | 0 | 0 | 0 | 0 |

Table 8

| GREENHOUSE VISITED | ADDRESS | REMARKS |
|---|---|---|
| Edward B. Kelley | South Hadley Falls, Mass. | Isopods occasionally found. Carnation buds damaged. Nocturnal feeding. |
| Keyes & Son | Florence, Mass. | Isopods occasionally found. Infestations in past. |
| Kosiorek the Florist | Chicopee, Mass. | No isopods found. |
| McAuslin, Florist (Mikolajczyk) | Granby, Mass. | No isopods found. Has had heavy infestations. |
| Rose C. McCarthy | West Springfield, Mass. | No isopods found. |
| McClelland's | Chicopee, Mass. | No isopods found. |
| Montgomery | Hadley, Mass. | Isopods found in connecting houses, not main greenhouse. |
| Frank M. Page | Springfield, Mass. | No isopods found. |
| A. J. Paillet | Montague, Mass. | Isopods occasionally found. Under boxes beneath benches. |
| Palmer Flower Shop | Palmer, Mass. | No isopods found. |
| Perella's Greenhouse | Springfield, Mass. | No isopods found. |
| Pine St. Greenhouses | Springfield, Mass. | No isopods found. |
| Roberts & Farmer | Hadley, Mass. | Isopods occasionally found. Along wooden bench sides. Seedlings damaged. |
| Wm. Schlatter & Son | Springfield, Mass. | No isopods found. |
| Scott's Greenhouse | South Hadley Falls, Mass. | No isopods found. |
| Shaw the Florist | Shelburne Falls, Mass. | No isopods found. |

### Table 8 cont.

### SPECIES OF ONISCIDAE AND ARMADILLIDIIDAE PRESENT IN GREENHOUSES VISITED

| Oniscus asellus Linn. | Porcellio scaber Latr. | Porcellionides pruinosus (Brandt) | Armadillidium vulgare (Latr.) | Armadillidium nasatum Budde-Lund |
|---|---|---|---|---|
| 0 | 1 | 2 | 0 | 0 |
| 0 | 4 | 1 | 3 | 4 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 12 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 10 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 16 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |

Table 9

| GREENHOUSES VISITED | ADDRESS | REMARKS |
|---|---|---|
| Simard's Flower Shop and Greenhouses | Chicopee, Mass. (Aldenville) | Isopods occasionally found. Severe infestation while owner in army. |
| Sinclair the Florist | Holyoke, Mass. | Heavy infestation of isopods under flats and on sides of wooden benches. Tops of plants extensively damaged. |
| Tatham Greenhouse | West Springfield, Mass. | Isopods occasionally found. Under pots sunk in sand. |
| Taylor Gardens | Ware, Mass. | No isopods found. |
| Charles Todt | South Hadley Falls, Mass. | Isopods occasionally found. |
| Village Hill Nurseries | Williamsburg, Mass. | No isopods found. |
| Wenk's | Springfield, Mass. | No isopods found. |
| Westover Florists and Greenhouses | Willimansett, Mass. | No isopods found. |
| Otto A. Winterle | Springfield, Mass. | No isopods found. |
| Yetter the Florist | Greenfield, Mass. | No isopods found. |

Table 9 cont.

SPECIES OF ONISCIDAE AND ARMADILLIDIIDAE PRESENT IN GREENHOUSES VISITED

| Oniscus asellus Linn. | Porcellio scaber Latr. | Porcellionides pruinosus (Brandt) | Armadillidium vulgare (Latr.) | Armadillidium nasatum Budde-Lund |
|---|---|---|---|---|
| 0 | 0 | 2 | 0 | 12 |
| 11 | 71 | 0 | 0 | 5 |
| 0 | 0 | 0 | 15 | 1 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 22 | 4 | 0 | 2 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |

# DISTRIBUTION OF
# CERTAIN SPECIES OF
# ONISCIDAE AND ARMADILLIDIIDAE
# IN COMMERCIAL GREENHOUSES
# ON
# CAPE COD, MASS.

## Table 10

| GREENHOUSES VISITED | ADDRESS | REMARKS |
|---|---|---|
| Kendall's Market Garden | West Harwich, Mass. | Isopods prevalent on wooden benches. Considerable damage to plants. |
| Lawrence Greenhouses | Falmouth, Mass. | Isopods occasionally found. |
| Orleans Greenhouse | South Orleans, Mass. | Isopods occasionally found. Damage to plant roots. |
| Small's Greenhouse | Harwichport, Mass. | Isopods occasionally found. Damage to seedlings, particularly petunias. |
| Thayer's | South Harwich, Mass. | Isopods occasionally found. Owner states worst in Spring. |
| Turney's | Middleboro, Mass. | Isopods occasionally found. Damage to seedlings. |
| Yarmouth Greenhouses | Yarmouth, Mass. | Isopods prevalent. |

Table 10 cont.

SPECIES OF ONISCIDAE AND ARMADILLIDIIDAE PRESENT IN GREENHOUSES VISITED

| Oniscus asellus Linn. | Porcellio scaber Latr. | Porcellionides pruinosus (Brandt) | Armadillidium vulgare (Latr.) | Armadillidium nasatum Budde-Lund |
|---|---|---|---|---|
| 3 | 0 | 0 | 1 | 67 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 15 |
| 1 | 1 | 0 | 2 | 2 |
| 1 | 0 | 0 | 1 | 4 |
| 1 | 10 | 0 | 5 | 0 |
| 0 | 18 | 0 | 1 | 3 |

regions. 2. In the case of Area I an inland area is represented and in the case of Area II the region is coastal. It was thus believed that the different ecological conditions present in each region might yield a different isopod fauna.

Sixty-one greenhouses were visited, fifty-four in Area I and seven in Area II, and each greenhouse was carefully examined for the presence of specimens. The figures concerning the number of specimens collected represent the relative abundance of the species present in each greenhouse but often not the number of specimens found.

An examination of tables 6 - 10 reveals that a total of five species of Oniscidae and Armadillidiidae was found in commercial greenhouses of the two areas studied. These species are *Oniscus asellus* Linn., *Porcellio scaber* Latreille, *Porcellionides pruinosus* (Brandt), *Armadillidium vulgare* (Latreille) and *Armadillidium nasatum* Budde-Lund.

New distribution records for each species of Oniscidae and Armadillidiidae found in commercial greenhouses of Areas I and II follow. (see plates 5 and 6).

Family Oniscidae

*Oniscus asellus* Linn.

distribution records:

Massachusetts: Holyoke, West Harwich, South Harwich, Harwichport, Middleboro.

Porcellio scaber Latreille

distribution records:

Massachusetts: Ware, Orange, Easthampton, Florence, Montague, West Springfield, Hadley, South Hadley, South Hadley Falls, Granby, Fairview, Holyoke, Middleboro, Yarmouth, Harwichport.

Porcellionides pruinosus (Brandt)

distribution records:

Massachusetts: Orange, West Springfield, South Hadley Falls, Florence, Chicopee.

Armadillidium vulgare Latreille

distribution records:

Massachusetts: Farley, Northhampton, Florence, Hadley, Holyoke, West Springfield, Middleboro, West Harwich, South Harwich, Harwichport, Yarmouth, Orleans.

Armadillidium nasatum Budde-Lund

distribution records:

Massachusetts: Farley, Orange, Easthampton, Florence, Hadley, South Hadley Falls, Chicopee, Chicopee Falls, Granby, Springfield, West Springfield, Holyoke, West Harwich, South Harwich, Harwichport, Yarmouth, Orleans.

The new distribution records listed on pages 119-120 provide information that does not always agree with the statements of Blake, 1931b. Blake states that *Porcellio scaber* "is strongly hygrophilous and hence more coastal in distribution." The author has listed many new inland areas where *Porcellio scaber* has been found. In addition Blake, 1931b, notes that *Armadillidium vulgare* "is distinctly southern in distribution, occurring as far north as Salem, Mass., and only near the coast. I have not found it even at Sharon where *Philoscia muscorum* occurs". New distribution records of the author show that this species also may occur in many inland localities.

Further inland records for *Oniscus asellus* add materially to the distributional data of this species as only three inland records have been previously listed. (see page 99)

## Analytic keys

To assist in the determination of the New England species of Oniscidae and Armadillidiidae and to provide a clearer understanding of taxonomic relationships, the author has devised the following analytic keys. These keys present the salient characters delineating the various groups of Oniscoidea that are widely accepted today. Complete keys, however, are provided only for those groups of which the species of Oniscidae and Armadillidiidae are members. In preparing the keys the author has selected characters that, for him, provided ready means of identification, although in some cases the author has consulted descriptions of groups and species available in the monographs of Richardson, 1905, and Van Name, 1936.

Analytical key to the superfamilies of the suborder Oniscoidea or land isopods of the order Isopoda.

1. Uropoda visible from the dorsal surface. . . . . . .2

   Uropoda not visible from the dorsal surface.
   superfamily HYPOTRACHEATA

2. Mandibles with molar process. Tracheae never present in exopodites of pleopoda. Uropoda with exopodites widely separated.
   superfamily ATRACHEATA

   Mandibles without molar process (replaced by process bearing tufts or setae). Tracheae commonly present in exopodites of two or five pairs of pleopoda, though in small species sometimes lacking. Uropoda with endopodites close together.
   superfamily PLEUROTRACHEATA

Analytical key to the families of the superfamily Pleurotracheata.

1. Maxilliped with masticatory lobe acutely produced; palp much longer than masticatory lobe and with large segments.
   family SCYPHACIDAE

Maxilliped with masticatory lobe truncate at tip; palp but little longer than masticatory lobe and with small segments. . . . . . . . . . . . . . . .2

2. Body not usually capable of being rolled into a ball. Uropoda long and reaching well beyond terminal segment and preceding segment of abdomen. Second antennae generally long with antennal openings large.
family ONISCIDAE

Body usually capable of being rolled into a ball. Uropoda not reaching, or extending slightly beyond, the terminal and preceding segment of the abdomen. Second antennae generally short with antennal openings small. . . . . .3

3. Uropoda with external ramus broad, lamellar, and forming part of external contour of posterior portion of body. Tracheae present in external plates of only two pairs of pleopoda.
family ARMADILLIDIIDAE

Uropoda with external ramus greatly reduced or vestigial, not forming part of external contour of posterior portion of body. Tracheae typically present in external plates of all five pairs of pleopoda.
family CUBARIDAE

Analytical key to the New England genera and species of the family Oniscidae.

1. Abdomen abruptly narrower than thorax. Epimera of abdomen not expanded. Lateral lobes of the head lacking or not well developed . . . . . . .2

Abdomen not abruptly narrower than thorax. Epimera of abdomen expanded. Lateral lobes of head present and well developed . . . . . . . . .4

2. Flagellum of second antennae with three segments . .3.

Flagellum of second antennae with two segments. Porcellionides pruinosus (Brandt)

3. Second antennae with first segment of flagellum more than one and one-half times the length of either second or third segment. Lateral lobes of head practically wanting. Dorsal surface of body smooth. Epimera of third, fourth and fifth abdominal segments rather narrowly acute and bent directly backward but not appressed to the side of the abdomen. Apex of terminal segment of abdomen quite acute. Philoscia muscorum (Scopoli)

Second antennae with segments of flagellum differing but little in length, the second segment slightly shorter than either the first of third segment. Lateral lobes of head slightly projecting under the eyes. Dorsal surface of body quite thickly dotted with short stiff scabrous hairs. Epimera of third, fourth and fifth abdominal segments with small, acute, posteriorly directed points that are appressed to abdomen. Apex of terminal segment of abdomen quite broadly rounded. . . Philoscia culebrae Moore

4. Flagellum of second antennae with three segments. Tracheae absent on all of external plates of pleopoda. . . Oniscus asellus Linn.

Flagellum of second antennae with two segments. Tracheae present on at least two of external plates of pleopoda . . . . . . . . . . 5

5. Frontal lobe obtusely triangular. Flagellum of second antennae about as long as last peduncular joint and with its two segments of nearly equal size. Color of dorsal body surface generally a uniformly grayish black although sometimes lighter with irregular patches, or rarely black with light yellowish side-plates. . . . . .Porcellio scaber Latreille

Frontal lobe broadly rounded. Flagellum of second antennae not as long as last peduncular joint and with proximal segment nearly twice the length of the distal one. Color of dorsal body surface yellowish gray with dark brown patches which are usually arranged in five longitudinal series on the mesosome; the middle of the mesosome and cephalon uniformly blackish although fresh specimens exhibit a double row of very conspicuous bright yellow patches along the middle of the mesosome. . Porcellio spinicornis Say

6. Lateral lobes of head truncated at the tip. Body capable of rolling into a ball.
   Cylisticus convexus (De Geer)

   Lateral lobes of the head rounded at tip. Body not capable of rolling into a ball.
   Tracheoniscus rathkei (Brandt)

Analytical key to the New England species of the genus Armadillidium, family Armadillidiidae.

1. Lobe into which the epistome is produced not extended forwardly. Outer ramus of the uropoda and tip of the terminal segment of the abdomen broadly truncated.
   Armadillidium vulgare (Latreille)

   Lobe into which the epistome is produced extended forwardly. Outer ramus of the uropoda and tip of the terminal segment of the abdomen rounded.
   Armadillidium nasatum Budde-Lund

| AREA I (fifty-four commercial greenhouses visited) | AREA II (seven commercial greenhouses visited) | CONCLUSIONS |
|---|---|---|
| *Porcellionides pruinosus* found in six greenhouses. | *Porcellionides pruinosus* not found in any greenhouses. | Thesis studies indicate that *Porcellionides pruinosus* apparently does not occur in greenhouses of Area II. |
| *Porcellio scaber* found in fourteen greenhouses.<br>*Armadillidium vulgare* found in six greenhouses. | *Porcellio scaber* found in three greenhouses.<br>*Armadillidium vulgare* found in six greenhouses. | *Porcellio scaber* most widely distributed in greenhouses of Area I. *Armadillidium vulgare* most widely distributed in greenhouses of Area II. |
| *Oniscus asellus* found in but one greenhouse. | *Oniscus asellus* found in four greenhouses. | *Oniscus asellus* apparently more widely distributed in greenhouses of Area II than in greenhouses of Area I. |
| Following three species found most abundantly. Listed in descending order of abundance.<br>1. *Armadillidium vulgare*<br>2. *Armadillidium nasatum*<br>3. *Porcellio scaber* | Following three species found most abundantly. Listed in descending order of abundance.<br>1. *Armadillidium nasatum*<br>2. *Porcellio scaber*<br>3. *Armadillidium vulgare* | The same three species appear to be present in greatest numbers in each area. *Porcellio scaber* and *Armadillidium vulgare* not limited to coastal occurrence as stated by Blake, 1931b. |
| Only three greenhouses had three species present. One house had four species. Remaining houses had two species or less. | Four of the greenhouses had three species present. One house had four species. Remaining houses had two species or less. | Greenhouses of Area I rarely contain more than three species per house (only 8% in studies). Over 70% of the greenhouses in Area II contained more than three species. |

Table 11.

## Conclusions

Further study of the tables allows one to draw several conclusions that appear to be substantiated by these studies. Table 11 lists observations made from a study of tables 6-10 together with conclusions based on the observations.

In addition to the conclusions listed in table 11, a general conclusion is made that all species of Oniscidae and Armadillidiidae collected by the author have a much wider range of distribution in Massachusetts than has been reported previously.

## CONTROL

### Literature Review

To the author's knowledge the fact that certain terrestrial isopods are capable of causing damage to living plants was not known until (sixty-seven years ago) Riley, 1880, mentioned that young of Philoscia or Porcellio perhaps caused damage in a particular instance to the roots of grape vines.

In 1885 Fitch noted that he was not aware of any publication on the American species of woodlice. He reported at this time that woodlice frequently found a favorite abode in the cavities caused by peach borers that extended down the sides of the roots of peach trees. No mention is made in this paper of any damage caused by these crustaceans. In fact Fitch states that "they are perfectly innocent and harmless, subsisting upon decaying vegetable and animal substances. They afford a dainty bit to domestic fowls, which devour them with avidity, and are always scratching our yards in search of these more than any other article of diet. This is their chief importance in an economical aspect."

After Riley, 1880, noted the possibility of grape vine root damage by young sowbugs, further damage by these creatures is not known by the author to have been disclosed until de Borre, 1887, mentioned that Oniscus murarius ate the corks of wine bottles probably after the corks had been attacked by insects.

The correspondence of Kohn, 1890, mentions that <u>Oniscus</u> severely damaged low growing flowering plants in his garden and those of his neighbors. The reply to his request for a remedy is found in the same reference. In the reply, doubt is expressed that <u>Oniscus</u> causes plant damage. The statement is made that these crustaceans are "popularly supposed to feed mainly if not entirely upon decaying vegetation." No remedy was given at this time.

Two more reports of sowbug damage were made in 1890. In 1890, there is an anonymous answer to the editorially expressed doubt of the sowbug damage that is mentioned in the preceding paragraph. It is revealed in this correspondence that sowbugs severely damaged a potted cactus plant that had been placed out of doors in a damp place and become overrun with grass. Wright, 1890, in correspondence speaks of damage to wistaria plants and possible damage to roses and geraniums. The plants, all of which had been heeled into the ground and covered quite closely with carpet, were found to be swarming with sowbugs. The sowbugs killed the wistaria by eating the buds.

Anonymous correspondence, 1892, indicates that species of <u>Oniscus</u> damage plants. Damage to violets and young rose bushes is reported. The first mention of sowbug control that the author has found is given in this correspondence. A "trapping system by means of slices of potato wet with Paris green or a thorough drenching of the soil with a diluted kerosene emulsion" is the remedy suggested.

Further plant damage by Oniscus is reported in anonymous correspondence of 1893.

In notes from correspondence, 1895, we learn that the decaying bodies of great numbers of sowbugs of the genus Porcellio polluted a well located in a woodshed located in Lawrence, Massachusetts. To control the pests the well was cleaned out; decaying wood in the woodshed was removed, and the woodshed floor was covered with cement.

Howard, 1898, repeats the suggestion concerning the use of poisoned potato slices as a control for Oniscus.

Chittenden, 1901, notes that Armadillidium armadillo Linn. causes occasional injury to cultivated violets. Damage to pansies by a species of sowbug is also mentioned. Chittenden claims that injury by sowbugs is apt to be exaggerated in many instances, although he comments that injury to plants in greenhouses often occurs. As a control, the same poisoned baits used for cutworms are recommended. However, Chittenden thinks a better control is obtained by distributing slices of potatoes or other vegetables that have been dipped in a solution of Paris green prepared at the rate of about 1 lb. to 100 gals. or a little less of water.

Armadillidium vulgare possesses great resisting power to ordinary insecticides according to Garman, 1901. Tobacco decoctions and kerosene emulsions are not effective against it. In infested soil the author recommends the use of bisulphid of carbon. It is noted that pillbugs are injurious to cucumbers and lettuce.

In Ireland Oniscus asellus causes plant damage according to Carpenter, 1903.

Richardson, 1905, in her monograph states that Armadillidium vulgare is reported to damage hothouse grown cucumbers and other vegetables. Injury by the same species to plants and young cotton occurred in Texas, while in Virginia the pest is very destructive to mushrooms.

An important paper was prepared by Pierce, 1907, who states that Armadillidium vulgare may do considerable damage to garden crops, flower gardens, vines and field crops in the vicinity of buildings. Among the plants reported to be injured in 1905 during a particularly rainy spring were cotton, beans, peas, tomatoes, radishes, lettuce, mustard, rose bushes and palmetto. Flower seeds were also damaged.

In the same paper, Pierce remarks that the species is said to be a valuable scavenger. However, the scavenger habit makes it undesirable in the house because of the possibility that it may carry disease. Other mention of the scavenger habit is made by Pierce. He states that sowbugs fed on dead ticks and eggs of ticks when no other food was available. A dead rat was also almost entirely eaten by sowbugs. Perira and Travassos, 1934, speak of the use of woodlice for cleaning vertebrate skulls. This likewise illustrates the ability of the creatures to serve as scavengers.

The control measures listed by Pierce, 1907, are as follows:

1. Poisoned baits, - use of potatoes poisoned either with London purple or Paris green. A thin covering of the powder is applied to sliced potatoes.

2. An effective measure is to sprinkle the soil about the injured plant with Paris green. The same powder may be dusted about the haunts of the sowbugs.

3. The ground of the garden patch should be kept well broken and raked to prevent clodding and cracking. Cracks in the soil frequently give sowbugs protection.

4. All rubbish should be removed.

5. For treatment of sowbugs in greenhouses and dwellings, carbon bisulphid has been recommended.

6. Kerosene emulsion as a contact spray proved to be fatal to the pests.

Hunter, 1912, determined that Roentgen rays have no effect upon the fertility or development of the various stages of Armadillidium vulgare or Porcellio laevis.

The injury to mushrooms by Armadillidium vulgare and Porcellio laevis is described by Popenoe, 1912. These pests attack the caps or the fruiting bodies of the mushrooms. The remedies mentioned include hand picking, pouring hot water along the cracks in the boards and in other places where the bugs may be concealed during the day, and treatment with sulphur dioxide after the mushroom crop has been harvested and the compost removed. The plastering of the wet surface of cut potatoes with Paris green and laying them about on the beds is frequently successful in ridding the houses of this pest. Buildings should be as tight as possible with few outlets and screened with wire gauze.

In an anonymous note of 1914 it is learned that *Armadillidium vulgare*, *Armadillidium quadrifrons*, and *Oniscus asellus* infested greenhouses in Ontario, Canada. *Asparagus*, *Primula*, *Lobelia*, *Solanum* and many other plants were badly attacked. Systematic trapping by means of inverted flower-pots containing damp hay reduced the crustacean numbers. Poisoned bait composed of 2 parts rye flour, 2 parts sugar and 1 part Paris green was also successful.

Collinge, 1914, reports that *Trichoniscus roseus* Koch may cause damage in greenhouses. *Oniscus asellus* Linn. is reported as a common pest in cold frames and potting sheds and also flower borders and vegetable gardens. *Porcellio scaber* Latr. is often found in orchid houses and ferneries and has been recorded as damaging the bark of lime trees. The latter species and *Oniscus asellus* are the two commonest sowbugs in England.

This same author notes that *Porcellio scaber* is frequently found in cold frames in the Channel Islands often accompanied by smaller numbers of *Porcellio dialtatus* Brandt and *Porcellio pictus* Brandt. *Porcellio laevis* has been found attacking the roots of strawberry plants in the Channel Island. Porcellionides pruinosus Brandt has been taken on potatoes and lettuce grown under glass. In flower borders an enormous amount of damage frequently attributed to slugs is caused by Armadillidium vulgare. This same pest also attacks potatoes and field beans, the latter plant also being attacked by Armadillidium nasatum. Collinge recommends the following control measures.

1. Clean outhouses, potting sheds, etc.
2. Kerosene emulsion as a contact spray is effective.
3. Sliced potatoes thinly covered with Paris green or London purple may be used as a bait.
4. Sprinkling Paris green on the floors of greenhouses and covering it with damp boards is effective.
5. Dusting the soil, especially along the sides of tiles surrounding flower beds, with equal parts of Paris green and ground unslaked lime is an excellent remedy.
6. Loose straw and rubbish that collects around manure heaps should be destroyed.

Hewitt, 1915, states that the following species of woodlice occurred on garden and greenhouse plants:

1. Oniscus asellus
2. Armadillidium vulgare
3. Armadillidium quadrifrons

Begonia and coleus were attacked.

"Slug shot" is recommended by Tipton, 1915, as a control for sowbugs. 5 pounds of this material is sufficient for a 100-foot house. It should be used in the evening when the foliage is dry.

An anonymous note of 1916 states that carbon bisulphide is used for injection into the ground to destroy various pests such as <u>Oniscus</u>. This material can be used without danger to plants at the rate of one ounce per square yard.

Dean, 1916, reports that sowbugs seriously injured alfalfa and clover plants in a Kansas greenhouse. Some of the plants were almost completely destroyed. Sliced potatoes poisoned with Paris green were first tried but did not prove effective. One application of a poison bran mash flavored with oranges, however, killed practically all the sowbugs. Small amounts of the mash were scattered about the base of the plants in the evening.

Sowbugs are mentioned by Ross and Curran, 1916, as causing depredations in greenhouses.

Weiss, 1916, notes that sowbugs have been known to feed on roots and tender portions of plants such as the fronds of ferns. The pests may be controlled by trapping in little heaps of wet grass, leaves or pieces of damp bark. A liberal use of tobacco dust will undoubtedly discourage the sowbugs. The formula for a suggested poison bait is given as follows:

2 parts of rye flour by weight
2 parts of sugar by weight
1 part of Paris green by weight

The above mixture should be scattered along the top of the edge board of the greenhouse bed or on narrow board laths across the soil in the frame or hotbed. The board must be dry or the mixture will become too lumpy for the sowbugs to eat. Only enough of the material should be mixed at one time for a single application as it cakes and deteriorates after standing.

Gravatt and Marshall, 1917, made studies with insects, woodlice and snails feeding on various species of the genus *Ribes* attacked by the blister-rust fungus, *Cronartium ribicola*. The experiments showed that the above pests show a preference for the infected leaves. *Armadillidium vulgare* was active on leaves close to the ground and was found to bear numerous urediniospores and sporidia of *Cronartium ribicola*. It was also found that after feeding on different spore-stages of the blister-rust fungus the excreta of *Armadillidium vulgare* contained abundant urediniospores and in some cases sporidia and pieces of telial columns. Elimination lessened the viability of both the urediniospores and the teliospores but the pests, nevertheless, are important agents in the dissemination and spread of this fungus.

Lockhead, 1917, mentions that woodlice may cause injury to plants.

According to Pierce, 1917, pillbugs and sowbugs injure cotton seedlings but can readily be controlled by the use of poisoned baits.

Popenoe, 1917, notes that sowbugs are frequently pests on mushrooms. As a general method of prevention against pests in the compost, the author recommends the sterilization of manure before planting. Sterilization may be accomplished in vats or boxes through which steam pipes are conducted. The compost should be heated to 150° F. and this temperature will destroy all animal life.

Ferdinandsen and Rostrup, 1919, state that beans and cucumbers were attacked by Oniscus in Denmark.

Gibson and Ross, 1922, mention that sowbugs are often very destructive in greenhouses. They recommend the following control measures:

Preventive measures: Deprive them as much as possible of hiding places. Coat the benches with a tar composition. The tar preserves the wood and thus robs the sowbugs of a favorite refuge. While fresh the tar also acts as a repellent.

Hot water: Pour hot water into the cracks and crevices in wooden partitions and benches.

Trapping: Inverted flower pots containing damp hay will serve as traps. Pots should be examined in the morning and the sowbugs destroyed.

Poisoning: 1. Paris green -- 1 part by weight
Icing sugar -- 10 parts by weight

2. Paris green -- 1 part by weight
Icing sugar -- 2 parts by weight
Rye flour -- 2 parts by weight

Scatter the bait along the sides of benches. Renew the bait when it becomes encrusted.

Miller, 1922, notes that *Porcellio scaber* may infest dwellings.

Speyer, 1923, reports that in greenhouses, *Armadillidium speyeri* and *Armadillidium pictum* infest cucumbers. *Armadillidium vulgare*, *Porcellio laevis*, and *Haplophthalmus danicus* infest tomatoes but do little damage. *Armadillidium speyeri* gnaws the stems, cropping the cotyledons of tomato seedlings in seedboxes up to a week after germination, but leaves cucumber seedlings of this age alone. When tomato seedlings reach six inches in height they are not attacked.

In this same paper Speyer notes that woodlice are easily killed by hot water. In the winter the borders may be cleaned out and the surfaces flooded to drive the woodlice to the top. The borders may then be sprayed with 8 pounds of potash soft soap (household), 1 gallon of cresylic acid (pale straw, 97-99%) and ½ pound of pure naphthaline. These should be heated until the soap is melted and the naphthaline is dissolved.

for spraying, 2 pints should be used for every 12 gallons of water. It was also found that the number of woodlice decreases with persistent trapping.

Phenol was found to be the best fumigant for destroying pests in soil according to experiments by Speyer, 1924a. The application of phenol was made in the concentration of 1 part to 1000 parts of soil. This formulation killed sowbugs up to the second day after mixing. Higher concentrations were lethal for a longer period of time but had a retarding effect upon tomato seed. In the case of experiments with poison baits, neither bread nor flour showed any appreciable advantage over oatmeal. The best results were obtained with 50 parts of oatmeal, 1 part of potassium bichromate, 2 parts of glucose and 30 parts of water. The poison is best distributed in the bait in the form of a solution. Sodium fluoride and Paris green had no effect on woodlice. Commercial pyridine was tried as a deterrent but was not particularly effective.

According to Speyer, 1924b, Armadillidium speyeri and Armadillidium pictum are practically confined to cucumber houses. Armadillidium vulgare is more often found in the cooler tomato houses, in peach houses and in the nests of ants. The latter species breeds from early spring to August and at the approach of winter buries deep in the ground and becomes inactive. The two species found in cucumber houses remain active unless they are turned outside when the borders are cleared.

Speyer mentions also in this same article that the stems of seedlings in boxes are often bitten through at soil level. If plants are potted, holes are eaten in the lower leaves, the cotyledons often being entirely destroyed. Armadillidium speyeri may do considerable damage by eating the petals of carnations while Armadillidium vulgare often removes bark from peach trees. Both species feed at night.

Concerning control of woodlice Speyer, 1924b, presents the following notes. Woodlice dipped for ½ a second in water at 149° F. died within a few minutes. Soil with an internal temperature of 146° F. and a surface temperature of 124° F. killed in thirty seconds all the woodlice placed on the surface. With soil having an internal temperature of 136° F. and a surface temperature of 108° F. all were killed within 2 minutes. If hot water is not available for this method of treatment, Speyer again suggests the method of spraying given in Speyer, 1923. As a means of treatment in the summer red beets or mangels proved to be quite successful as baits in tomato and cucumber houses. The beets should be cut in half and placed face downwards on the soil, ½ to every 4 plants. Woodlice collecting on the beets should be shaken into a pail of hot water every morning. Red beets will remain effective from 6 weeks to 2 months but mangels not for quite as long a period. Speyer also suggests a trap of inverted flower-pots containing straw with added glucose.

Ogilvie, 1925, records that woodlice, probably _Armadillidium_ _vulgare_, caused much damage to seedling string beans in Bermuda. Repeated sprayings with 2 pounds of lead arsenate powder to 40 gallons of water protected the plants until they had outgrown the attack.

Saverin, 1925, notes that _Armadillidium_ _vulgare_ is a pest in the greenhouses of South Dakota.

Further experiments with poisoned baits were conducted by Speyer, 1925. Best results were obtained by using 90% coarse oatmeal, 5% white flour, and 5% Paris green. The ingredients are thoroughly shaken in a large bottle with a rather wide neck. The bottle should possess a cork through which a hole ½ inch in diameter has been cut. A light scattering of the bait on the staging of the benches can then be accomplished, the seed boxes then being placed upon the bait. It was noted that much of the bait material falls through to the ground where it is very useful. Speyer had not tested the bait in cucumber houses with growing plants. Species of woodlice killed by the bait are Armadillidium pictum, Armadillidium vulgare, and Porcellio laevis. Naphthalene treatment proved to be effective against woodlice although the pests can escape when loose soil or clods of earth provide shelter for them.

Ogilvie, 1926, found Armadillidium vulgare boring into pumpkins in Bermuda.

Speyer, 1926, recommends a new bait for the control of woodlice. The bait, consisting of 1 pound Paris green thoroughly mixed with 28 pounds dry bran, is broadcast over the whole surface to be treated at the rate of ½ ounce per square yard. For plants in pots a little bait should be sprinkled over each pot in addition to broadcasting under staging. The bait should be used early in the season, before the woodlice begin to breed, as towards the end of the season they do not appear to feed upon the bran so readily. In cucumber houses the chief advantage of this bait is that the collars of the cucumber plants are not injured in any way by the bait. A severe infestation of cucumber houses by Armadillidium vulgare was controlled by two applications of the above bait. Control of Porcellio laevis and *Porcellio rathkei* was also achieved.

Weigel, 1926, notes that sowbugs feed on roots and tender portions of plants. The carnation and the sweet pea are particular favorites of the pest. The following control measures are recommended:

1. Paris green, sugar mixture

   9 parts sugar } sprinkle surface of soil
   1 part Paris green } lightly with the mixture

2. Poisoned bran mash

Mix white arsenic or Paris green and dry bran thoroughly in a container. In another vessel stir 1 pint of cheap molasses or sirup into 4 to 6 quarts of water. Then prepare a mash by slowly adding the mixture of sirup and water to the poisoned bran. Allow it to stand for several hours to permit the bran to take up the arsenic. Scatter thinly over the surface of the soil along the rows of plants after sundown.

3. Paris green, sugar, flour mixture (similar to number 2.)

   2 parts of white flour
   2 parts of sugar
   1 part of Paris green

4. Dry tobacco dust as a repellent

5. Nicotine sulphate and soap solution spray

6. Kerosene emulsion spray

7. Sanitation; all rubbish should be destroyed

*Porcellio laevis* was found in the soil about citrus stocks in Hawaii, according to Whitney, 1926.

Speyer, 1927, notes that woodlice have been on the list of greenhouse pests recorded by the Experimental Research Stations of England since 1920.

Geiser, 1928, presents instructions for the making of a simple trap for the collection of isopods from the soil. A potato or a carrot is bored completely through lengthwise with a large cork borer. A short section of the plug removed is cut off and used as a stopper at one end, the other end being left open. These traps should be laid in piles of rubbish where woodlice are abundant and should be lightly covered with litter. If necessary the traps may be baited with bacon. When a trap has been in place for some time it is held vertically, sharply tapped, and the contents shaken into a dish. By this means, many usually rare species have been obtained.

Gibson, 1928, states that sowbugs attack the roots of carnations, young growth of carnations, sweet peas and other flowering plants. The following controls are given:

1. Poisoned bait

   2 parts of white flour by weight
   2 parts of sugar by weight
   1 part of Paris green by weight

2. Trapping

Use inverted flower-pots containing damp hay. Traps should be examined in the morning and the pests destroyed.

Blake, 1929a, notes that woodlice are particularly destructive in gardens and hothouses. When plant damage of obscure origin is discovered, the woodlice should be kept in mind.

Gibson and Twinn, 1929, list the following control measures for sowbugs:

1. Old boxes and other debris should be burned to destroy hiding places.

2. Poison bait

1 part Paris green by weight
10 parts icing sugar by weight

The mixture should be placed where the sowbugs congregate and should be replaced when it becomes encrusted. It should not, of course, be placed on vegetables or where children or house pets might reach it.

Lesne, 1930, speaks of a journey taken to points in Mozambique. He mentions that great numbers of _Oniscus_ migrate and are very destructive to cotton.

Sein, 1930, states that in sugar cane a woodlouse, _Philoscia culebrae_ Moore, eats out irregular shallow cavities near the tip of the roots and also continues the injury caused by other pests. In the field it is usually found near the surface at the base of the cane stool.

Thomas, 1931, mentions that woodlice are minor pests on mushrooms.

An anonymous note, 1932, tells of successful laboratory experiments in Germany with two proprietary pyrethrum powders against Porcellio scaber and Oniscus asellus. 100% mortality was obtained in all cases. Such dusts are recommended for the control of woodlice in cellars.

In an anonymous note, 1933, E.R. Speyer reports attempts to utilize in poison baits the attractiveness to woodlice of dried blood used as a top-dressing in the culture of cucumbers and tomatoes. The best results were obtained by mixing Paris green with the dried blood at the rate of 1 to 56 parts by weight. The mortality was not appreciably greater at 1 to 28 parts, but at 1 to 100 parts it was considerably less. Potassium bichromate (1 to 28 parts by weight) gave a high mortality within a week in warm weather, but proved disappointing under less favorable conditions.

Austin, 1933, reports that Oniscus asellus is frequently found in large numbers on mushroom beds where it injures the caps.

Kemper, 1933, states that fumigation tests with Venoxiol, a jelly-like preparation claimed to contain 96% of carbon bisulphide, showed that the substance killed woodlice. The tests were made in cellars and in a fumigation chamber.

Thompson, 1933, comments on a heavy infestation of woodlice that occurred in a dump at Ontario, Canada in 1931. The species present in the dump was probably Porcellio laevis. The pests migrated at night to houses in the vicinity of the dump and crawled over food kept in cellars. Plots in the infested dump were treated with paradichlorobenzene (1¼ pound per 100 square feet), baits of Paris green and brown sugar (1 to 40 parts) or Paris green, bran and sirup. These all resulted in some reduction of the pest, but the infestation was eventually controlled by covering the dump with slag to a depth of six inches. The slag was pounded down and left to harden.

Bewley, 1934, lists Armadillidium vulgare and Porcellio laevis as minor pests of tomato in glasshouses of the British Isles. They may be controlled by Paris green baits, by drenching the soil around the base of walls, gutter pipes, etc., with boiling water. Another control is the use of pyrethrum dust or an emulsion of

1 gallon cresylic acid, 1 pound naphthalene and 8 pounds soft soap in 98 gallons of water as a contact insecticide.

Jary and Austin, 1934, report *Oniscus asellus*, *Porcellio scaber* and *Porcellio laevis* in mushroom houses where they injure the mushroom caps. They are frequently found in mushroom houses not specially constructed where half-rotten straw occurs in damp dark situations.

Mc Daniel, 1934, states that woodlice, particularly *Armadillidium vulgare*, were troublesome in houses in Michigan. The woodlice were attracted by the following bait: ½ U.S. pint sodium arsenite solution and 2 U.S. pints molasses in about 1 U.S. gallon of water. These constituents are mixed with 12 pounds of bran with the addition of 1 ounce amyl acetate. Since the pests prefer moist dark places, they may be prevented from entering houses by placing the bait under boxes, boards, etc., or even in trenches dug near the foundations and covered with sacks or loose earth.

Herold, 1935, mentions that an infestation of a damp ground-floor room in Pomerania by *Porcellio pictus* was cleared in about three weeks by spreading a proprietary preparation of thallium sulphate near the cracks where the pests sheltered.

Speyer, 1935, writes that investigations indicated that stunting of nursery tomatoes combined with a blue appearance of the foliage and marks of gnawing around the collars was more probably due to *Armadillidium vulgare* than to *Scutigerella immaculata*.

Stepanov, 1935, gives a detailed account of the work on biological control carried out in 1932-34 in the Republic of Abkhazia on the Black Sea Coast of Transcaucasia. In trap bands, large numbers of the females and eggs of *Pseudococcus gahani* (mealybug) are destroyed by woodlice, especially in the autumn during the rains.

Britton, 1936, reports injury to rhododendron seedlings by *Oniscus asellus*.

In a paper by Pyenson and MacLeod, 1936, it is stated that a test was conducted to determine the effects of naphthalene on woodlice, *Bruchus obtectus* and *Tenebrio molitor*.

Speyer, 1936, writes that *Armadillidium speyeri*, *Armadillidium vulgare*, *Porcellio laevis* and *Oniscus asellus* were controlled in greenhouses by the use of a bait consisting of 1 part Paris green with 28 parts bran or 56 parts dried blood.

Kelsall and Stultz, 1937, note that 100% pyrethrum killed woodlice present in greenhouses.

Strong, 1937, states that fumigation with paradichlorobenzene (1 pound per 1000 cubic feet of air space) for 48 hours gave a good control of woodlice on mushrooms.

Davis, 1938, cites sowbug damage to mushroom beds. The crustaceans eat holes in the buttons and in the caps of the matured mushrooms. It is possible to control sowbugs in a cellar or other small area by hand-picking them off the beds. Where they congregate in clusters along the edges of the beds, hot water may be poured upon them. Pyrethrum dusts as used for the mushroom flies will give some control if they actually come in contact with the sowbugs. In using dusts, the beds should be allowed to dry slightly and should not be watered for approximately 24 hours after application of the insecticide. Light fumigations with calcium cyanide when the sowbugs are feeding on the surface of the beds (usually at night) are said to be effective. Poisoned baits also provide good control against pests but their use in mushroom houses cannot be recommended because of the danger of accidentally getting poison on the mushrooms.

Miller, 1938, mentions that certain isopod species may cause considerable damage to gardens and crops. Armadillidium vulgare has a particularly bad record as a hothouse pest. *Porcellio scaber* is reported to eat holes in the stems of artichoke plants, one of the principal crops on the peninsula south of San Francisco.

Metcalf and Flint, 1939, write that sowbugs feed upon the roots and tender portions of plants near the ground. They will attack mushrooms and nearly all greenhouse plants. The following control measures are recommended:

1. Poison bran mash

   1 peck of dry bran
   ¼ pound of Paris green
   1 quart of molasses
   4 quarts of water

   place the mixture
   upon the benches
   in small piles

2. Paris green, sugar mixture

   1 part Paris green
   9 parts sugar

Sprinkle over the benches or place beneath clods, bits of manure, or boards where the sowbugs gather.

3. Hot water

Lange, 1941, states that *Porcellio scaber* is a pest of minor importance on the artichoke. Holes are eaten in the leaf-stalks.

Bewley, 1942, includes a section on pests of tomato in glasshouses in Britain that has been revised by E. R. Speyer. It is stated that woodlice may destroy large numbers of seedlings by biting through the stems and devouring the upper portions of the plants. The pests can be controlled by spreading a poison bait containing 1 pound Paris green in 28 pounds of dry bran, 56 pounds of dried blood or 20 pounds each of dried blood and castor meal at the rate of about ¼ ounce per square yard.

Blauvelt, 1942, found that as poisons against sowbugs, Paris green and sodium arsenate were most effective. 1 pound of Paris green to 20 pounds of sugar gave 100% kill in 24 hours. 1 pound of Paris green to 20 pounds of dry dog food, and 1 pound of Paris green to 10 pounds of bran plus 10 pounds of fish meal were also excellent. 1 pound of Paris green to 20 pounds of bran was reasonably effective if kept dry but was inferior to the sugar mixture. Occasional applications scattered at the rate of 1 pound to 100 feet of bench was sufficient.

Bohart and Mallis, 1942, present a survey of the damage that Armadillidium vulgare and Porcellio laevis have caused to various plant species. They mention the frequency of greenhouse damage by these pests and the fact that they may attack field crops under favorable conditions. Woodlice are also accused of separating the earth from the sides of benches in greenhouses, causing uneven drainage, devouring fertilisers and girdling plants at or near the ground level, and sometimes congregating in large numbers in the moist basements of dwellings.

In the same paper experiments with various insecticides are described. Acid lead arsenate, cuprous carbonate, sodium fluosilicate and pyrethrum dust (0.2% pyrethrins) gave 64-83% mortality after three weeks. Arranged in order of decreasing toxicity, based on lower dosages, mecuric chloride, sodium arsenate, manganese arsenate, calcium arsenate and cuprous cyanide gave 100% mortality in one or two weeks. White arsenic gave 97% mortality in 3 weeks. Calcium arsenate appears to be the most practical from the standpoint of cost, availability and plant injury. The presence of flour, which was used as a diluent, adhesive and attractant, accelerated the kill but did not seem to effect the final mortality. Paris green and cuprous cyanide were capable of causing considerable mortality purely by contact with the under surface of the sowbug body. Calcium arsenate was less toxic as a contact poison. In field tests against both Armadillidium vulgare and Porcellio laevis, calcium arsenate applied at the rate of 3-5 pounds per 1000 square feet, alone or with flour, gave satisfactory results.

Thomas, 1942, writes that sowbugs chew clean holes into small mushrooms. They may also occur in large numbers in the bed manure which they break down and destroy along with the mycelium it contains. However, the injury is usually not extensive. Sowbugs are easily killed by pyrethrum fly dusts if the dusts contact them. Therefore growers may profitably raise the side boards of their beds and dust the manure surface back of them, the bed surfaces, the floor under the bottom beds, and the walks, especially along the walls. Light doses of calcium cyanide also have been used against sowbugs. Poisoned baits should not be used in mushroom houses. The grower should first determine whether sowbugs are really causing injury, otherwise there may be a waste of time and materials.

Collinge, 1943, found the following exctic woodlice in greenhouses in the British Isles: Trichorina thermophila, Trichoniscus linearis, Nagara nana, Nagara cristata, Angara lenta and a species of Cubaria.

The following paper is not included in the bibliography because the author was unable to find the complete reference. Martin, 1944, found that both Gesarol and a dust containing 0.8% of DDT were effective as contact poisons against sowbugs.

White and Doolittle, 1944, note that sowbugs feed upon the roots and tender portions of plants.

As a control they recommend the following measures:

1. Paris green, sugar mixture

   | | |
   |---|---|
   | 1 ounce Paris green<br>9 ounces sugar | sprinkle on the surface of the infested soils |

2. Paris green, wheat flour, sugar mixture

   2 ounces wheat flour
   2 ounces sugar
   1 ounce Paris green

3. Nicotine sulphate spray

   1 tablespoonful nicotine sulphate (40%)
   1 cubic-inch cake soap (or 2 level tablespoonfuls of soapflakes)
   1 gallon water

4. Pyrethrum spray mixture

5. Sanitation; destroy rubbish

Dustan, 1945, compared a DDT bait with a Paris green bait as a control for sowbugs. The species of isopod used was probably <u>Armadillidium vulgare</u> and the experiments were of the nature of laboratory tests in glass jars. A bait of DDT and rye flour (1 - 9) gave 100% kill in 5 days. Paris green resulted in complete mortality in 4 hours.

Smith and Goodhue, 1945, found that woodlice (<u>Armadillidium</u>) were killed by DDT aerosols or their residues. The aerosols caused no injury to the plants except in certain cases to cucumber, tomato and soybean seedlings. Experiments indicated that the injury was caused by the cyclohexanone. Treatment of greenhouse plants with DDT aerosols was found to be cheap and safe. They left no visible residue but had both immediate and residual effect.

Neiswander, 1946, states that DDT is effective against sowbugs.

## Investigational Work Of The Author

### Control

The studies in the control of woodlice were divided into three phases.

1. Laboratory tests with DDT.
2. Greenhouse test with azobenzene.
3. Commercial greenhouse data concerning various methods of control used against woodlice and the damage caused by the pests.

Each of the three phases will be discussed separately.

### Laboratory tests with DDT

In an effort to find a satisfactory control for woodlice, laboratory tests were conducted to determine the effectiveness of DDT as a control measure. Two species of Armadillidiidae, *Armadillidium vulgare* (Latreille) and *Armadillidium nasatum* Budde-Lund, were used throughout the tests.

The following is a list of the percentages and the types of DDT used for the experimental work:

3% DDT, 97% inert ingredients, Gesarol A3 dust.
5% DDT, 95% inert ingredients, Neocid A5 powder.
10% DDT, 90% inert ingredients, larvicide, dust.
40% DDT, 60% inert ingredients, Gesarol dust conc.

During the experiments the crustaceans were maintained in three ounce salve boxes to which small amounts of manure obtained from greenhouse benches were added to serve as food. The manure was moistened to supply essential moisture. Five specimens of the crustaceans were placed in each container.

In each of the three successive tests, four containers were included for each percentage of DDT to provide the conditions listed below:

1. Pillbugs in constant contact with DDT, container covered.
2. Pillbugs in constant contact with DDT, container uncovered.
3. Pillbugs in non-constant contact with DDT, container covered.
4. Pillbugs in non-constant contact with DDT, container uncovered.

It was desired to determine whether or not constant contact with DDT would produce more rapid mortality than non-constant contact with DDT and to discover whether or not the fluctuations of humidity in greenhouses would hamper the toxic action of the DDT or because of a lack of sufficient moisture hasten the death of the Crustaceans. An attempt was made to gain this information by creating the four conditions listed above. In the case of the specimens in constant contact with DDT, one gram of each percentage of DDT was placed on the bottom of its respective container before the specimens were introduced. As previously stated, a small piece of moistened manure was added to each container. To provide the conditions for non-constant contact with DDT, the specimens were placed in a Petri dish and DDT was dusted over them by means of a salt shaker containing successively the various percentages of DDT. The specimens were then placed in the proper containers. Containers were prepared in covered and uncovered conditions in an effort to obtain information concerning the effect of humidity fluctuation. Tin covers closed the covered containers while the uncovered containers had placed over them pieces of cheese cloth held in position by rubber bands. Four check containers were maintained for each of the three tests, a check container for each condition. Each test was conducted in a greenhouse so that proper conditions of temperature and humidity might be approximated.

Observations were made every twelve hours until specimens in all the containers were dead and it was certain that no recovery occurred. A specimen was termed active as long as it was capable of making co-

Average number of hours required for each percentage of DDT to produce moribund and dead specimens under four container conditions. *

| Container conditions | DDT percentages | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 3% | | 5% | | 10% | | 40% | |
| | Mori. | Dead | Mori. | Dead | Mori. | Dead | Mori. | Dead |
| Constant contact, container covered | 36 hrs | 68 hrs | 32 hrs | 64 hrs | 20 hrs | 44 hrs | 24 hrs | 40 hrs |
| Constant contact, container uncovered | 40 hrs | 56 hrs | 24 hrs | 36 hrs | 28 hrs | 44 hrs | 28 hrs | 32 hrs |
| Non-constant contact, container covered | 32 hrs | 48 hrs | 56 hrs | 72 hrs | 32 hrs | 56 hrs | 60 hrs | 76 hrs |
| Non-constant contact, container uncovered | 36 hrs | 44 hrs | 44 hrs | 60 hrs | 48 hrs | 60 hrs | 44 hrs | 64 hrs |

* The average number of hours was obtained by averaging the results of the three tests.

Table 12

ordinated movements. When coordinated movements were no longer possible, a specimen was termed moribund. A specimen presumably lost its ability to serve as a pest by means of plant feeding when this condition was reached. Death was recorded when no movement existed. It was found that death could be accurately ascertained by noting the response of the antennae to the touch of a forceps. Movement of the antennae frequently occurred when no other movement was noticeable.

Special forms were prepared on which all data were recorded. These data were later expressed graphically and it is from these prepared graphs that our conclusions are drawn.

## Discussion of results and conclusions

A few of the results are stated in the form of generalizations while others are stated more specifically. Table 12 shows the results of the experiments upon which the discussion is based. All results are listed below.

1. The validity of the tests is assumed as specimens in all check containers were still living several weeks after the completion of the tests.

2. All percentages and types of DDT produced the death of the Crustaceans.

3. Complete kill of all specimens within a given container required from one to five days.

4. On the whole, the specimens in constant contact with DDT were killed sooner than those not continually exposed to DDT although the difference in the results between constant contact and non-constant contact with DDT was not sufficient to interfere with control under greenhouse conditions.

5. Variation in humidity under greenhouse conditions had no appreciable effect on the killing effectiveness of the DDT or the length of life of the crustaceans for the duration of the tests.

6. 3% DDT might be selected as the optimum percentage of DDT to use against pillbugs. This percentage of DDT produced the mortality of all the specimens of pillbugs and it would, moreover, be the most economical percentage to use. Percentages lower than three percent might be effective.

7. A study of table 12 shows that on the whole the specimens in constant contact with DDT were killed more rapidly as the percentage of DDT increased. In the case of specimens not continually exposed to DDT, the specimens were killed less rapidly as the percentage of DDT increased. It might be concluded that the inert in-

gredient serving as a sticker causes a greater amount of DDT to adhere to the pillbugs and hence results in more rapid death even though the percentage of DDT is less.

### Greenhouse test with azobenzene

A test with azobenzene as a possible means of controlling the pillbug *Armadillidium vulgare* (Latreille) was conducted on October 5, 1946 in a greenhouse owned by Butler and Ullman Inc. in Hadley, Massachusetts. The author did not carry out the fumigation procedure since the instance was a routine fumigation against red spider accomplished by employees of the company.

The greenhouse in which the fumigation test took place is 250 feet long, 60 feet wide and contains eleven benches, each of which is about 240 feet long.

### Procedure:

Before fumigation was begun, the author prepared the jars and specimens to be used in the experiments. Each of the twelve coverless jars used was four inches deep and two inches in diameter. Jars without necks were used since it was desired to make every portion of the jar bottom equally accessible to the azobenzene fumes. Ten jars were labeled and numbered from 1-10. The control jars were also marked so that they could be easily distinguished from the test jars. A small amount of moistened cow manure was placed in the bottom of each jar in order to provide food, shelter and moisture for the crustaceans and to simulate the covering of cow manure on the greenhouse benches. Ten specimens of <u>Armadillidium</u> <u>vulgare</u> (Latreille) were then placed in every jar, and ten of the jars were distributed in various parts of the greenhouse which was to be fumigated. The two remaining jars served as controls and were placed in a greenhouse that was not to be fumigated.

In preparation for the fumigation the thick azobenzene paste made by mixing the orange-red azobenzene powder with water was painted the entire length of four closed steam pipes (one wall pipe on either side of the house and two pipes near the center of the house).

With the greenhouse temperature at 74° F. fumigation was begun at 5:20 P.M. At this time steam was admitted to two pipes (one wall pipe and one center pipe) and dense orange azobenzene fumes were quickly released. At 7:20 P.M. the two remaining pipes (one wall pipe and one center pipe) were opened. The greenhouse was closed when the first pipes were opened and remained closed for six hours after the opening of the last two pipes.

On October 6, 1946 at 5:30 P.M., about twenty-

Results of azobenzene test.

| Observation number | Time of observation | * Number of specimens dead in each jar | | | | | | | | | | Total dead |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | jar: 1 | jar: 2 | jar: 3 | jar: 4 | jar: 5 | jar: 6 | jar: 7 | jar: 8 | jar: 9 | jar: 10 | |
| 1 | Oct. 6, 1946 8:00 P.M. | 1 | 2 | 0 | 3 | 1 | 2 | 0 | 0 | 1 | 2 | 11 |
| 2 | Oct. 9, 1946 11:30 P.M. | 2 | 3 | 0 | 2 | 2 | 2 | 0 | 2 | 2 | 2 | 17 |
| 3 | Oct. 12, 1946 11:00 P. M. | 2 | 3 | 0 | 2 | 3 | 2 | 0 | 2 | 2 | 2 | 18 |
| 4 | Oct. 24, 1946 10:00 P. M. | 2 | 4 | 1 | 2 | 4 | 2 | 0 | 3 | 2 | 3 | 23 |

* 10 specimens in each jar

Table 13

four hours after the fumigation was begun, all twelve jars were removed from the Butler and Ullman greenhouses and brought back to the Fernald Hall greenhouse at the University of Massachusetts. They remained in the latter greenhouse for the entire period of observation.

Four observations were made after the jars containing the specimens were returned to the Fernald Hall greenhouse. The results of the test and the time of each observation are given in table 13.

Discussion of results

Data presented in table 13 permits a complete analysis of the results of the azobenzene test. Since ten specimens were present in each of the ten test jars, each specimen represents one percent of the total number of specimens included in the test. Thus the total number of dead at the time of each observation also represents the percentage dead.

Twenty-six hours and forty minutes after the tests were begun, only 11% of the specimens in the test jars were killed. Between observation 1 and 2, an interval a little over three days, death was rapid, the total dead rising to 17%. From that day until the time of the last observation, nineteen days after the test was begun, the total dead only reached 23%.

Within the control jars all specimens were active at the end of the observation period except two specimens killed by cannibalism.

Conclusion

1. Under the test conditions, azobenzene did not provide a good control measure against *Armadillidium vulgare* (Latreille).

Commercial greenhouse data concerning various methods of control used against woodlice and the damage caused by the pests.

While making a distribution study of the species of Oniscidae and Armadilliidae found in greenhouses, the author visited sixty-one commercial greenhouses in two widely separated areas of Massachusetts. Both of these areas are illustrated in plates 5 and 6. Throughout the study, conversations with many greenhouse keepers enabled the author to accumulate data concerning the various means of control used in both areas against woodlice. The following control measures were applied:

1. "To-na-cide"

This commercial preparation was used by seven of the greenhouse keepers and hence was the most popular material. Apparently good control was obtained.

<u>analysis</u>:

| | |
|---|---|
| naphthalene | 75.00% |
| nicotine | .20% |
| inert ingredients | 24.80% |
| | 100.00% |

2. "Go West"

Used by four greenhouse keepers but not always successfully.

<u>analysis</u>:

| | |
|---|---|
| fluosilicate | 3.50% |
| apple pulp | 95.50% |
| | 100.00% |

3. 3% DDT used in an aerosol.

This was very effective according to the proprietors of four greenhouses.

4. 5% DDT

Three greenhouse keepers found this a good means of control. The DDT was dusted on the edges of benches.

5. Sterilization of the soil.

Reported in two instances to be highly successful.

6. Paris green in various mixtures.

Naphthalene, bran, corn meal or sugar included.

7. "Dutox"

A barium fluosilicate insecticide.

8. "Snarol"

This commercial preparation used by one greenhouse keeper but not with success.

<u>analysis</u>:

| | |
|---|---|
| tricalcium arsenate | 5.00% |
| metaldehyde | 1.75% |
| inert ingredients | 93.25% |
| | 100.00% |

9. "Nico-fume"

A nicotine fumigant.

10. Potato slices used as bait.

Two methods of prevention against plant attack by woodlice were used with success:

1. Potted plants set on inverted flower pots placed in pans of water.

2. Bottoms and sides of benches whitewashed.

Data accumulated during the study indicated that the following damage was caused by woodlice.

1. carnations

Feed on seedlings, lower leaves and buds.

2. Petunia seedlings damaged.

3. Ageratum attacked.

4. Roses damaged.

In addition to the specific plants listed, the author was informed by some greenhouse proprietors that woodlice fed upon many species of seedlings and that the tops and bases of plants were destroyed. Roots of plants protruding from the bottoms of flats were a good source of food for the woodlice. The crustaceans were also reported frequently eating the wood of benches; in one case until the wood was "paper thin".

Conclusions

1. Although woodlice are usually minor pests in greenhouses they may sometimes become pests of major importance.

2. Successful control of woodlice is usually achieved by greenhouse keepers with the use of various control measures available. A number of commercial preparations provide satisfactory control.

# CONCLUSIONS

1. Small cultures of *Armadillidium vulgare* (Latreille) are easily maintained in Petri dishes containing moistened cow manure to supply the need for moisture and food.

2. Beet pulp is a good culture medium for *Armadillidium vulgare* (Latreille) but mould forms readily on the material if too much moisture is present.

3. During the first moult in *Armadillidium vulgare* (Latreille), slightly over eight hours is the average time required to complete the casting of the skin from the posterior portion of the body.

4. The first moult in *Armadillidium vulgare* (Latreille) requires an average of seventeen hours for completion.

5. Moulting of the posterior portion of the body may take place in five and one-half hours during the first moult in *Armadillidium vulgare* (Latreille).

6. The rhythmical movements that assist in casting the skin of *Armadillidium vulgare* (Latreille)

may continue for slightly over twenty minutes after the moulting of a body portion.

7. Based on the thesis studies, an average of twenty-five days is required for Armadillidium vulgare (Latreille) to undergo the second moult.

8. Armadillidium vulgare (Latreille) usually eats the cast skin after moulting.

9. Armadillidium vulgare (Latreille) cannot cast the skin of the anterior portion of the body until the legs of the posterior portion have regained the usefulness lost during the first part of the moulting process.

10. Fifteen hours may be required before the legs regain normal function after a moult.

11. Studies indicated that the average number of young liberated by Armadillidium vulgare (Latreille) from September to February is 47.8.

12. Regenerated antennae or legs are nearly normal in length after the first moult following the removal of the particular appendage even though the number of segments removed from the original appendage varies greatly.

13. The length of time required to regenerate an antenna of nearly normal size in the case

of Armadillidium vulgare (Latreille) is between eleven and nineteen days.

14. Over a wide range of temperature, humidity determines the length of the survival period of Armadillidium vulgare (Latreille) to a much greater extent than does temperature.

15. Under the conditions of the experiments, Armadillidium vulgare (Latreille) requires a humidity close to the saturation point in order to survive for an extended period of time.

16. 22° C. is within the optimum temperature zone for the survival of Armadillidium vulgare (Latreille).

17. 7° C., 27° C. and higher temperatures do not provide optimum conditions for the survival of Armadillidium vulgare (Latreille) even at high relative humidities.

18. At temperatures of 27° and 33° C., a relative humidity of 100% is not as favorable as one of 97% probably because under conditions of a saturated atmosphere evaporation of water from the crustacean and the resultant cooling effect cannot take place.

19. 7° C. permits a long survival period for Armadillidium vulgare (Latreille) under conditions of high humidity.

20. Temperature is the controlling factor in survival time at 37° C.

21. Dormancy is present at 7° C. and this condition results in the ceasing of certain normal functions such as feeding, moulting and reproduction.

22. Cannibalism does not occur either at 7° or 37° C.

23. All species of Oniscidae and Armadillidiidae collected by the author have a much wider range of distribution in Massachusetts than has been reported previously.

24. Porcellionides pruinosus (Brandt) apparently does not occur in commercial greenhouses of Area II. (see plate 6).

25. Porcellio scaber Latreille is most widely distributed in commercial greenhouses of Area I. (see plate 5).

26. Armadillidium vulgare (Latreille) is most widely distributed in commercial greenhouses of Area II.

27. Oniscus asellus Linn. is apparently more widely distributed in commercial greenhouses of Area II than in commercial greenhouses of Area I.

28. Armadillidium vulgare (Latreille),

*Armadillidium nasatum* Budde-Lund, and *Porcellio scaber* Latreille appear to be the most common species in Area I and Area II.

29. Commercial greenhouses of Area I rarely contain more than three species of terrestrial isopods in each house.

30. Over seventy percent of the commercial greenhouses in Area II contain more than three species of terrestrial isopods.

31. Under the laboratory conditions that prevailed, all types and percentages of DDT used in the experiments will produce the death of the crustaceans in from one to five days.

32. Variation in humidity under greenhouse conditions has no appreciable effect on the killing effectiveness of DDT.

33. 3% DDT may be selected as the optimum percentage of DDT to use against pillbugs.

34. Under the conditions of the test, azobenzene does not provide a good control for *Armadillidium vulgare* (Latreille).

35. Although woodlice are usually minor pests in greenhouses they may sometimes become pests of major importance.

36. Successful control of woodlice is usually achieved by greenhouse keepers with the use of various control measures available. A number of commercial preparations provide satisfactory control.

# PLATES, FIGURES AND TABLES

PLATES, FIGURES AND TABLES, CONT.

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