

THE BIONOMICS OF
ONYCHIURUS JUSTI PORTERI N. SSP.
(ONYCHIURIDAE: COLLEMBOLA)

Thesis for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY
Richard John Snider
1972



This is to certify that the

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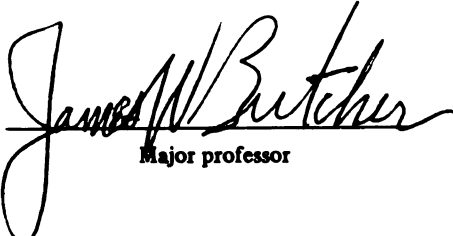
The Bionomics of Onychiurus justi porteri n. sp.
(Onychiuridae:Collembola)

presented by

Richard J. Snider

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of the requirements for

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ABSTRACT

THE BIONOMICS OF ONYCHIURUS JUSTI PORTERI N.SSP. (ONYCHIURIDAE: COLLEMBOLA)

By

Richard J. Snider

A new subspecies of Onychiurus justi (Denls) was described from Michigan and its taxonomic position defined. The male ventral organ was illustrated and analyzed as a taxonomic character.

Culture techniques for mass and individual rearing procedures were developed for observation of over 2000 specimens. A method for assessing the effect of relative humidity on survival using various concentrations of glycerol and water was employed at 50°, 60°, 70° and 80°F. As temperature increased and RH decreased, survival decreased accordingly.

The egg laying process and subsequent embryonic development of O. justi porteri was described for the first time. Egg cannibalism was found to occur in the case of non-developing eggs.

Fecundity of mass, low-number reared, and paired cultures was observed. In general, an increase in temperature lowers the number of eggs produced.

Instar duration was shown to be related to temperature. And, in addition, the presence or absence of individuals of the opposite sex may govern instar duration.

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measurements. Females developed more rapidly than males and attained a larger size. Maximum length of both males and females was reached by the 12th and 14th instar and decreased thereafter.

The development of the chaetotaxy of the fifth abdominal segment was described. In addition, the dorsal setal pattern of the first thoracic segment, the male and female genital plates, and the male ventral organ was described.

Investigation of the effect of yeast, high protein, low protein and no food was undertaken. Indications were that food quality can influence growth, fecundity and morphology.

Survival at the four temperatures was found to be highest at 60°F. In mass culture, juveniles appeared to have a higher percentage of survival than in low number reared cultures. Whereas the adults in the same cultures exhibited prolonged survival.

THE BIONOMICS OF
ONYCHIURUS JUSTI PORTERI N. SSP.
(ONYCHIURIDAE: COLLEMBOLA)

By
Richard John Snider

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Entomology

1972

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Special thanks go to Mr. Ernest Bernard for helping with the preparation of the graphs. To Mr. Erhard Wawra I am indebted for his help with microphotography.

To my wife, Renate, I dedicate this thesis for her constant help with typing, library research, criticism and enthusiasm. Without her aid this work would never have been completed.

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I. THE GENUS ONYCHIURUS GERVAIS SENSU LATU

The genus Onychiurus is one of the largest taxa in the order Collembola and has been studied since the time of Linneaus (1758). Certain species are herbivorous and because they inhabit the soil in large numbers, are easily collected with the Berlese funnel. As a result, many additions to the list of known species are being made.

Communication between researchers prior to the beginning of the twentieth century was not as easy or common as today. Consequently many taxonomists worked independently of others in the same area. This led to duplication of generic and specific designations. Moreover, early workers often did not use illustrations in their species descriptions, causing compilation of long and complicated lists of synonyms for almost any individual species of Onychiurus.

Another factor contributing to taxonomic difficulties was stated by Salmon (1964):

"The classification of Collembola has remained almost static since Börner's 'Das System der Collembolen' in 1906 and his 'Die Familien der Collembolen' in 1913 and no attempt has been made since the latter date either to evaluate or to revise the currently accepted system for classification of these insects."

Salmon's viewpoint notwithstanding, there have been some major contributions to the systematics of the Onychiuridae and more specifically Onychiurus. In 1917, Folsom attempted to bring together the known species of Onychiurus in a small monograph listing eleven North American representatives. Stach (1934) produced a major paper discussing the genus Onychiurus. In it he lists thirty-eight species and varieties known from Europe. Again in 1954, Stach monographed the family Onychiuridae, integrating the European species with the known world fauna. The list of world species of Onychiurus came to one hundred and thirty six. Twenty-

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two species for which he lacked sufficient data were not included.

Since Stach's (1954) monograph, the major work on Onychiuridae has been produced by two taxonomists. The careful and detailed analysis of Onychiurus species by Hermann Gisin (1956, 1957, 1960, 1961, 1962, 1963a, 1963b, 1964a, 1964b, 1968) led to a better understanding of specific characters and variation. In his monograph on the European Collembola, Gisin (1960) recognized two subgenera, Onychiurus s. str. and Onychiurus (Protaphorura) Absolon (1901). The total number of species listed was one hundred and thirty-five of which twenty-one were questionable species.

An evolutionary approach to Onychiuridae was taken by Salmon (1959). He proposed a new and revised scheme of classification which recognized twenty-six genera under the family, many of which had previously been designated as subspecific in rank. Most important to note here is that he redefined Onychiurus Gervais, 1841, on the basis of morphological characters; separating it from a complex of subgenera which he subsequently ranked as genera.

Salmon (1964) used the scheme developed in 1959 as a basis for his key to the known genera of Onychiuridae. Because his approach clears the taxonomic difficulties of subgeneric ranking, I have followed his lead. In the present paper the taxonomic status of Onychiurus follows Salmon (1964). For a taxonomic history of the genus Onychiurus see Salmon (1959).

Before any discussion of bionomics can proceed, I feel it necessary to explain the specific status of Onychiurus justi Denis (1938). To prevent unnecessary confusion about the new subspecies considered in this investigation, an explanation of the current status of O. justi Denis and a description of the new subspecies are offered. In the event of possible misinterpretation concerning the species determination and subsequent

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11. ONYCHIURUS GERVAIS, 1841, SENSU SALMON, 1964,
IN NORTH AMERICA

The list of North American representatives of Onychiurus Gervais sensu Salmon is not impressively long. Salmon (1964) records seventy-four species for the world, seven of which are found in the United States. Guthrie (1903) incorrectly identified a new species as (Aphorura inermis Tullberg) = Onychiurus fimetarius (Linnaeus). Folsom (1917) erected a new species, Onychiurus pseudofimetarius, and placed Guthrie's inermis as a synonym of pseudofimetarius. In the same paper, Folsom (1917) incorrectly recorded Onychiurus fimetarius (Linnaeus) from North America. Later, Denis (1938) showed that Folsom's specimens were a new species and proposed the name Onychiurus justi. The additional species listed by Folsom for North America are included in other genera under Salmon's (1964) classification. Folsom somehow missed the collection data of Packard (1873) who recorded Onychiurus ambulans (Linnaeus) from the United States. This species was subsequently reported by MacGillivray (1891), Guthrie (1903), Dow and Smith (1909) and Mills (1930) from North America.

Mills (1934) recorded seven species of Onychiurus from Iowa. However, under Salmon's systematics only O. pseudofimetarius is representative of the genus. Wray (1950) described a new species, Onychiurus wilchii, from North Carolina, and Maynard (1951) recorded O. fimetarius from New York. His taxonomic description is almost a direct parallel to Folsom's (1917). Therefore, his record would seem to be of Onychiurus justi rather than fimetarius. Christiansen (1961) described a new species, Onychiurus reluctus, from Iowa, while Scott (1961) records Onychiurus fimetarius

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TABLE I.

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(Linneaus) from North America for the first time. He also lists O. justl, O. pseudofimetarius, and O. wilchi. There remains to be mentioned one subspecies with the somewhat dubious designation Onychiurus ambulans-inermis oregonensis described by Denis (1929).

The following table lists the species, distribution, and authority for the known North American members of the genus Onychiurus Gervais, 1841, sensu Salmon, 1964.

TABLE I. Distribution of North American species of Onychiurus.

SPECIES	DISTRIBUTION	AUTHORITY
<u>O. ambulans</u> (L.)	Wash., Mass. Wash.D.C., N.Y., Ohio N. America Minn. N. J. Agriculture pest Agriculture pest	Packard, 1873 MacGillivray, 1891 MacGillivray, 1893 Guthrie, 1903 Dow & Smith, 1909 Mills, 1930 Folsom, 1933
<u>O. ambulans-inermis</u> <u>oregonensis</u> Denis	Oregon U.S.A.	Denis, 1929 Bonet, 1931
<u>O. fimetarius</u> (L.)	U.S.A.* Mass.* N.Y.* Mass., Wash., Ohio., N.Y.* Calif.* North America* Florida, California* Florida* Minn.* N.J.* Agriculture pest* N. American caves* Agriculture pest* Calif.* N. Carolina* Western U.S.* U.S.A.* N.Y.* Conn.* Utah* Calif.* N. Mex. N. Carolina*	Packard, 1871 Packard, 1873 Lintner, 1885 MacGillivray, 1891 Schött, 1891 MacGillivray, 1893 Lonnberg, 1894 Schött, 1894 Guthrie, 1903 Dow & Smith, 1909 Mills, 1930 Bonet, 1931 Folsom, 1933 Scott, 1937 Brimley, 1938 Scott, 1942 Chamberlain, 1943 Maynard, 1951 Bellinger, 1954 Wray & Knowlton, 1956 Wilkey, 1959 Scott, 1961 Wray, 1967

(Table 1 continued)

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SPECIES	DISTRIBUTION	AUTHORITY
<u>O. just</u> Denis	Mass., Penn., Fla. Calif. N. Mex.	Folsom, 1917 Scott, 1961
<u>O. pseudofimetarius</u> Folsom	Minn. Ill. Iowa Utah Calif. N. Mex.	Guthrie, 1903 Folsom, 1917 Mills, 1934 Wray & Knowlton, 1956 Wilkey, 1959 Scott, 1961
<u>O. reluctus</u> Christiansen	Iowa	Christiansen, 1961
<u>O. wilchi</u> Wray	N. Carolina N. Mex.	Wray, 1950 Scott, 1961

*/ These citations must be considered in question because they are probably based on Folsom's (1917) designation.

ONYCHIURUS JUSTI DENIS

The following description, exclusive of the pseudocellar pattern, is taken from Folsom (1917). It consists of his observations on what he thought to be O. fimetarius:

"White. Abdomen broad, rounded behind. Postantennal organs elongate, each with 8 to 17 branched tubercles. Antennae shorter than the head. Sense organ of third antennal segment with four slender papillae, five guard setae, two sense rods, and two ovate erect smooth sense clubs. Unguis slender, curving, untoothed. Unguiculus gradually tapering, distally attenuate, three-fourths as long as unguis. Anal spines absent. Anus ventral. Clothing of sparse short setae, a little longer and stiffer on the posterior part of the abdomen. Cuticular tubercles relatively coarse; coarser on the head than on the body. Length, often 1.8 mm; maximum 2.1 mm."

ONYCHIURUS JUSTI PORTERI N. SSP.

White. Abdomen broad, rounded behind (fig. 1). Postantennal organs

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HEAD	Ant.	Beh.	Pos	Ven
THORAX	Pro	Prox	Meso	Prox
	Ante	Meta	Prox	Ante
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elongate (fig. 2), each with 8 to 17 branched tubercles (figs. 3 and 4); antennae shorter than the head; sense organ of the third antennal segment with four slender papillae, five guard setae, two sense rods, and two ovate, smooth, erect sense clubs (fig. 5). Unguis slender, curving, un-toothed in the first three instars, (figs. 6 and 7), but from the fourth instar on, with a single tooth inserted at one quarter the length from the apical end (fig. 8); unguiculus gradually tapering, distally attenuate, as long as the unguis; pretarsus with an anterior and posterior setula. Anal spines absent; anus ventral; ventral organ of the male (on second abdominal segment) consists of four to five setae (figs. 12 and 13), sometimes six, having a seta-like thick median shaft wrapped by a broad cover which is slit longitudinally on one side, variable with increased age (figs. 14 to 19); male genital plate with 42 to 57 setae; female genital plate with 28 to 37 setae; ratio of M/s setae of abdominal segment V is 46/26, seta M' somewhat longer than M.

The following table (II) compares the new subspecies *pseudocellar* arrangement with that of justi:

TABLE II.

LOCATION		FOLSOM (1917)	SNIDER
HEAD	Ant. base	2+2	2+2
	Beh. ant. base	1+1	1+1
	Post. bord. head	1+1, 2+2	2+2
	Ventral head	1+1	1+1(ant.), 1+1(post.)
THORAX	Pro.th. dorsal	1+1	1+1, 0+0
	Prox. precoxal	2+2	2+2
	Meso. dorsal	2+2	2+2
	Prox. precoxal	2+2	2+2
	Antero-ventral	1+1	1+1
	Meta.th. dorsal	2+2	2+2
	Prox. precoxal	2+2	2+2
	Antero-ventral	1+1	1+1

(Table I)

Abd.
Lat.
Ant.

Abd.
Ante.
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ABDOMEN
Abd.
Vent.
Pos.

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Abd.
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Abd.

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(Table II continued)

LOCATION		FOLSOM (1917)	SNIDER
ABDOMEN	Abd.I. dorsal	3+3	3+3
	Lat. (base V.T.)	1+1	1+1
	Antero-lateral	1+1	1+1
	Abd.II. dorsal	3+3	3+3
	Antero-ventral	1+1	1+1
	Postero-ventral	1+1	1+1
	Abd.III. dorsal	3+3	3+3
	Ventral-lateral	1+1	1+1
	Postero-ventral	1+1	1+1
	Abd.IV. dorsal	5+5 (d=3+3, lat=2+2)	3+3 (d=2+2, lat=1+1)
	Postero-ventral	1+1	1+1
	Abd.V. dorsal	3+3	3+3, 2+2
	Ventral	1+1	1+1
	Abd.VI.	0	0

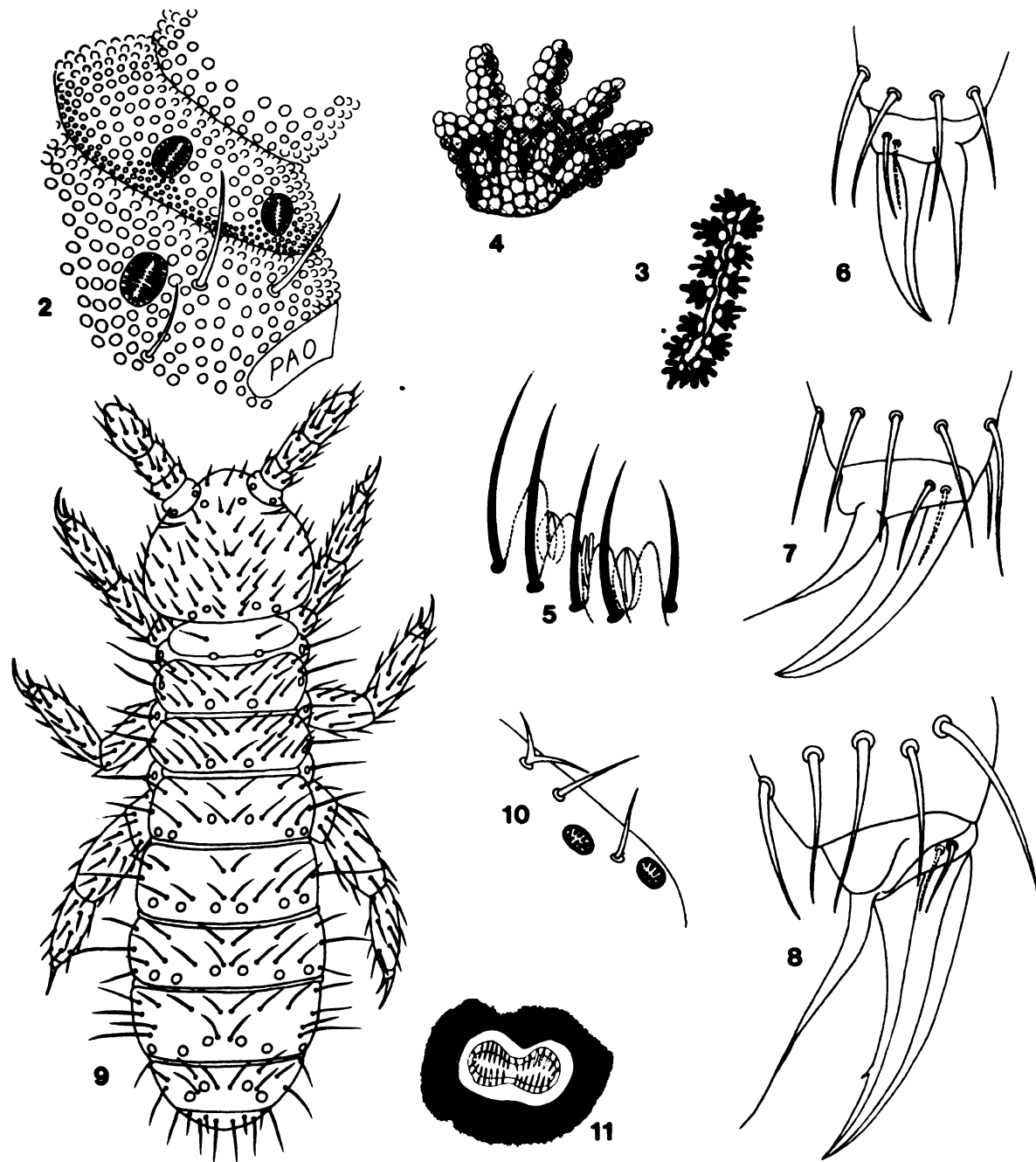
Clothing of sparse short setae, a little longer and stiffer on the posterior part of the abdomen; occasionally a seta will be split (fig. 10). Cuticular tubercles relatively coarse, coarser on the head than on the body; dorsum of the head with six distinct areas lacking major tubercles (figs. 20-24). Length, average 1.9 mm, maximum of 2.2 mm. It is with great pleasure that I name this new subspecies Onychiurus just i porteri for Dr. T. Wayne Porter.



Figure 1. *Onychiurus justiporteri* n.ssp., culture containing adults, juveniles, and eggs.

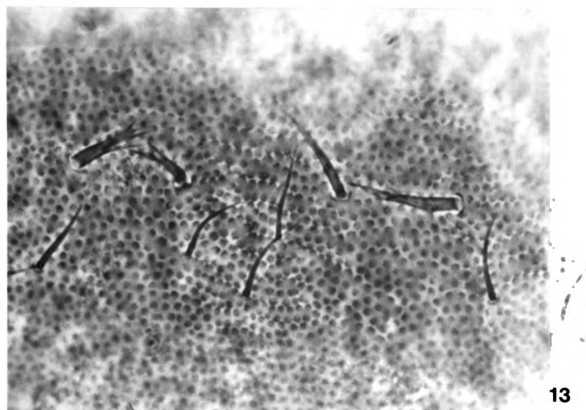
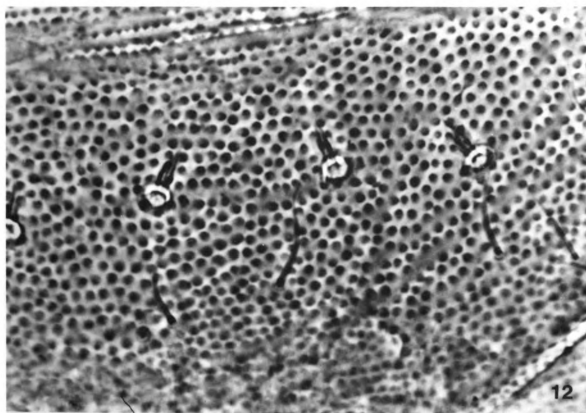
Onychiurus justl porteri n. ssp. - list of figure captions

2. Position of the post antennal organ and associated pseudocelli.
3. Post antennal organ, detail.
4. Post antennal organ, single tubercle (oil).
5. Antennal organ, third antennal segment of a seventh instar individual.
6. Hindclaw of first instar juvenile (oil).
7. Foreclaw of first instar juvenile (oil).
8. Foreclaw of seventh instar adult showing inner tooth on unguis.
9. First instar juvenile showing dorsal pseudocellar pattern.
10. Split seta on the posterior part of abdominal segment V, third instar juvenile.
11. Double pseudocellus on the fourth abdominal segment of a fifth instar individual.



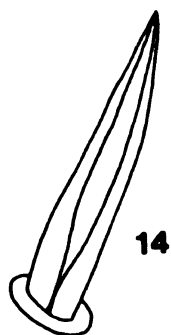
Onychiurus justi porteri n. ssp. - list of figure captions

12. Photograph, phase-contrast oil, of the eleventh instar male abdominal organ.
13. Photograph, phase-contrast oil, of the twenty-fifth instar male abdominal organ. Note the splitting of the seta typical of senile adults.

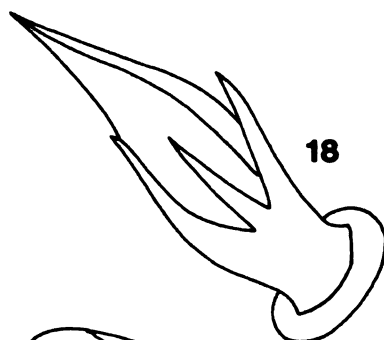


Onychiurus just porteri n. ssp. - list of figure captions

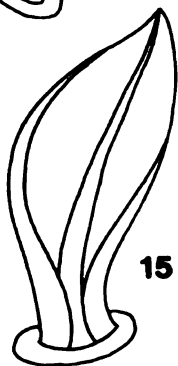
14. Male ventral organ seta, fourth instar (oil).
15. Male ventral organ seta, fifth instar (oil).
16. - 18. Male ventral organ setae, thirty-fourth instar, of a 339 day old individual raised at 70°F (oil).
19. Male ventral organ seta, thirty-fourth instar, of a 339 day old individual raised at 70°F (oil).
20. - 24. Diagrams showing position of areas lacking major tubercles on the dorsum of the head.



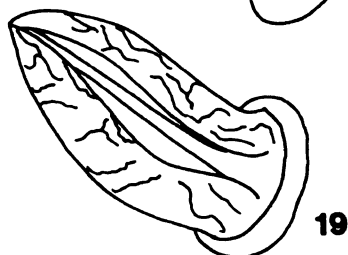
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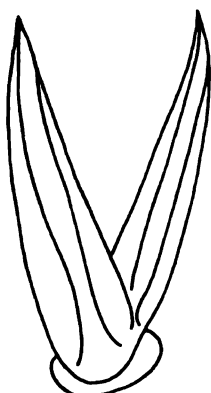
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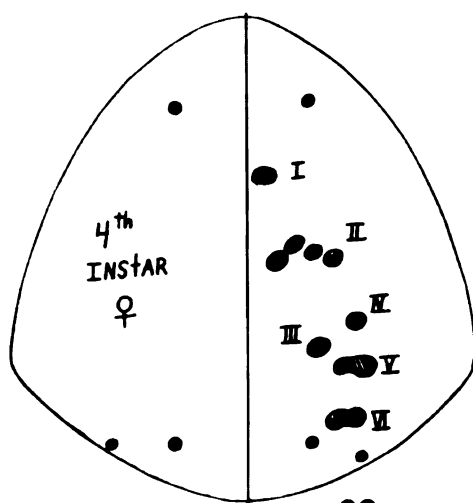
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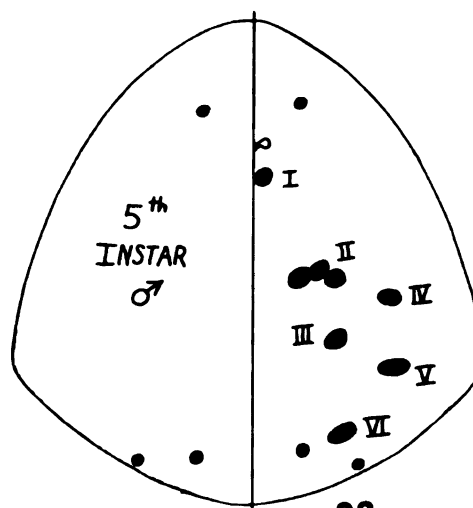
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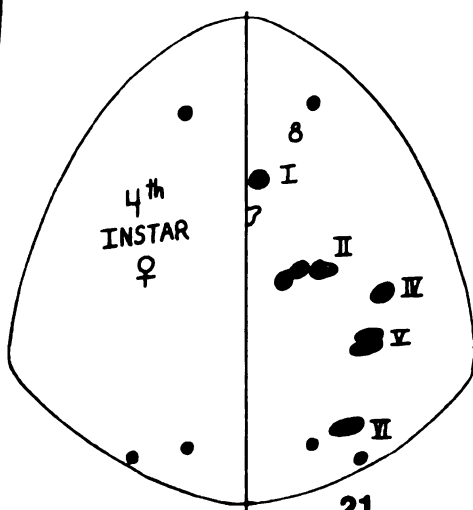
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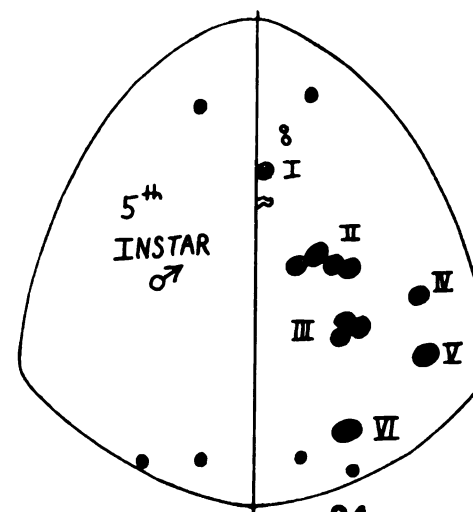
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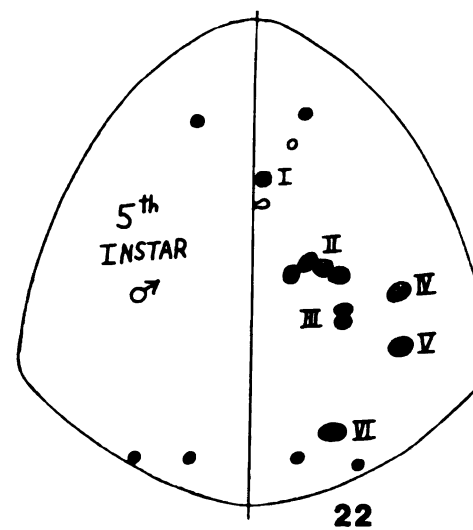
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Discussion

Folsom's 1917 description of O. fimetarius (Linneaus) was adequate enough for Denis (1938) to recognize it as a new species. He was quick to point out that the two ovate, erect, smooth sense clubs of the third antennal segment separated Folsom's species from fimetarius. On the strength of that morphological character he designated Onychiurus fimetarius (Linneaus) Folsom, 1917 as Onychiurus justii. It must be mentioned that while Folsom states the pronotum has dorsal pseudocelli (1+1), Denis missed this in translation and writes, "lacking the pseudocelli of the pronotum." Folsom makes no mention of a male ventral organ and Denis later writes "no ventral organ." Denis does, however, recognize that the unguiculus may be more elongate than the one drawn by Folsom.

In the course of a discussion of known morphological characters used in the identification of Onychiurus, Hale (1969) states that it is possible to recognize two general types of antennal organs. In one of these the organ usually consists of four or five papillae, each with a guard seta protecting a pit with tuberculate sensory clubs. The other possesses smooth sensory clubs, which may be either curved or straight.

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the antennal organ, Stach (1954), p. 173, states that straight, smooth sensory clubs appear in ..."Onychiurus justi Denis 1938, and Onychiurus novae-zealandia Salmon, 1942." In order to differentiate these two species from other members of the group which includes O. gridelli Denis, O. subantarcticus Salmon, O. stachianus Bagnall, O. nervosus Stach, O. sinensis Stach, and O. subcadaverinus Denis, he suggests that justi and novae-zealandia can be recognized through the presence of pseudocelli on the pronotum. He also makes this point on page 166 of the same paper. However, on page 177, he recognizes that there can be variation of the pronotal pseudocelli in the case of O. fimetarius.

Care must be exercised in reading the pseudocellar pattern on body segments. The onychiurid Collembola are notorious for variation in the number of pseudocelli. Salmon (1959) states:

"The pseudocelli of the Onychiurinae have been extensively used in the past by many authors as specific characters. Much reliance has been placed by some authors, and, indeed, by myself, on the number of pseudocelli on each body tergite. I have noticed repeatedly, in working through Onychiurid material, that the number of pseudocelli on individual body tergites can vary, sometimes quite considerably, between specimens of the same species and even between the two sides of the same individual."

Hale (1968) comments that when one side of the animal has an aberrant number, the corresponding side has the normal number, "generally speaking." He found the average variation in five species of Onychiurus to be two percent. In the same paper, Hale found the incidence of a tooth on the claw too variable for use. Of four reliable and consistent characters which he described, the following three are used in the present investigation: The pseudocellar formula, the chaetotaxy of abdominal segment V, and the ratio of the lengths of setae M and s.

The differences between O. justi and the population from Michigan are enough to justify erection of a new subspecies. Folsom's (1917) analysis

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agrees with respect to the antennal and postantennal organs. As Hale (1968) mentions, the tooth on the unguis can not be used as a serious character. In the present subspecies, the inner tooth of the unguis does not appear until the fourth instar. Even then, there are a few adult specimens in which it is lacking. Denis (1938) observed that variation may occur in the length of the unguiculus. Folsom, in his population, found the unguiculus to be $3/4$ the length of the unguis. The Michigan specimens all exhibited an unguiculus as long as the unguis.

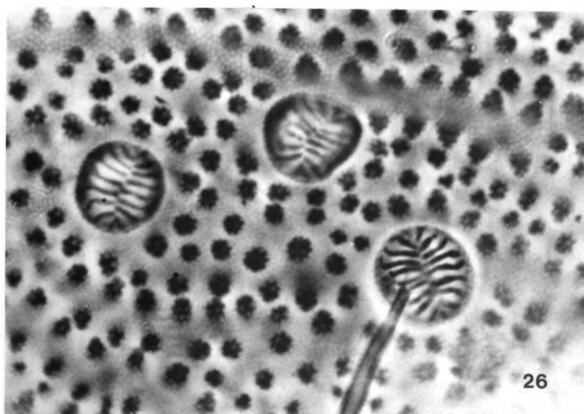
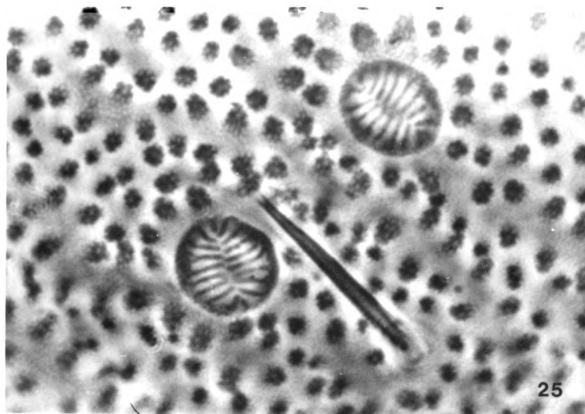
Examination of the pseudocellar formula (fig. 9) shows enough variation between justi sensu stricto and justi porteri to warrant discussion. Table 11 summarizes the differences between justi and justi porteri. Mention is made of the ventral pseudocelli of the head. In justi it is 1+1 while in justi porteri it is 2+2, one set anterior and the other posterior. The dorsal pseudocellar pattern of abdominal segment IV is 5+5 in justi as described by Folsom, while in justi porteri it is 3+3 consistently. Abdominal segment V in justi has 3+3, but out of over two thousand Michigan specimens examined, only three had the 3+3 formula, the dominant condition being 2+2 (figs. 25 and 26). Occasionally two pseudocelli will converge and form one locus (fig. 11).

Variation in the male ventral organ is confusing. At first it was thought that the shape of the setae could be correlated with the instar. But after careful examination, the setae of the male ventral organ were found to be extremely variable. They first appear in the fourth instar as heavy lanceolate setae. In the later instars they unroll and become spatulate. From instar to instars this change from rolled lanceolate to unrolled spatulate occurs (figs. 14 to 19). Sometimes members of the same instar exhibit this variation.

The position of distinct areas on the head lacking major tubercles

Onychiurus justi porteri n. ssp. - list of figure captions

25. Fifth abdominal segment pseudocellar pattern of a tenth instar female, left side of body.
26. Same female, right side of body.



is used as a key characteristic, consistent from the fourth instar on. Hale (1969) lists these patterns or "new characters" in his stereoscan studies of the genus Onychiurus.

Taking into consideration the antennal organ structure and the pseudocellar pattern, I find it difficult to erect a new species. The variation in the pseudocelli of abdominal segment V, the consistency of segment IV, the presence of a tooth on the unguis, and the length of the unguiculus indicate a population which differs consistently from the type in respect to significant minor characters.

Distribution

Specimens of O. justi porteri first came to my attention in the spring of 1967 when a sample was sent from a mushroom grower in Wayne County, Michigan, for identification. It seems they were a pest in the mushroom culture medium, where they ate fungal hyphae. From this sample cultures were raised for experimental life cycle studies and have been maintained ever since.

Many of my collection records in the past which were listed as O. fimetarius Linneaus are probably O. justi. However, it will take careful examination of all museum specimens to determine its true distribution in North America. The only reliable records we can use are those of Folsom (1917) and Scott (1961). That would lead to the following distribution: Massachusetts, Pennsylvania, Florida, California, and New Mexico.

In Europe, Denis (1938) records O. justi from Italy. Tarsia in Curia (1943) found it in Italian caves. Stach (1954) describes justi from New Zealand, based on Salmon's (1941) determination of O. fimetarius. Salmon's drawings show clearly the erect position of the antennal organ

papillae and the similarity to Folsom's (1917) description of the pseudocellar pattern; leading to the conclusion that what Salmon really saw and reported was justi.

Onychiurus justi porteri n. ssp. is so far known only from one mushroom house in Michigan. Onychiurus justi Denis has been taken from under bark, leaf mould, around root systems, and caves.

III. THE BIONOMICS OF ONYCHIURUS JUSTI PORTERI N. SSP.

Introduction

Collembolan bionomics studies have in recent years undergone many changes in methodology and direction. The "curious naturalist" approach of the last century has given way to laboratory and field techniques based on both qualitative and quantitative data. Observations on the physiology, behaviour, and population dynamics of Collembola in natural systems have magnified the apparent role of these animals in organic breakdown and chemical translocation. The study of life cycles and composition of diets has been recognized as an important factor in the understanding of the dynamics of soil communities (Christiansen, 1970a, b).

Recent symposia such as the "International Symposium on Pesticides in the Soil" at Michigan State University (1970), the "IV Colloquium Pedobiologiae" in Dijon (1970), the "Colloque International sur les Collembolés" in Paris (1970), and the "Symposium on Soil Microcommunities" at Syracuse (1971) have been largely concerned with biology, population dynamics and biomass, energy flow, and edaphic factors. This shift in emphasis from taxonomy to biological investigations points out the need for critical data on individual species.

Fortunately reviews of literature dealing with collembolan bionomics

have received much attention in the last decade (Christiansen, 1964; Schaller, 1970; Butcher, Snider and Snider, 1971). Hale (in: Burges and Raw, 1967) compiled a paper similar to Christiansen's (1964) review, which included predominantly European literature. More specific compendia are offered by Vannier (1970) in his "Réaction des Microarthropodes aux Variations de l'État Hydrique du Sol" and by Thibaud (1970) in "Biologie et Écologie des Collembolles Hypogastruridae Édaphiques et Cavernicoles."

Publications by North American workers on collembolan bionomics in the past have been few, with some notable exceptions (Davis and Harris, 1936; Britt, 1951). Perhaps this could be attributed to insufficient knowledge of the North American collembolan fauna. In recent years, investigation of nearctic Collembola has increased. Life cycle studies by Marshall and Kevan (1962), Sharma and Kevan (1963 a,b) and Sharma (1967 a,b) have dealt with food, embryonic development, postembryonic development and temperature effects.

Specific studies contributing to our knowledge of collembolan biology have been made in the following areas: ingested food and dietary requirements (Knight and Angel, 1967); colonization (Vail, 1965); experimental studies on aggregation and dispersion (Christiansen, 1970a); competition between species (Christiansen, 1967); survival (Christiansen, 1970b); factors affecting predation on Collembola by various Arthropods (Christiansen, 1970a); reproductive biology, oviposition inhibition, and egg cannibalism (Waldorf 1971 a,b,c); and the effect of light and temperature on phenotypes (Willson, 1960).

The present study was undertaken to ascertain what some of the ecological factors impinging on a soil collembolan are and how the animal responds to them under laboratory conditions. In addition, data were collected on egg laying, hatching and dietary requirements as collateral

information. It is my conviction that basic laboratory observation of these animals will reveal patterns in development that might be taken for granted or overlooked in field studies. The following investigations are presented in the belief that Collembola are important contributors to the fertility of soil and that knowledge of their bionomics will lead to a better understanding of their role in soil communities.

Culture Method Review

The culture methods used for rearing members of the family Onychiuridae all bear close resemblance to each other. Basically the technique was started by Wharton (1946) in an effort to raise mites. Goto (1960) described a rearing method consisting of a mixture of charcoal and plaster poured into a container with a close fitting lid or stopper; the food material most frequently used was yeast.

One of the first papers dealing with onychiurid life histories was written by Milne (1960) who used the method of Edwards (1955) for his observations. It consisted of plaster blocks with cells inserted for culturing individual specimens. Milne reared Onychiurus furcifer Börner, O. latus Gisin, O. procampatus Gisin and four other species at 5°, 12°, and 24°C, using bracken spores as food source.

Choudhuri (1961), while studying the influence of temperature on O. furcifer, used small glass containers with a charcoal-plaster substrate and yeast as food. A similar technique, employing tubes covered with coverslips and a constant temperature of 15°C, was used by Hale (1964) for experimental studies on members of the Onychiurus armatus species group. Hale (1965 a) applied the same method for observations on the breeding biology of Collembola, among them O. furcifer, O. procampatus, O. latus and O. tricam-

patus Gisin. The cultures were maintained at 8°C. In later work, the same species were observed during postembryonic development (Hale 1965 b) at a temperature of 15°C.

Among the species studied by Törne (1967), Onychiurus cf. cebennarius Gisin was reared on various soil materials and on pure sand to determine whether food substance or microbial flora affected the reproduction rate; temperature was held at 21°C. Ashraf (1969) tried to use wide mouth glass jars fitted with wire gauze screw caps. One of the three species he observed was O. bhattii Yosii. A mixture of three parts ground and sterilized soil with one part leaf manure constituted the substrate; food consisted of freshly fallen leaves of Trifolium and Sesbania aegyptica. The cultures were kept at room temperature (13.6°-27°C).

In a recent paper, Petersen (1970, in press) reports using plastic canisters (32 x 36 mm) as culture containers, filled to half their depth with plaster-charcoal mixture. Before the substrate sets, a glass tube (8 mm x 42 mm) is pushed into the soft mixture, and a rubber bung is inserted in the top of the tube. According to the author the advantage over other types of rearing chambers is that water can be administered to the surrounding plaster-charcoal instead of directly to the culture surface. He used this type of chamber to rear O. furcifer at 15°C and provided yeast as food (Candida sp.).

Culture and Manipulation Techniques with Stock Cultures

Stock cultures of Onychiurus justii porteri were set up in the laboratory as a source of eggs, juveniles and adults. The rearing technique employed was basically that reported by Snider et al (1969). The only modifications are described as follows.

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Plastic snap-top containers, 50 mm by 37.5 mm (fig. 27 b), were used instead of screw-top glass jars, allowing assessment of the condition of the cultures without opening the container. A plaster-activated charcoal mixture in a 1:1 ratio, stirred with water, was poured into the containers to a depth of 20 mm and allowed to set. It was necessary to leave the container lids off until this substrate was hardened to prevent condensation on the container walls. Usually a piece of cloth was placed over the newly poured jars or they were kept in a chemical hood to keep them dust free.

When in use, the cultures were maintained at a relative humidity as close to 100% as possible. Distilled water was initially added to the substrate until it was saturated, but not wet. Thereafter, each day, or as required upon inspection, distilled water was added with a pipette to keep moisture conditions constant.

It should be mentioned at this point why a plaster-charcoal substrate was used instead of some other material. Daily examination of the cultures and of subsequent smaller versions (fig. 27 a) of the same container type necessitated a stable substrate that could not be shifted or spilled. The tendency of plaster to give up water in combination with the absorbent quality of charcoal guaranteed slow evaporation from the substrate surface and uptake of noxious gases evolved as by-products from fecal material and food.

Another advantage was the color of the substrate. The dark background it provides made it possible to observe eggs, exuviae and juveniles with relative ease.

Food for the stock cultures, and in most experiments, was provided in the form of powdered brewers yeast. Depending on the number of individuals within each culture container, yeast was added in appropriate quantities

every day. The stock cultures were maintained in controlled temperature cabinets at $15\pm 2^{\circ}\text{C}$ and $21\pm 2^{\circ}\text{C}$, in total darkness.

Transfer Technique

Once the adults initially placed in the culture jars had reproduced, a simple method of transferring 1st instar juveniles without damaging them was needed.

Eggs are usually laid in large batches, and the presence of many females in a stock jar can result in a brood numbering over a hundred at a given time. The difficulty lies in lifting a known number of juveniles from the stock jar and transferring them to test jars. In the past, a fine bristle brush, number 0000, dipped in distilled water and touched to the body of the juvenile, was sufficient. However, after a time, a high number of the transferred individuals died. Evidently the mere pressure brought on by touching them with a brush was enough to rupture internal tissues and kill them.

The method finally used was simple. Stock jars where a number of eggs had hatched within a period of 12 hours or less were flooded to a depth of several millimeters with distilled water. A fine needle was carefully brought up underneath the juveniles floating on the surface, until the animals grasped it with their legs. The needle was tapped over the new container selected until the juvenile dropped into it. All test containers were set up in this way. Very few deaths occurred in the first 24 hours after transfer by this "floating technique."

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IV. RESPONSE TO VARIABLE RELATIVE HUMIDITY

Introduction

The effects of relative humidity on species of Collembola has been the subject of numerous investigations. Davies (1928) studied the effect of humidity on five epigeonistic species of Collembola. Using a constant temperature of 25°C and relative humidities of 0, 10, 20, 50, 90 and 100%, he concluded that the species studied needed saturated environmental conditions to survive. Additional studies by Ripper (1930), Davidson (1932), Strebel (1932), MacLagan (1932) and Agrell (1941) followed, with emphasis on bionomics. Davis and Harris (1936) observed the biology of Pseudosinella violenta (Folsom) and found that even this scaled species needed close to 100% RH to survive.

More recently, Thibaud (1968 a) investigated the effects of temperature and humidity on the embryonic development of six species of Hypogastruridae. In another paper Thibaud (1968 b) observed the postembryonic development of the same species and found that temperature and humidity played an important role in the habitat distribution of the animals. In a detailed investigation of edaphic and cavernicolous Hypogastruridae, Thibaud (1970) brings together the results of his studies and states that, in the hypogastrurid Collembola observed, postembryonic survival was highest at 98 to 100% RH. For further detailed observations on the water relationships of microarthropods, see Vannier (1970).

One of the first papers reporting on the importance of relative humidity to survival of Onychiuridae was presented by Mayer (1957). He found that a soil species, Protaphorura armatus (Tullb.) was unable to survive at less than 100% RH. Choudhuri (1963) studied the effects of various humidities on three species of onychiurid Collembola at 24°C constant

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temperature. His data indicate that adults are more resistant to lower humidities than juveniles, but that 100% RH was necessary for survival over a long period of time.

Materials and Methods

Stock cultures of Onychiurus justiporteri n. ssp. were maintained in the laboratory at 70°F using the method previously described. In the present study smaller jars made of plastic, 25 mm high by 34 mm in diameter (fig. 27 a), were employed for culturing small numbers of individuals and for constructing humidity test chambers.

In order to build one humidity test chamber, two of the above containers were used. The bottom of one container was cut away with a hand saw, resulting in a plastic ring a little less than 25 x 34 mm in size. A piece of fine mesh nylon screen was fitted over the opening of the second container and by holding the screen in place with a rubber band, ethyl ether was brushed over the rim in order to fix the cloth in place. The ring made from the first container was then fitted over the second and the two cemented together.

The sealing cement was made by breaking the discarded plastic bottoms into small pieces and dissolving them in ethyl ether. The cement was applied to the inside and outside seams with a brush, until there were no gaps between the upper and lower halves of the test chamber. This treatment produced a taut, even screen surface on which the Collembola could be placed. When the cement was thoroughly dried, it was possible to remove the lid of the chamber without danger of breaking the cemented joint.

To achieve 0% RH, silica-gel was heated in a laboratory drying oven until the crystals had all turned from blue to straw-yellow color. The dry silica-gel was introduced through a hole cut into the bottom half of the

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containers; the hole was then sealed with a piece of tape (fig. 28). Ten plastic test chambers were prepared in this manner.

In the past, different concentrations of sulfuric acid have been used to produce desired percentages of relative humidity (Davies, 1929; Choudhuri, 1963). Other workers have used saturated solutions of acids and alkali (Davis and Harris, 1936; Mayer, 1957; Thibaud, 1968 a,b). However, White and Zar (1968) reported that acids and alkali may give off toxic vapors, and Kawasaki and Kanou (1965) showed that sulfuric acid may be absorbed by the container surface. Saturated salt solutions (Winston and Bates, 1960; O'Brien, 1948) have also been used, but their effectiveness was found to be related to the temperatures at which they were stored.

The present study utilized different concentrations of glycerol and distilled water to obtain various relative humidities. This mixture was chosen because glycerol is easily mixed with water, does not give off harmful vapors, and maintains constant relative humidity for extended periods of time (White and Zar, 1968).

Silica-gel was employed to obtain 0% RH and distilled water for 100% RH. Specific gravity tables prepared by Braun and Braun (1958) were followed in order to mix glycerol-water solutions appropriate to achieve the other desired RH levels. The following concentrations of glycerol-water were used (Table III):

Table III.

Specific Gravity	RH
Distilled H ₂ O	100%
1.049*	95%
1.082*	90%
1.135*	80%
Silica-gel	0%

*/ Data from Braun and Braun, 1958

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All glycerol-water solutions were incubated at 70°F for 12 hours before animals were introduced.

To make sure that the solutions were actually producing relative humidities of the desired levels, a Honeywell humidity and temperature meter with a lithium-gold sensor (fig. 29) was employed. The glycerol-water solution was first mixed and checked with a hydrometer, then incubated at 70°F for 8-12 hours. After incubation, the solution was poured into a 2000 ml cylinder which had been stored in the incubator. The lithium-gold sensor was lowered into the air space above the solution and the cylinder was sealed with a neoprene stopper. A wad of putty was used as a seal at the point where the electric cord entered the cylinder. Cylinder and sensor were then put back into the incubator and given 8 hours to equilibrate. RH of the solution was checked at the end of 8 hours by plugging the sensors into the meter and the RH read directly (fig. 30).

When a desired concentration was confirmed, the solution was injected into the bottom half of the previously described test chambers through a small hole placed in the bottom half to admit a hypodermic needle (fig. 31). After the solution was injected, the hole was sealed with tape (fig. 32). The test chambers were then returned to incubators of various temperatures to equilibrate for 8 hours.

While the test chambers were equilibrating, clean culture containers (25 x 34 mm) were brought up to 100% RH by addition of distilled water, and were used to hold Collembola until needed for the tests. Subsequently, ten adults of indeterminate age were placed into each of the ten plaster-charcoal jars just before the test chambers were readied for the timed test. The test chamber lids were then removed one at a time and the culture container was inverted over it and sharply tapped in order to dislodge the ten individuals onto the screen. The lid was quickly replaced.

Rearing and relative humidity techniques -
list of figure captions

27. (a): small rearing container (25 x 34 mm) with plaster-charcoal substrate. (b): large rearing container used for stock cultures (50 x 37,5 mm) with plaster charcoal substrate.
28. Dessication chamber constructed from two 25 x 34 mm containers welded together, with silica-gel as a dessicant.
29. The Honeywell humidity and temperature meter.
30. Method of checking RH of a specific gravity solution.
31. Injection of specific gravity solution into a test container.
32. Relative humidity test container.

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Ten test containers were used for each test run. The total number of individuals for each humidity test was 100. Collembola were exposed to four temperatures: 50°, 60°, 70° and 80°F. During the first 3 hours of each test run the chambers were checked every ten minutes for mortality. The chambers were not opened; visual assessment was made with a binocular microscope through the clear plastic lids of the containers. An individual was judged to be dead when all movements had ceased. Sometimes the chambers had to be tapped to activate the Collembola, thus permitting accurate assessment of immobility.

Results and Discussion

At each test temperature, the control individuals held at 100% RH survived for longer periods than did those at other humidities. In the case of animals held at 80°F, even those at 100% RH showed a marked decline after 60 hours exposure (Graph 1). Results obtained at the other three temperatures indicate that the lower the temperature, the longer the survival at any of the given relative humidities (Graphs 2, 3, 4 and Appendices I, II, III and IV). The results of the experiment show that with constant humidity and increase in temperature, there is a decrease in survival.

In a comparison of the four temperatures at 0%, 80% and 90% RH, only the 50°F test shows a wide range of survival. At 0% RH, there is a marked similarity between temperatures, and all animals died within one hour. Even at 80% and 90% RH survival of O. justii porteri is limited to 4 hours or less. Individuals subjected to 95% RH clearly show a relation between temperature and relative humidity, with increased survival as the temperature is lowered.

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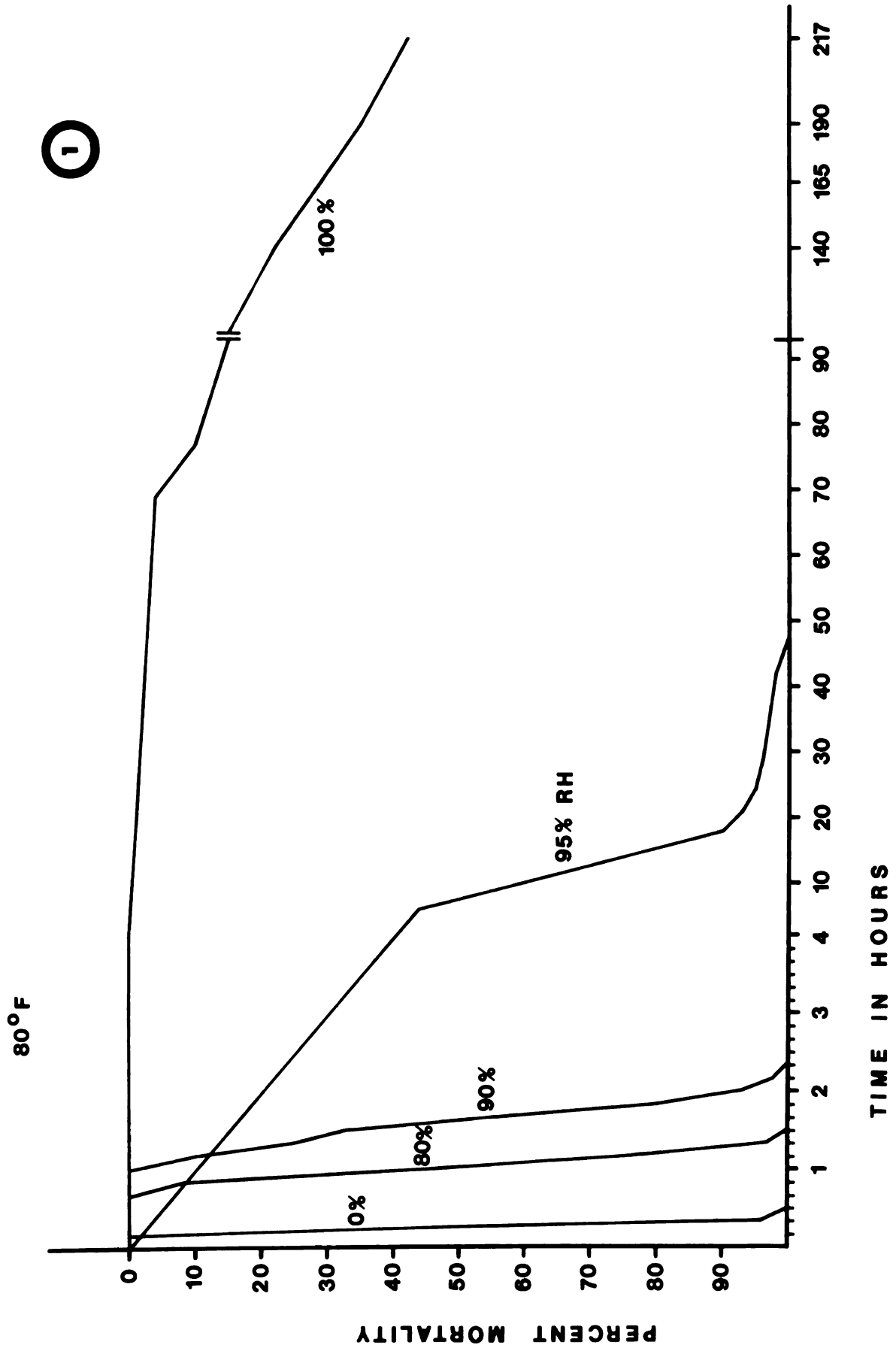
As indicated earlier, several species of epigeonistic and cavernicolous Collembola have been studied for temperature-humidity responses. However, not many species of edaphic Collembola have been investigated. From the few research papers on Onychiuridae a similar pattern of results seems to emerge. The studies of Mayer (1957) who examined Protaphorura armatus at $20^{\circ}\text{C}\pm 2^{\circ}$, can be compared with the 70°F run presented here. The curves derived from his data show the same pattern as do those for O. justi porteri. After 135 minutes at 93% RH, P. armatus showed total mortality. In the case of O. justi porteri at 95% RH, mortality reached 50% after about 10 hours and slowly increased to about 95% after 135 hours.

The data presented by Choudhuri (1963) for Protaphorura fimatus, P. parthenogeneticus and P. imperfectus indicate little tolerance of those species to humidities below 100%. Choudhuri's constant temperature was 24°C , which compares roughly with the present 70°F run. At 95% RH, mean survival for P. fimatus was 139.2 minutes, for P. parthenogeneticus 62.8 minutes, and for P. imperfectus 95.6 minutes. Similar conditions in the present study produced a mean survival time of 39 hours for Onychiurus justi porteri. Comparison of the survival data of Mayer (1957) and Choudhuri (1963) to the data presented here, shows that O. justi porteri is more resistant to dessication than were any of the related species so far studied. There is an indication that the genus Onychiurus, possibly as a result of greater body mass or greater thickness of body wall at the ventral tube, may be more resistant to dessication than the genus Protaphorura. Further investigations are needed for confirmation. The present study clearly indicates that the temperature-humidity relationship suggested by Thibaud (1970) is a factor which must be considered important in survival of edaphic and cavernicolous Collembola.

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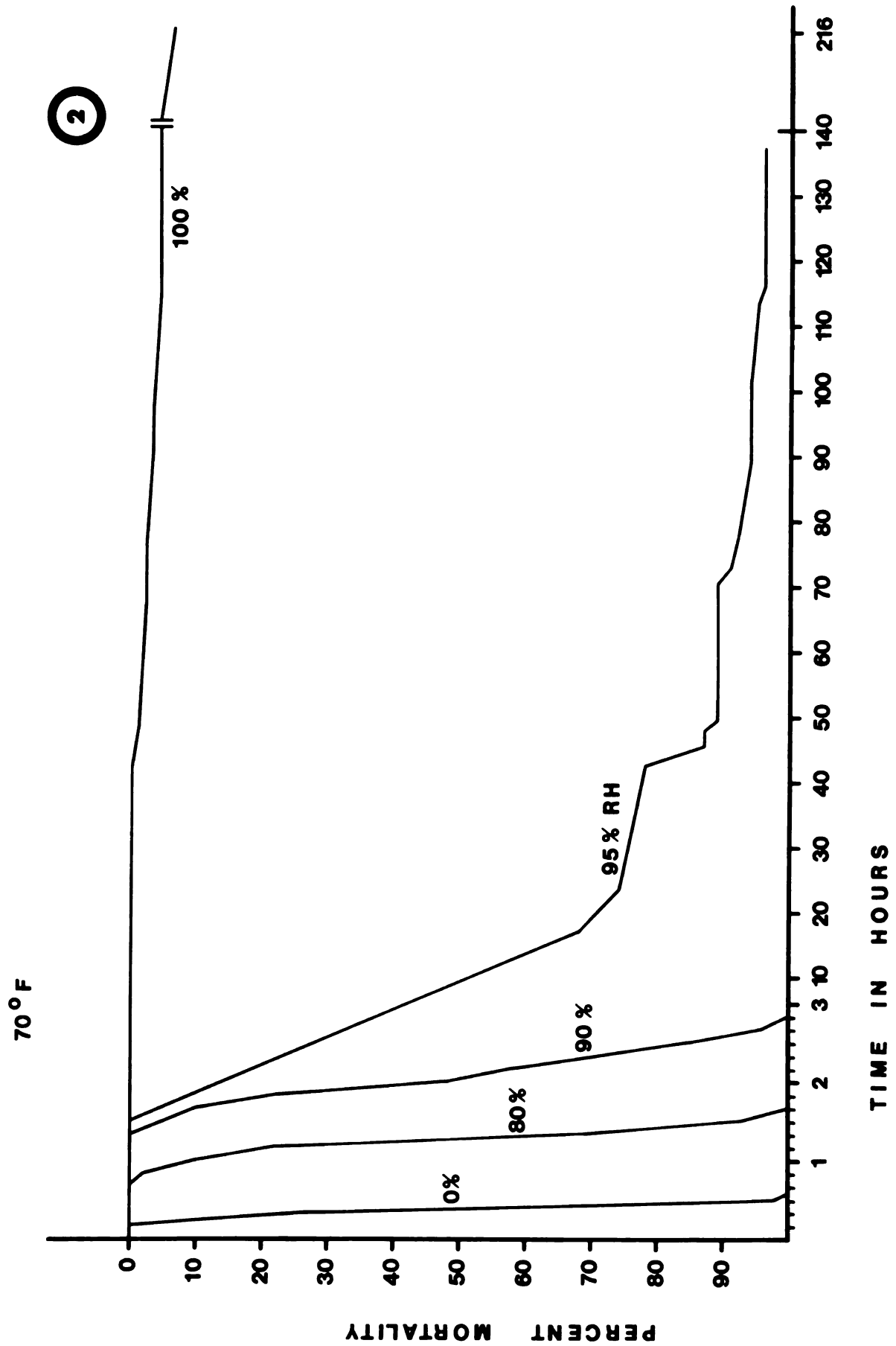
Graph 1. Onychiurus justii porteri, percent mortality at 80°F and five relative humidities.

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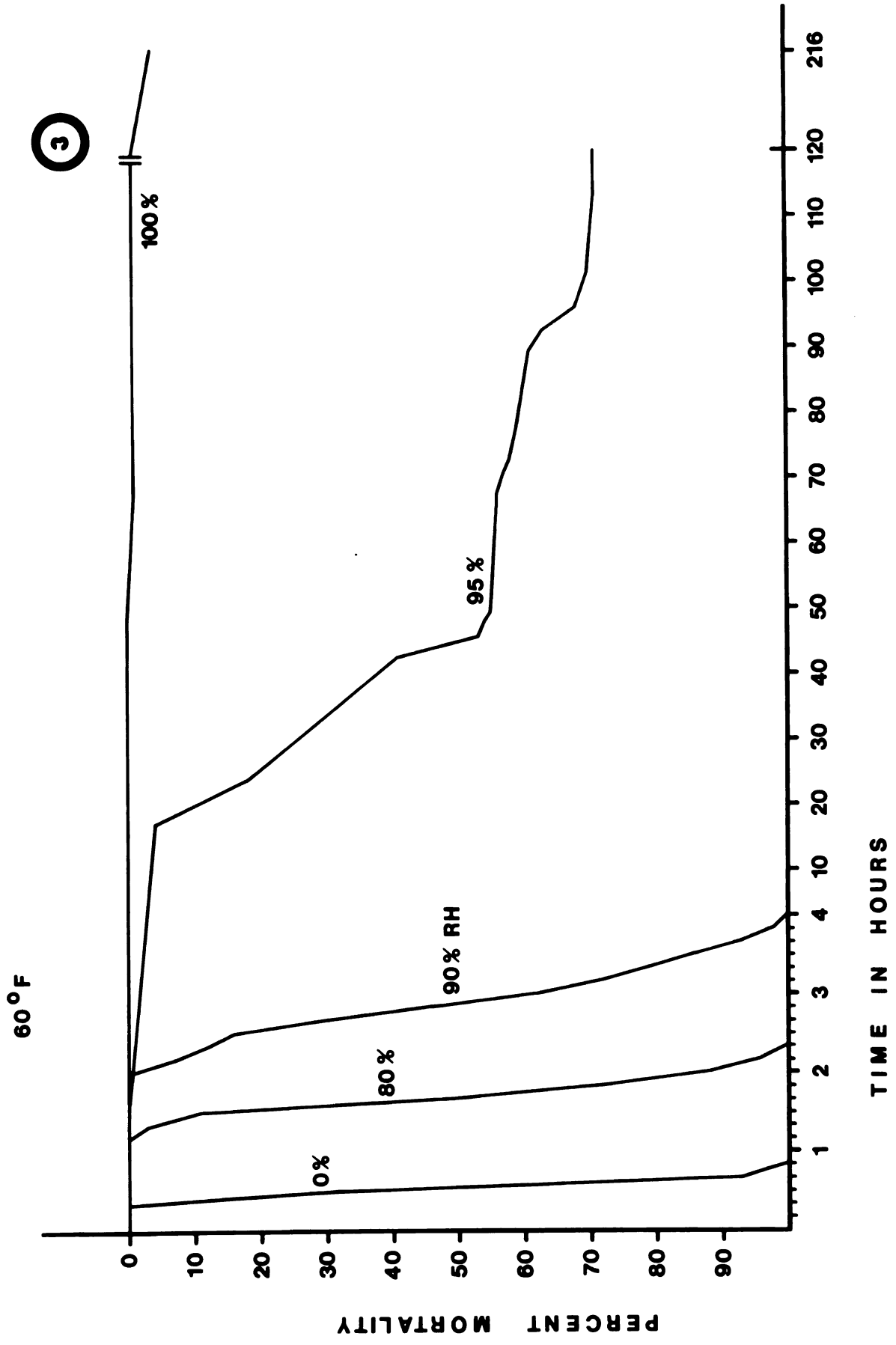
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Graph 2. Onychiurus justiporleri, percent mortality at 70°F and five relative humidities.



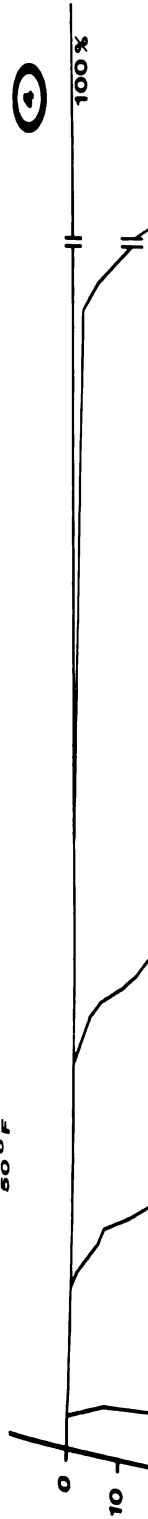
Graph 3. Onychiurus justiporterl, percent mortality at 60°F and five relative humidities.

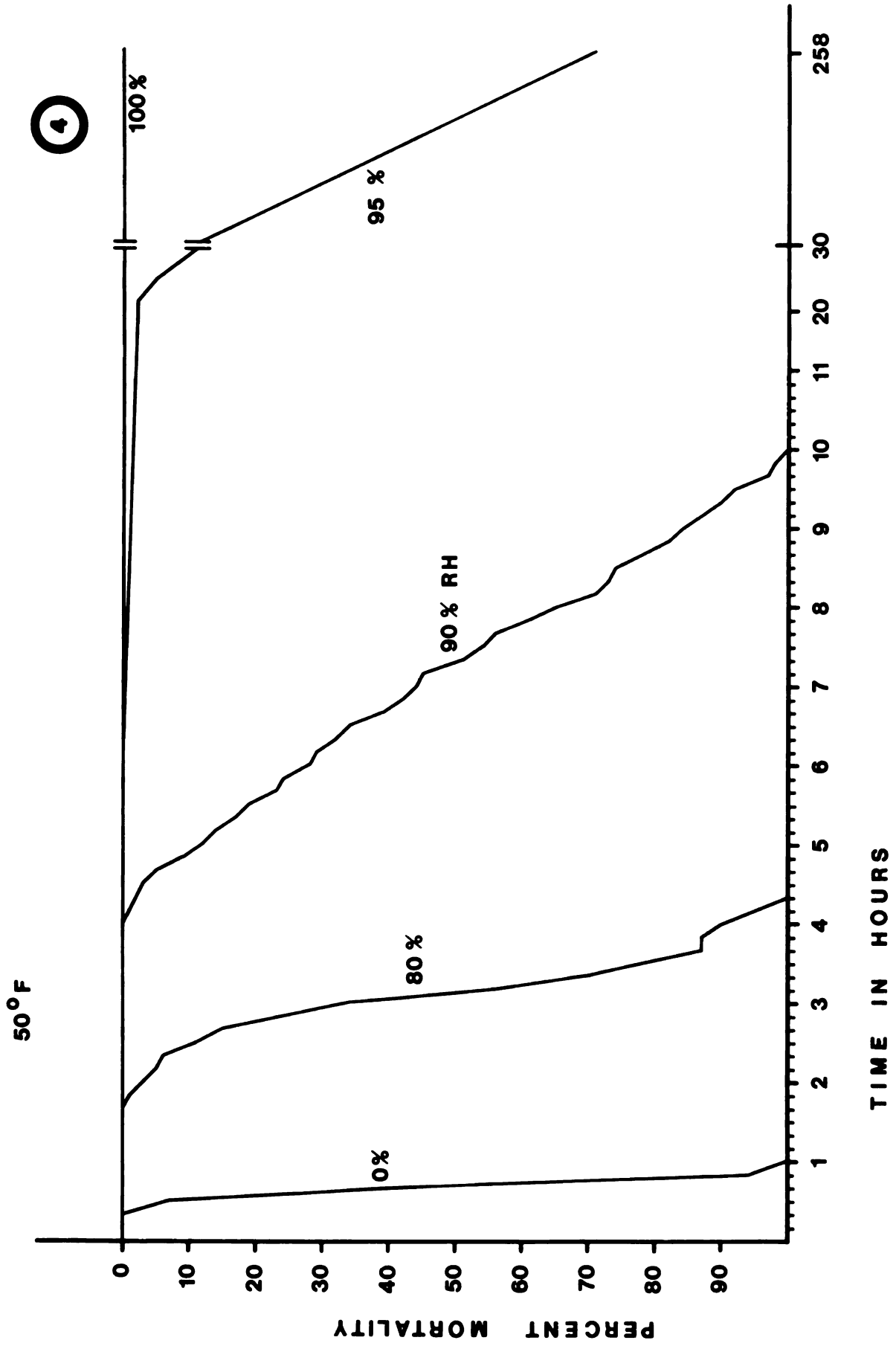
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Graph 4. Onychiurus justiporleri, percent mortality at 50°F and five relative humidities.

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V. OVIPOSITION

The egg laying process in Collembola has been described by several investigators (Davidson, 1934; Pacit, 1956; Sharma and Kevan, 1963 a,b; Hale, 1965 a; Sharma, 1967 b; Waldorf, 1971 a). Present observations are in agreement with previous descriptions of the general mechanics of egg deposition.

During daily counts and measurements of O. justl porteri cultures, the physical process of depositing eggs was frequently observed. As Hale (1965 a) points out, the animal raises its abdomen and remains immobile. This position permits the extrusion of the egg without danger of misplacement on the substrate surface.

In a female of O. justl porteri about to oviposit, the abdomen begins to pulsate with a series of contractions occurring roughly every ten seconds. Gradually the egg is forced out. As observed by the authors cited above, a fluid is secreted with the egg, giving it a very shiny appearance. On the average, it takes O. justl porteri two minutes to lay a single egg.

In general appearance freshly laid eggs are opaque white and slightly elongate in shape. The chorion is so delicate that the touch of a fine needle immediately results in destruction of the egg. After a few minutes of contact with the air, it assumes the spherical shape typical of the species. By the time the succeeding egg is laid, the chorion of the previous one is rigid enough to support it. The fluid secretion provides adhesion between successively laid eggs.

VI. EGG CANNIBALISM

It was noted that occasionally an egg would not firm up and remained

amorphous. The adult individuals in the culture would often feed on such atypical eggs. This happened more frequently in older individuals that had reached 250 days or more in age. Eggs laid by senile females were sometimes stuck together in misshaped clumps of twos and threes. The chorion would not harden and the eggs either disintegrated or were eaten.

In addition to amorphous eggs, what appeared to be non-viable eggs were laid. They were clear yellow in color and never developed. In most cases they were eaten by the adults in the culture. The ones that remained grew smaller and smaller with progressing dessication.

Green (1964 b) suggested that oophagy was density independent and that the amount of food was not responsible for reduction in either fecundity or egg cannibalism. A similar observation by Vail (1965) produced evidence that transparent yellow eggs were non-viable, and that those eggs were eaten by the adults. In a recent paper Waldorf (1971 b) showed that egg cannibalism in Sinella curviseta Brook seemed to be centered on non-viable and very young eggs (up to 24 hours from the time of laying). When eggs were healthy, only about 1% of them were subject to cannibalistic attack. Thus it would seem that Collembola are able to recognize non-viable or atypical eggs and destroy them.

VII. EGG DEVELOPMENT

Collembola eggs, as those of other groups of Apterygota, undergo holoblastic cleavage. The process begins with total equatorial cleavage leading to a typical blastula. After formation of the blastula, most of the nuclei migrate to the surface of the egg, constituting the blastoderm. At this point starts the formation of a lower layer along the entire periphery (Paclt, 1956).

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TABLE I

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Figures 33 to 40 illustrate the embryonic development of O. justi porteri at 70°F (21°C) constant temperature and 100% RH. Figure 33 represents the egg when first laid, smooth and opaque white. After 14 hours the 8-cell stage is reached (Fig. 34). By the third day sculpturing of the chorion takes place and the egg becomes elongate (fig. 35). Between the third and fourth day the chorion splits, exposing the serosa mucosa (fig. 36). The fifth day embryo clearly shows the development of the antennal and furcular buds, as well as leg buds (fig. 37). By the sixth day the furcular appendage begins regression while the other appendages become more distinct (fig. 38). On the eighth day the embryo shows definite body segmentation and the segments of the appendages are clearly demarcated (fig. 39). After eleven days the embryo is recognizable as a species (fig. 40). Eclosion at 70°F takes place on the average by the thirteenth to fourteenth day. A summary of the embryonic development of O. justi porteri is given in Table IV.

TABLE IV. Onychiurus justi porteri n. ssp., 70°F: Time-table for various stages in the development of the embryo. In parenthesis: number of replicates observed

Age in hours	Average diam. of egg (in microns)	Average dimensions of egg (in microns)			Development of embryo
		Width	Depth	Length	
1	168,9 (5)				
6	191,8 (4)				
12-14					4-32-cell stage
23					64-cell stage

(Table IV continued)

Age in hours	Average diam. of egg (in microns)	Average dimensions of egg (in microns)			Development of embryo
		Width	Depth	Length	
24-37	200,4 (4)				blastula formation
72	215,4 (1)				
94-100		172,4 (3)	215,4 (3)	221,1 (3)	distinct, opaque embryo
100-118					appendage buds visible, chorion rupturing
118-124		184,4 (41)	230,7 (41)	244,9 (41)	
124-150		186,7 (6)	228,3 (6)	246,6 (6)	head, legs, abdomen visible
266		189,6 (1)	232,6 (1)	258,6 (1)	
310-365					eclosion

After 72 hours, the egg begins to elongate to conform to the growing embryo. During these first 72 hours, the spherical diameter of the egg expands with the uptake of water from the surrounding atmosphere.

The size increase of the egg up to the time of eclosion is described by Milne (1960) for O. furcifer Börner, O. latus Gisin and O. procampatus Gisin. Marshall and Kevan (1962) note the expansion in egg diameter in Folsomia candida Willem and state that after rupturing of the chorion no

Onychiurus justus porteri n. ssp. - list of figure captions

33. Freshly laid egg (70°F).
34. Egg, fourteen hours old, eight cell stage (70°F).
35. Egg, three days old (70°F).
36. Egg, between three and four days of age, showing the ruptured chorion (70°F).
37. Egg, fifth day (70°F).
38. Egg, sixth day (70°F).
39. Egg, eighth day (70°F).
40. Egg, eleventh day (70°F).



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further increase in diameter occurs. Sharma and Kevan (1963 a) give similar data for Isotoma notabilis (Schäffer), and again (Sharma and Kevan 1963 b) for Folsomia similis Bagnall. Concurrent reports by other authors state that after rupturing of the chorion, the size of the egg remains stable until eclosion (Britt, 1951; Sharma, 1967 a,b; Ripper, 1930; Sedlag, 1952; Davies, 1928).

In the above cited literature, the criterion used for description of egg size is the measurement of diameter. Yet many of the authors state that the collembolan egg becomes elliptical, which would seem to make measurement of length and width necessary. Waldorf (1971 a) gives length and width figures for Sinella curviseta and again indicates no further size increase after rupturing of the chorion.

It becomes apparent that three measurements of collembolan eggs should be made in order to express egg size in relation to embryonic growth. The figures in Table IV indicate that the egg, spherical at first, not only undergoes elongation but also lateral compression. Hence in this investigation measurements of the egg after the first 72 hours of development are given in terms of width, depth and length. It can also be seen that the egg continues to expand after the rupturing of the chorion; indicating that apart from growth of the embryo, uptake of water through the serosa mucosa may further determine size of the egg. Apparently this increase in size is made possible by a certain elasticity on the part of the serosa.

Data on the influence of a range of temperatures on the duration of the egg stage in a given species are not as extensive as information on the effect of a single temperature regime. There are some notable exceptions where comparisons are made (Davis and Harris, 1936; Britt, 1951; Choudhuri, 1961; Sharma and Kevan, 1963 a,b); but on the whole, data are sparse. In the course of this investigation, O. justl porteri eggs were

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subjected to four temperatures to ascertain their effect on the rate of development. Table V indicates the four temperatures and the average number of days required to reach eclosion

TABLE V. Onychiurus justl porteri n. ssp.: Number of days required for the development of the eggs from the time of laying to eclosion.

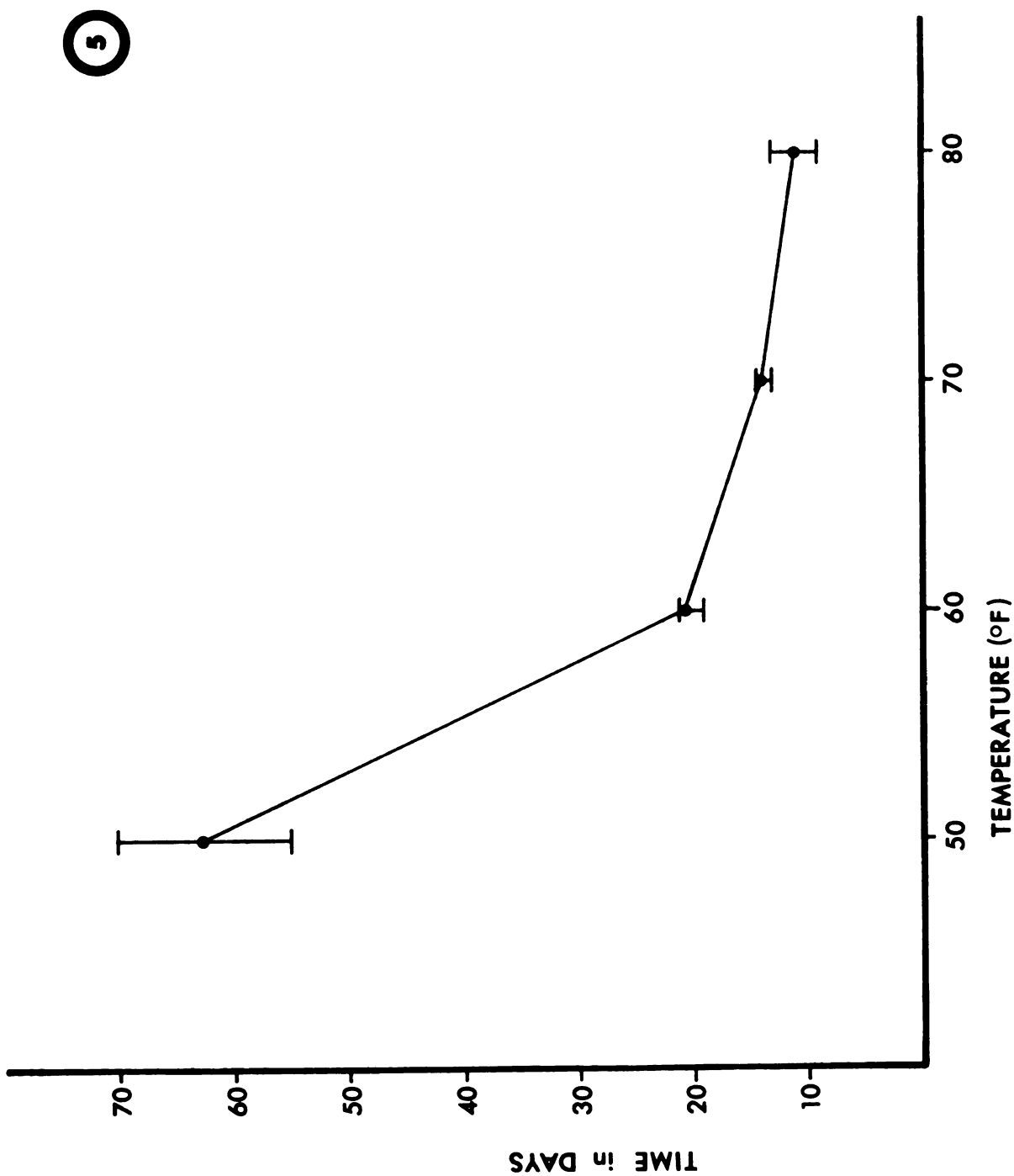
	50°F	60°F	70°F	80°F
Average no. of days to eclosion	62,6	20,5	13,9	11,0
Range	55-70	19-21	13-14	9-13

Parallel to Table V, Graph 5 indicates a close relationship between temperature and the average duration in days of the egg stage. Note that at 50° and 80°F the duration range is greater than at 60° and 70°F. This would be an indication that the optimum temperature for incubation of O. justl porteri eggs in the laboratory lies between 60° and 70°F.

VIII. EGG PRODUCTION

Introduction

In 1965 Hale stated that the knowledge of collembolan fecundity had not progressed very far beyond Lubbock's observations of 1873. The most precise data on egg production dealt with the economically important species Sminthurus viridis (Linn.). Davidson (1934) gave 60 eggs per batch as an average number for viridis. Further investigations by Holdaway (1927) and MacLagan (1932) revealed that S. viridis lays two egg batches in a ten day interval.



Graph 5. Onychiurus justiporleri, relationship of temperature to the duration (in days) of the egg stage.

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I. Mass culture
egg production
II. Low humidity
containers
III. Cultures

Britt (1951) found the number of eggs per batch laid by Hypogastrura armatus (Nicolet) to vary from a few to 70. He cites a mean of 28 eggs, obtained by counting 50 groups, the upper and lower limits being 12 and 96 eggs. Hale (1965 b) presents a table of estimates of fecundity in Collembola covering the period from 1930 to 1965. Green (1964 a,b), an author not mentioned by Hale, investigated the life history, fecundity, and effects of crowding on fecundity in Folsomia candida Willem. He describes four egg laying periods within 48 days. The average total number of eggs laid by 11 females surviving to maturity was 167,5. Sharma (1967 b) states that Tomocerus vulgaris (Tullberg) raised in the laboratory oviposited only once in 6 months, the number of eggs laid by a female ranging from 6 to 10. More recently, Waldorf (1971 a) reports that isolated pairs of Sinella curviseta produce about 400 eggs. It should be pointed out that investigators are inclined to attribute variations in fecundity estimates to the influence of laboratory techniques and mortality factors as yet unexplained (Christiansen, 1964; Hale, 1965 b).

Methods

The present investigation aimed to determine the fecundity of Onychiurus justl porteri at three temperatures, 60°, 70° and 80°F, and a relative humidity of 100% RH. Three methods were used to obtain information on the number of eggs produced and on the batch size.

- I. Mass cultures; 20-50 individuals per container, to estimate egg production per individual.
- II. Low number reared cultures; five or less individuals per container, to estimate egg production per individual.
- III. Cultures of pairs; containing a male and a female, to estimate

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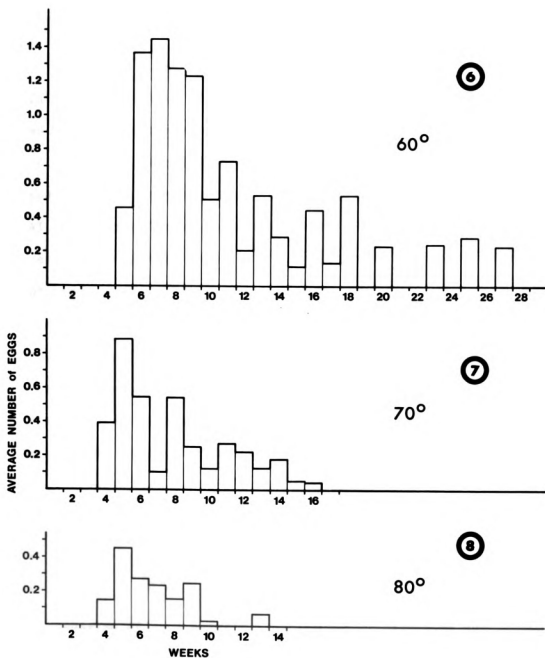
All experimental containers were set up in the manner previously described. Mass reared individuals were placed in 50 mm x 37,5 mm containers (fig. 27 b). Individuals reared in low numbers and in pairs were kept in 25 x 34 mm containers (fig. 27 a) for greater ease of manipulation. All experimental cultures were started from eggs.

Fecundity in Mass Reared Cultures

In this experiment more than 20 individuals of equal age were maintained per container. Counts of daily egg production were recorded along with ecdyses, deaths and hatching success. The fact that ecdyses in mass cultures can not be attributed to specific individuals made it necessary to choose arbitrary time periods, i.e. weeks rather than instars, for the calculation of egg production. At the same time, samples were periodically removed from the containers, decreasing the population densities with each successive week. Moreover, the ratio of males to females in each population was unknown, leading to the calculation of egg production per individual rather than per female. The following formula was used to determine the average:

$$\text{Average egg production per individual} = \frac{\text{Total number of eggs per week}}{\text{Average number of individuals/week}}$$

Graphs 6, 7 and 8 illustrate the average number of eggs per individual at 60°, 70° and 80°F. At 60°F, no eggs were laid until the fifth week with an average number of individuals of 550,28 for 18 replicates (Appendix V). At 70°F, eggs were laid during the fourth week, with an average of 645,42 individuals in 29 replicates (Appendix VI). Likewise, at 80°F egg laying began in the fourth week, with 338,14 individuals in 10 replicates (Appendix VII). At all three temperatures, the same basic pattern emerges; batches of



Graphs 6, 7 and 8. *Onychiurus justus porteri*, average number of eggs per individual at 60°, 70° and 80°F laid in mass cultures.

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eggs laid in the first week of production are small; the succeeding week is characterized by an impressive increase, followed by a gradual decline.

Fecundity in Low Number Reared Cultures

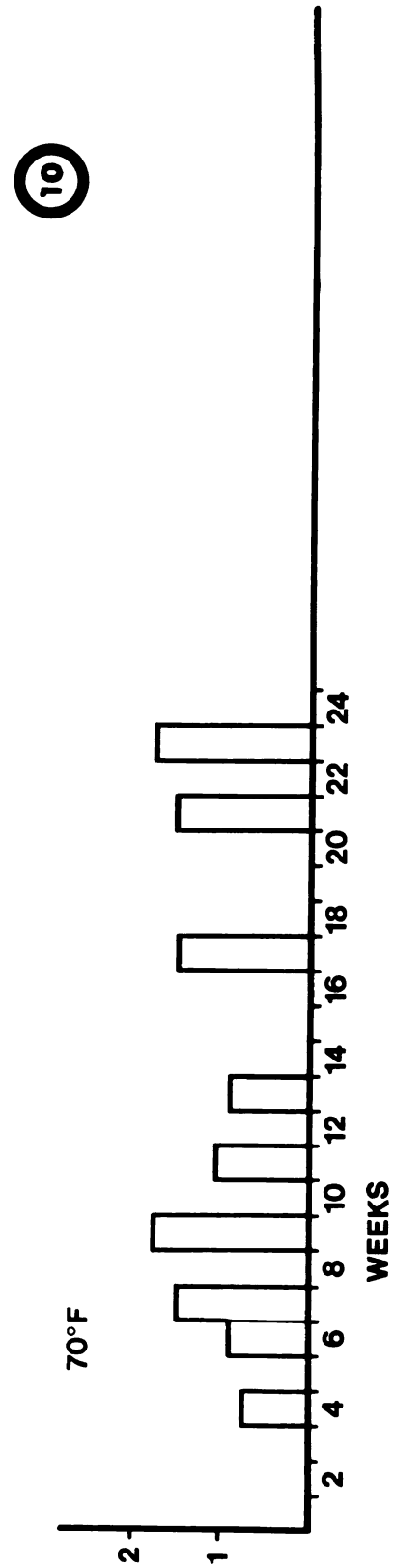
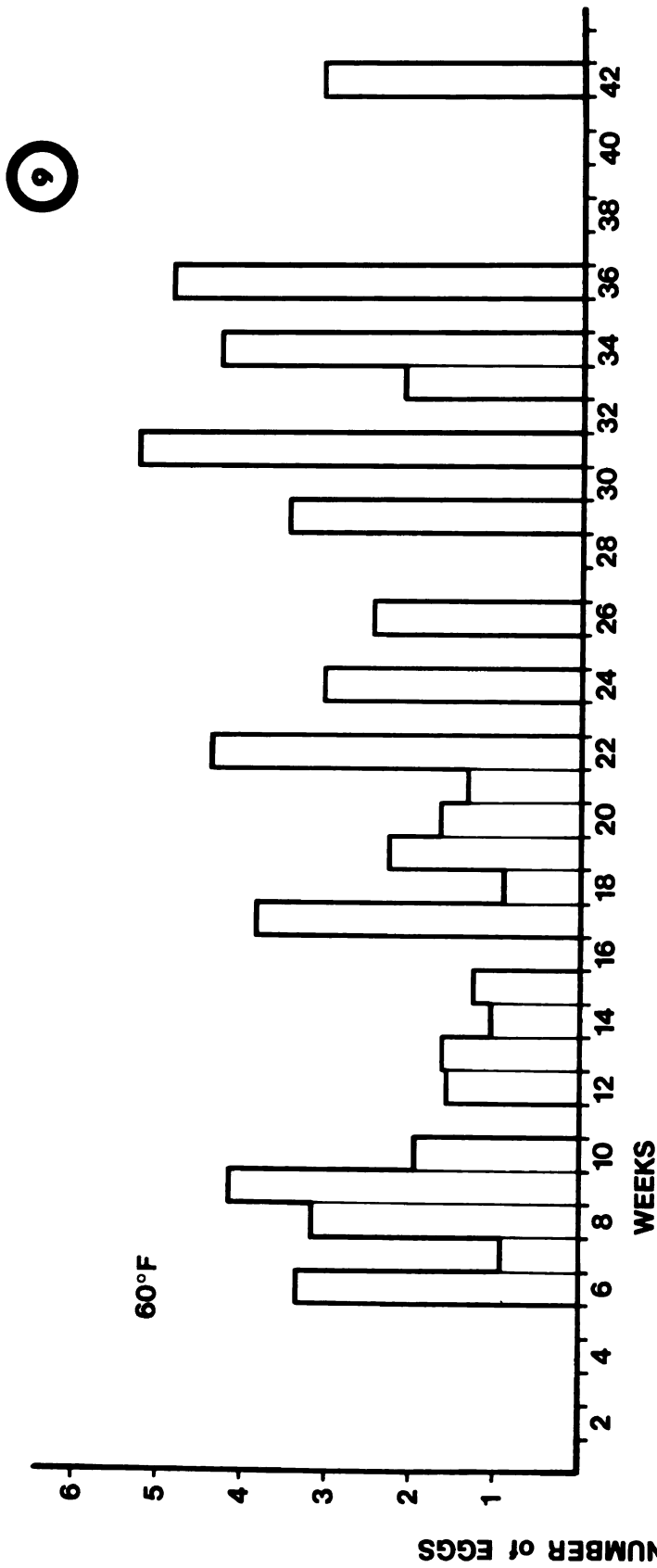
Cultures containing five or less individuals of even age were manipulated in the same manner as the mass reared cultures. Once again the sex ratio was not known and the above formula for average egg production was used. No specimens were withdrawn for samples, thus only deaths from natural causes contributed to weekly changes in density. Only two temperatures are represented here because the cultures maintained at 80°F did not produce eggs.

Graphs 9 and 10 illustrate the average number of eggs laid per individual at 60° and 70°F. Note that at 60°F eggs were not laid until the sixth week after hatching, whereas at 70°F egg production began in the fourth week. Eight replicates, comprising an average of 23,0 individuals in week 6, made up the 60°F series (Appendix VIII). While ten replicates with an average of 31,85 individuals in week 4 constituted the 70°F run (Appendix IX).

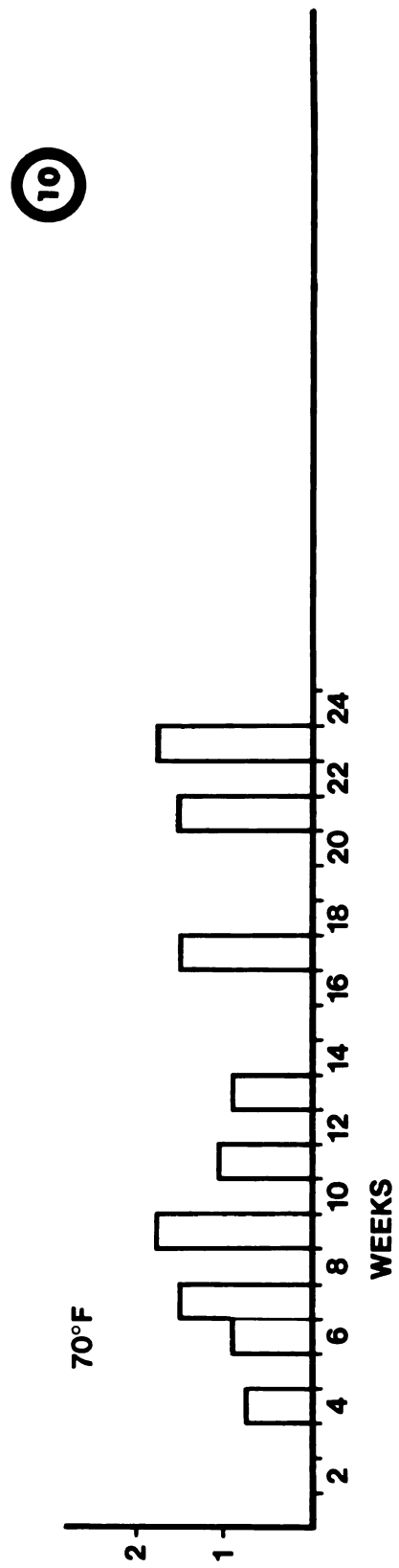
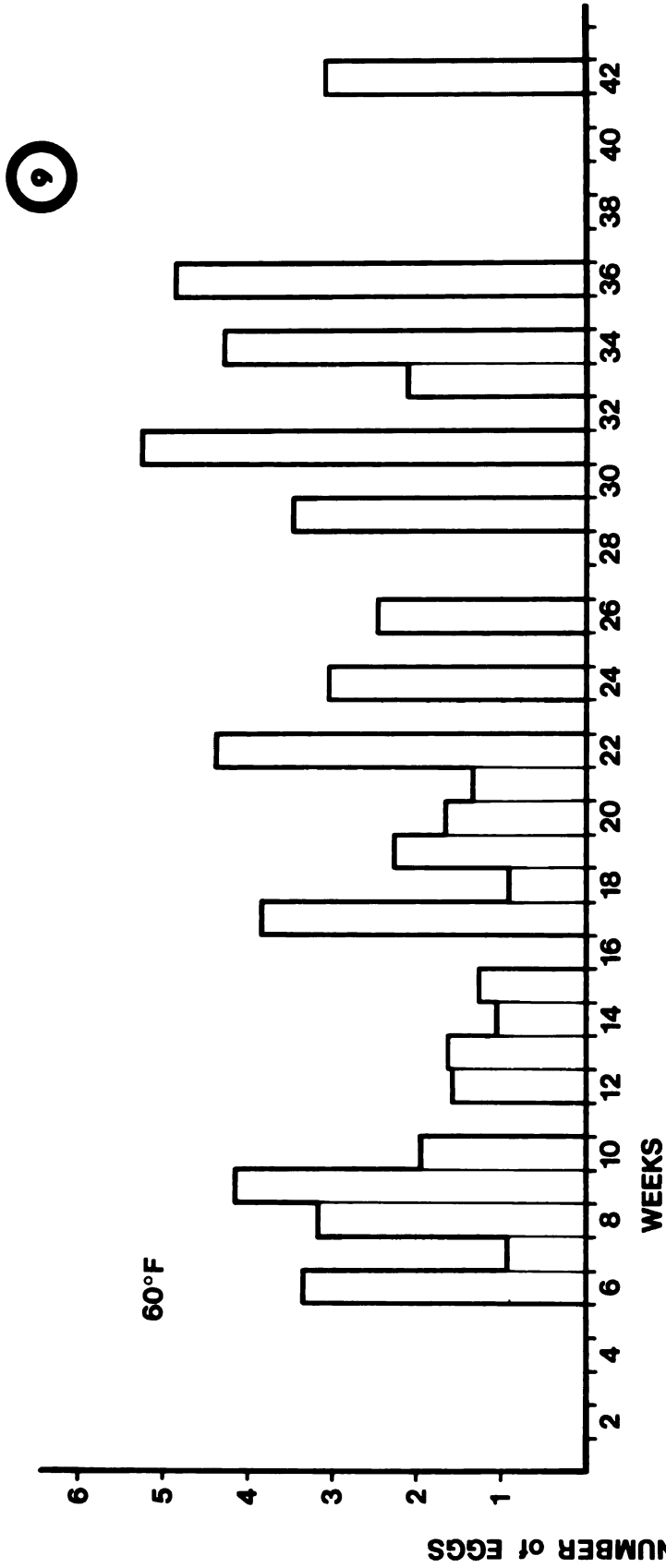
Fecundity of Isolated Females

Observation of true pairs was undertaken to determine egg production by single females both on a weekly and an instar basis. As in the low number reared cultures, no animals were withdrawn for samples. Two temperatures are represented, the 80°F individuals not having laid eggs.

Graphs 11 and 12 illustrate the average number of eggs per week laid by individuals at 60° and 70°F. The figures for 60°F are based on 9 replicates



Graphs 9 and 10. *Onychiurus justii porteri*, average number of eggs per individual at 60°, 70° and 80°F laid in low number reared cultures.



Graphs 9 and 10. *Onychiurus justii porteri*, average number of eggs per individual at 60°, 70° and 80°F laid in low number reared cultures.

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(Appendix X) and those for 70°F on 21 replicates (Appendix XI). It becomes apparent that the egg production pattern for isolated females and for mass cultures show little similarity.

The present data on fecundity of single females do not represent the potential life time production of a single female kept at constant temperature. At 60°F, observation throughout 35 weeks revealed a total of 9 oviposition periods per female; at 70°F, 8 oviposition periods were recorded within a time span of 18 weeks. Tables VI and VII illustrate egg production and hatching success per oviposition for isolated pairs. At both temperatures there is an increase in egg production and a decrease in egg mortality as the female matures.

TABLE VI. *Onychiurus justiporteri* n. ssp., 60°F: Egg production and percent hatching per oviposition, for pairs of male and female reared in isolation.

Oviposition	1	2	3	4	5	6	7	8	9
Total no. of eggs	136	156	211	217	101	84	79	89	31
No. females laying	9	8	7	6	4	3	2	2	1
Average per female	15,1	19,5	30,1	36,1	25,2	28,0	39,5	44,5	(31)
Total no. hatching	102	112	171	191	85	72	76	86	28
Percent hatching	75,0	71,7	81,0	88,0	84,1	85,7	96,2	96,6	90,3

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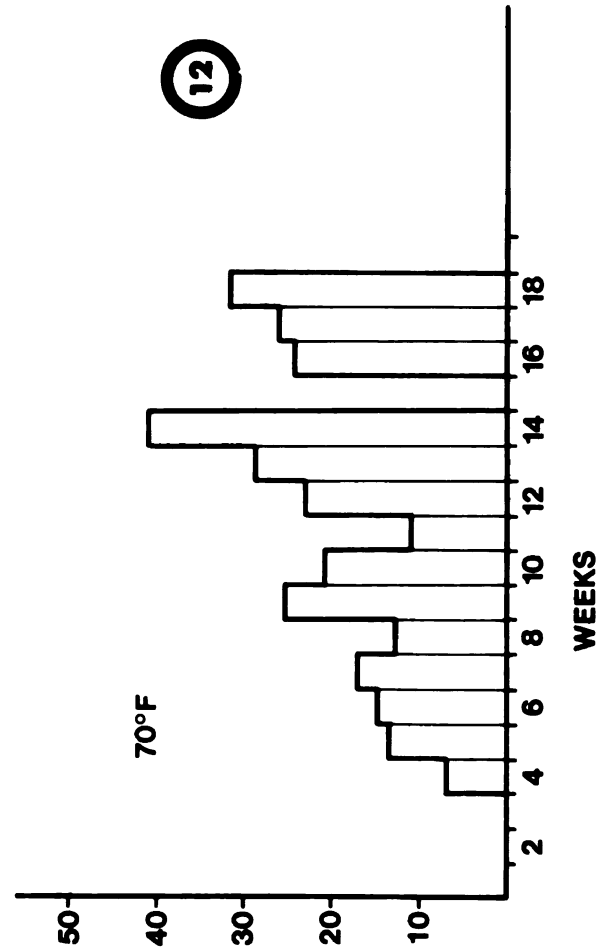
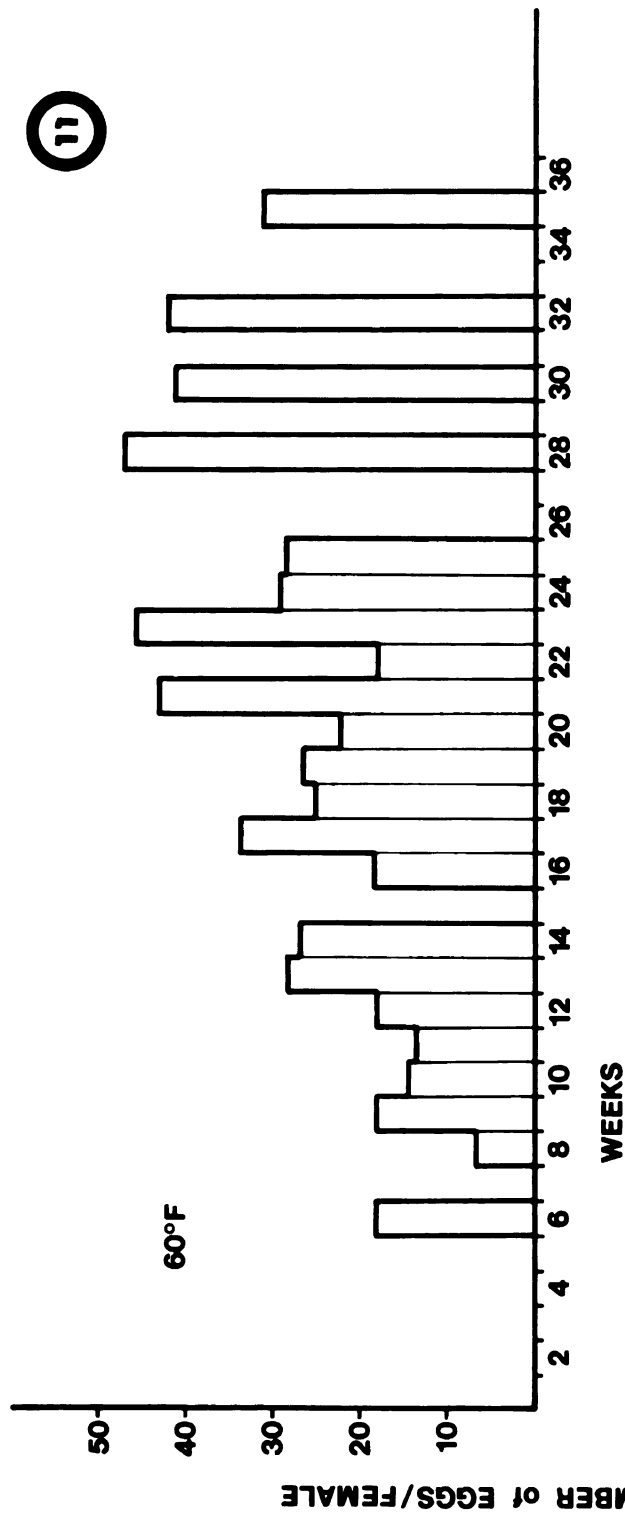
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TABLE VII. Onychiurus justi porteri n. ssp., 70°F: Egg production and percent hatching per oviposition, for pairs of male and female reared in isolation.

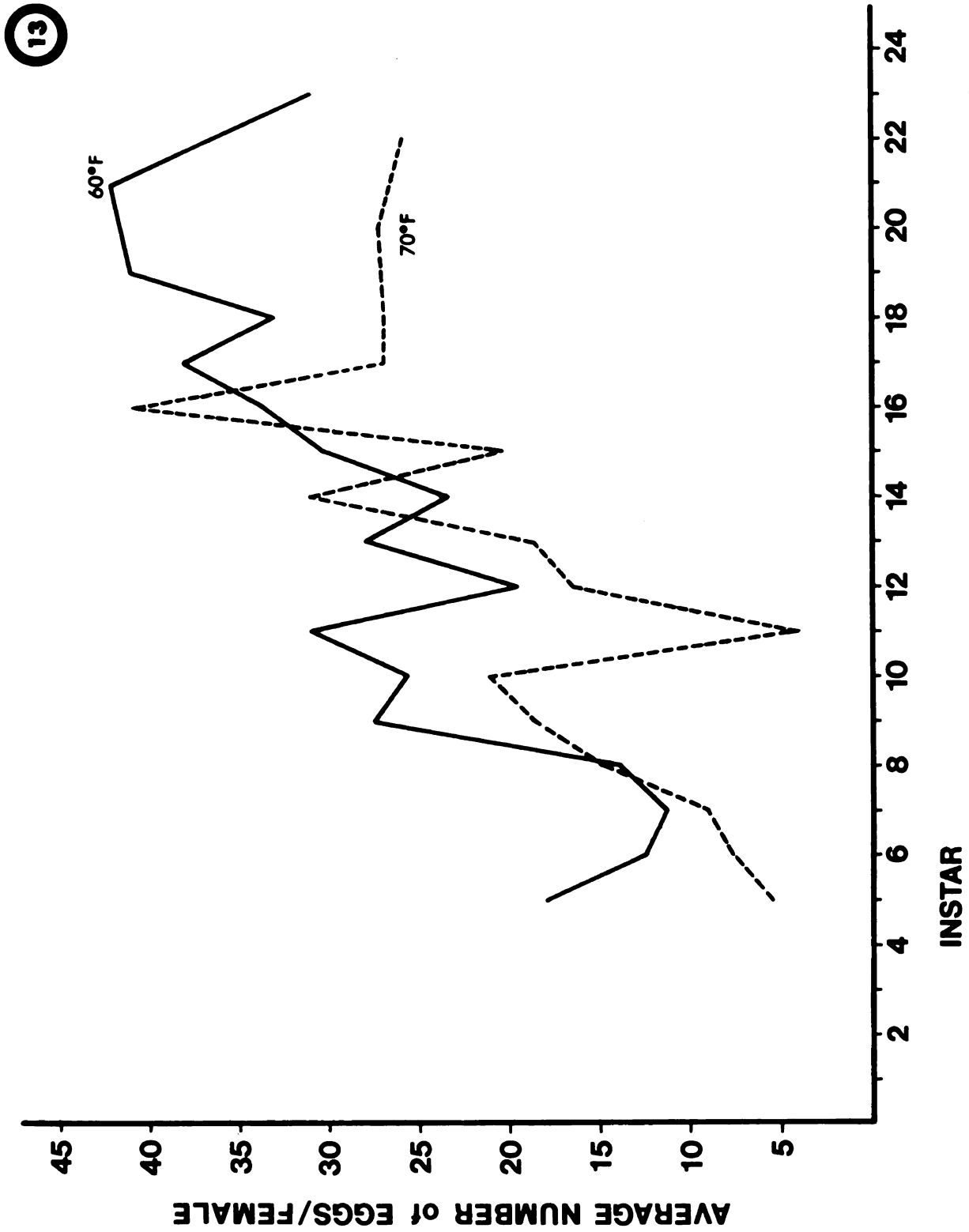
Oviposition	1	2	3	4	5	6	7	8
Total no. of eggs	259	221	152	190	111	67	71	37
No. females laying	21	13	10	8	5	3	2	1
Average per female	12,3	17,0	15,2	23,7	22,2	22,3	35,5	(37)
Total no. hatching	183	147	68	114	57	51	59	36
Percent hatching	70,6	66,5	44,7	60,0	51,3	76,1	83,1	97,3

Discussion

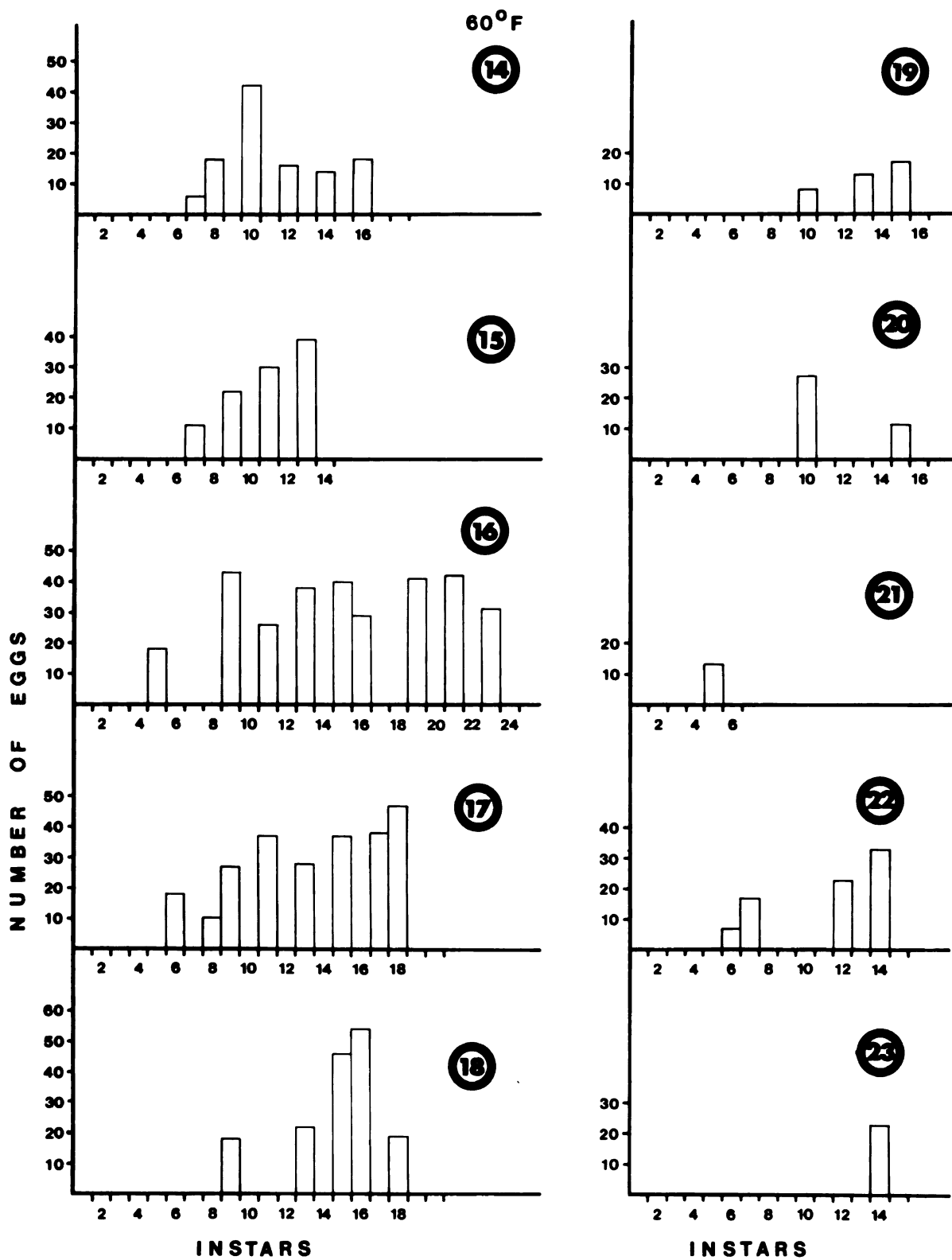
From the data presented it is obvious that several factors have influence on the fecundity of O. justi porteri. Comparison between the effects of temperature on low number and mass reared cultures shows that an increase in temperature lowers the number of eggs produced. However, the overall oviposition pattern is similar. A slightly different situation exists in the case of isolated females, although the effect of temperature again becomes clear (Graphs 11 and 12). Furthermore, egg mortality in mass and low number reared cultures equally reflects the influence of temperature. Table VIII compares percent survival of eggs at three temperatures. As the temperature increases, egg mortality amplifies. In a small test run where 495 eggs were incubated at 50°F, the percent survival was 78,58%. The optimum egg survival temperature would then seem to lie near 60°F, where survival was 80,51%.



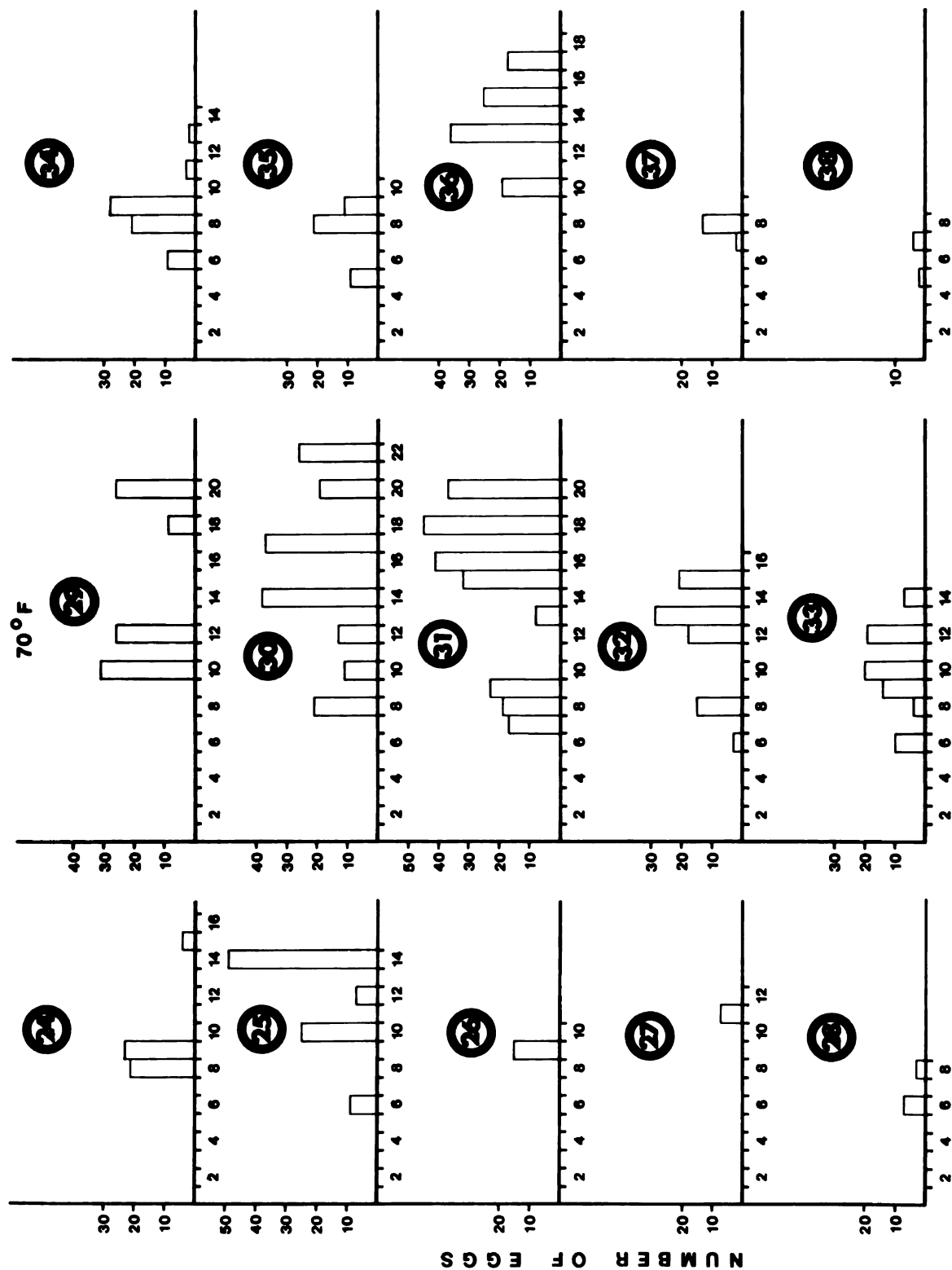
Graphs 11 and 12. Onychiurus justus porteri, average number of eggs laid at 60° and 70°F by isolated females.



Graph 13. *Onychiurus justii porteri*, average number of eggs laid per female at 60° and 80°F, plotted against instar.



Graphs 14 to 23. Onychiurus justus porteri, egg production per instar of 10 females reared at 60°F.



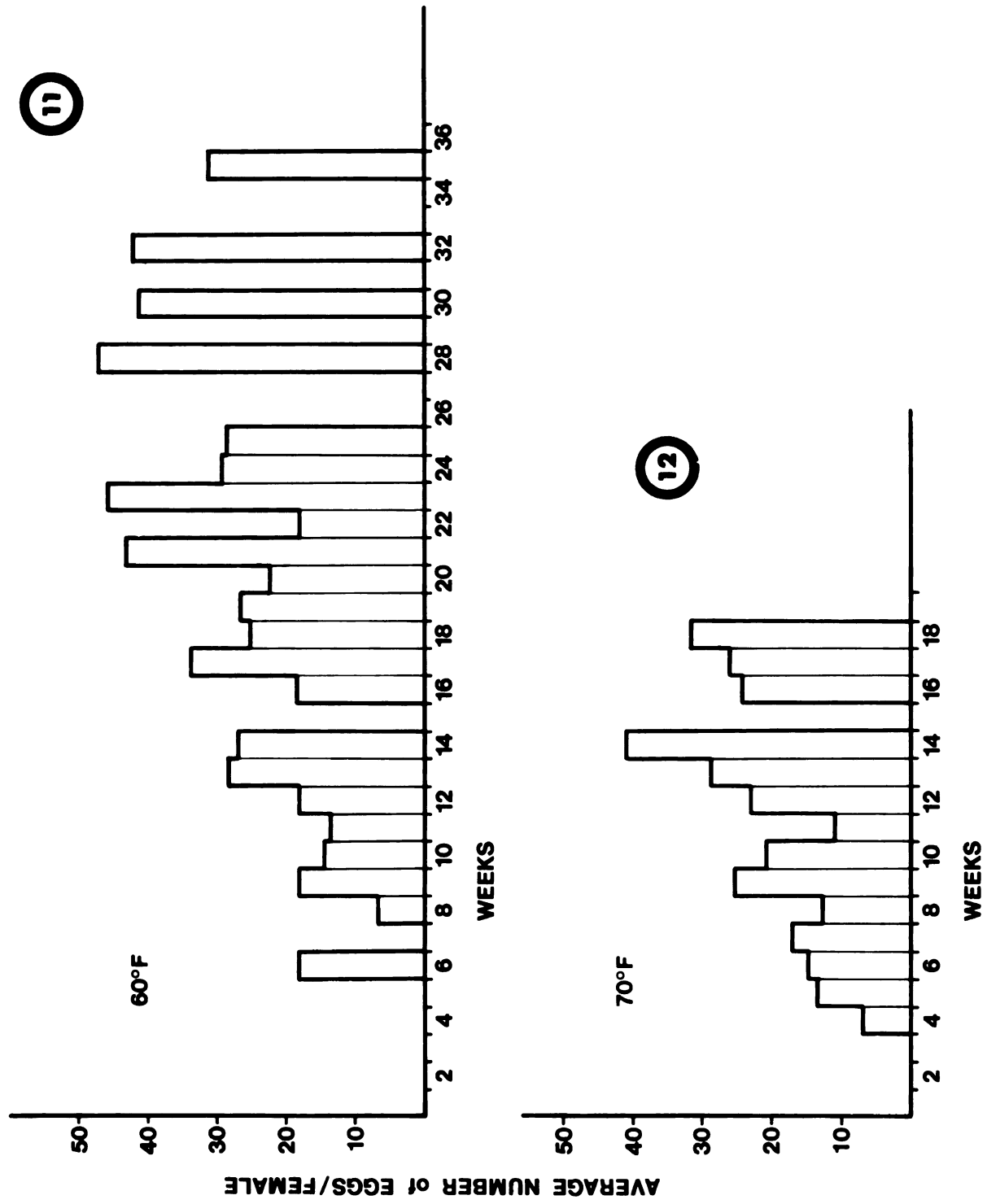
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TABLE VIII. Onychiurus justus porteri n. ssp.: Over-all survival of eggs produced in mass and low number reared cultures.

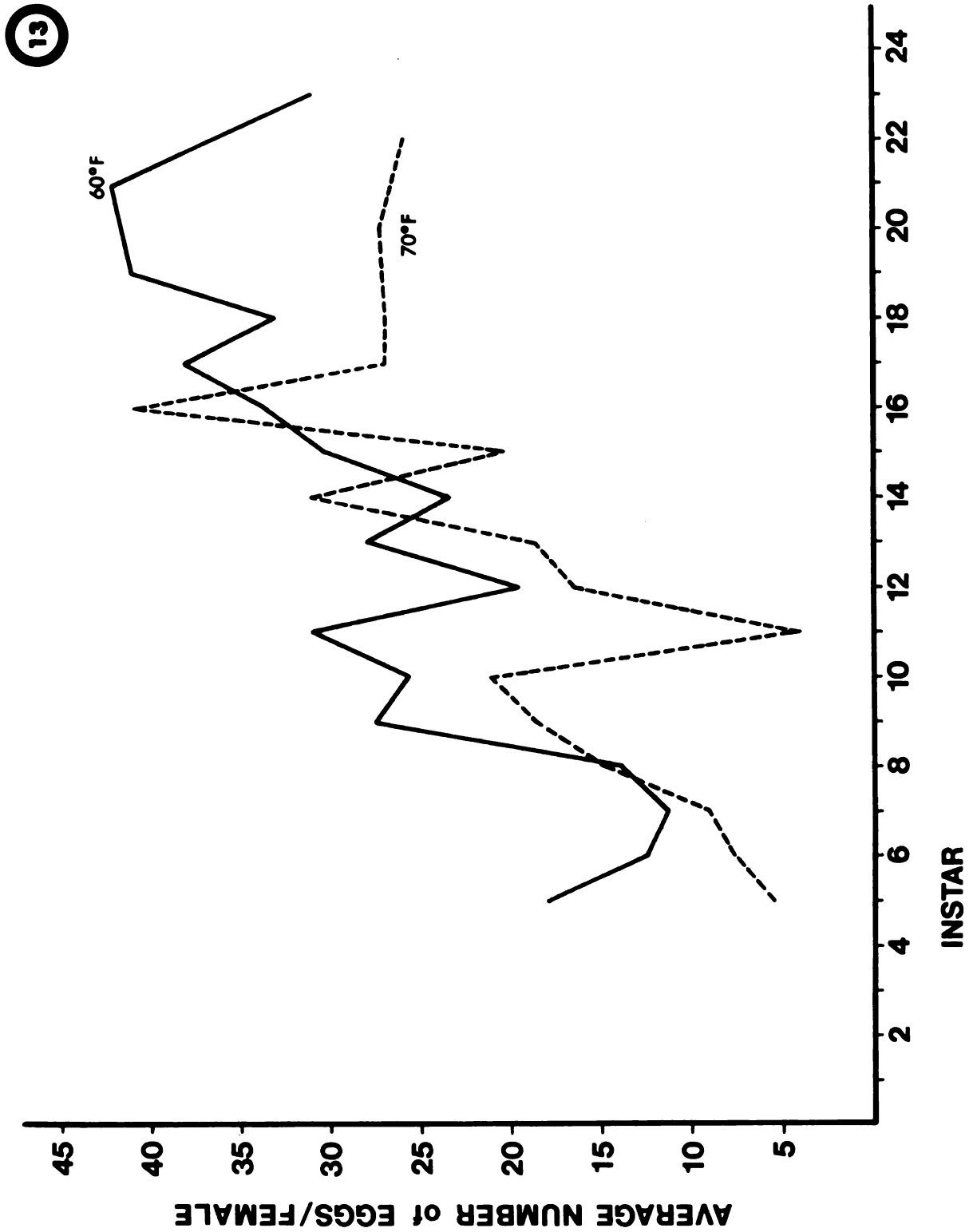
	60°F	70°F	80°F
No. of eggs left to hatch	4671	1642	506
No. of eggs hatched	3761	1268	303
Percent survival	80,51	77,22	59,88

Comparison of the first 14 weeks of egg production in mass, low number and paired cultures at 60°F reveals a dissimilarity in these three series. Individual females do not exhibit an early peak and then gradual tapering off in egg production. Instead the number of eggs, low at first, increases steadily with progressing age (Graph 13 and Appendices XII and XIII). This pattern is also reflected in Tables VI and VII where average egg production per female increases with successive ovipositions. Graphs 14 to 23 illustrate extreme examples of egg production per instar in 10 females reared at 60°F. With few exceptions the trend is a gradual increase from an initial low. The same pattern occurs in individual females at 70°F (Graphs 24 to 38). Comparison of egg production per instar in individual females at 60° and 70°F (Graph 13) shows a faintly discernible rhythm seemingly corresponding to that illustrated in Graphs 9 and 10. Graphs 14 to 23 and 24 to 38 also illustrate variation in fecundity between individual females.

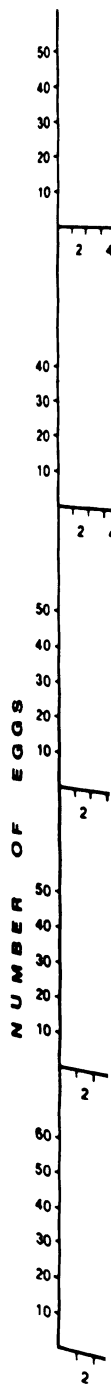
Green (1964 b) found that fecundity was reduced in crowded cultures of Folsomia candida. Oviposition was inhibited by contact between individuals attempting to lay eggs and those searching for food. The



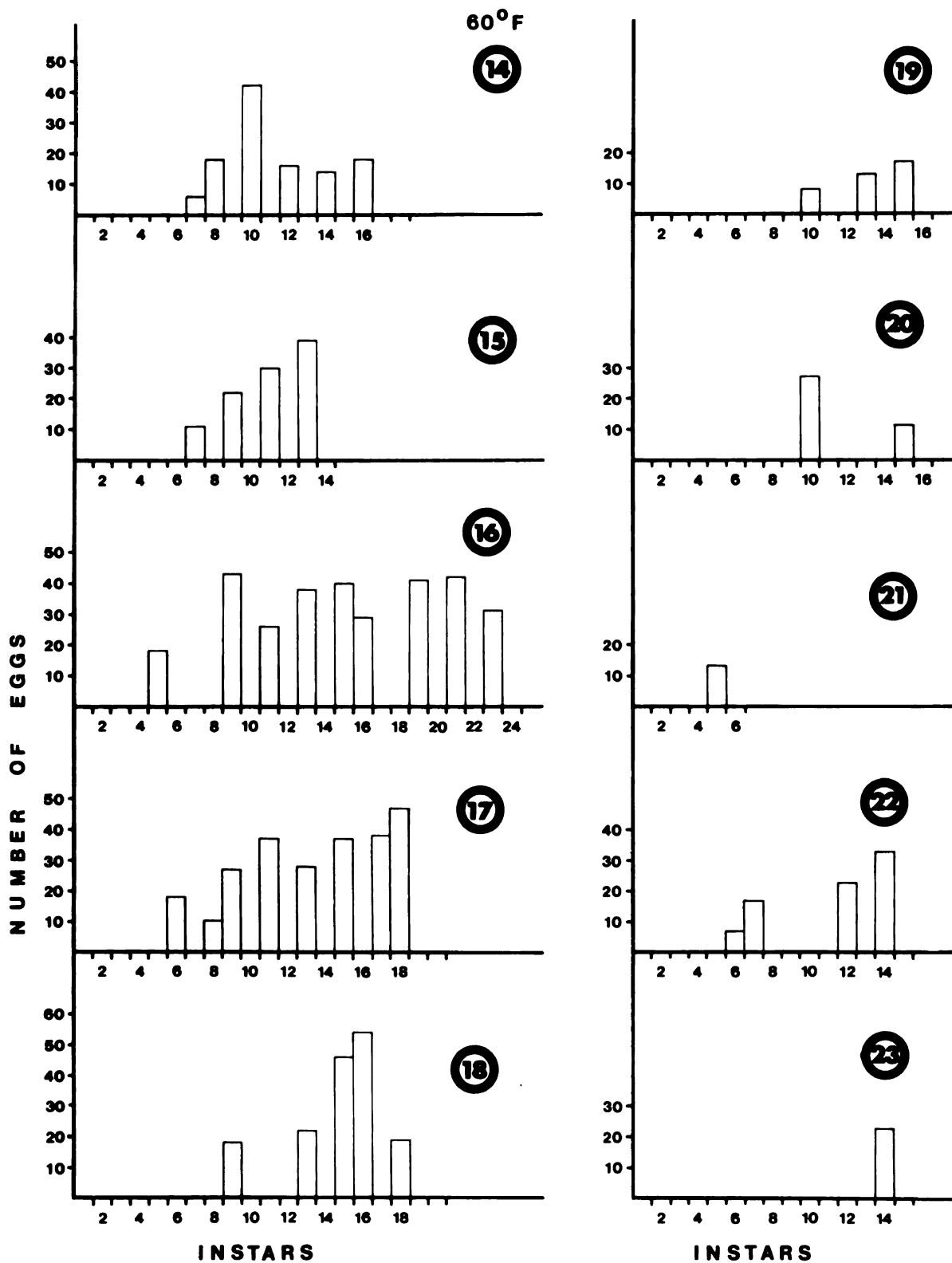
Graphs 11 and 12. Onychiurus justus porteri, average number of eggs laid at 60° and 70°F by isolated females.



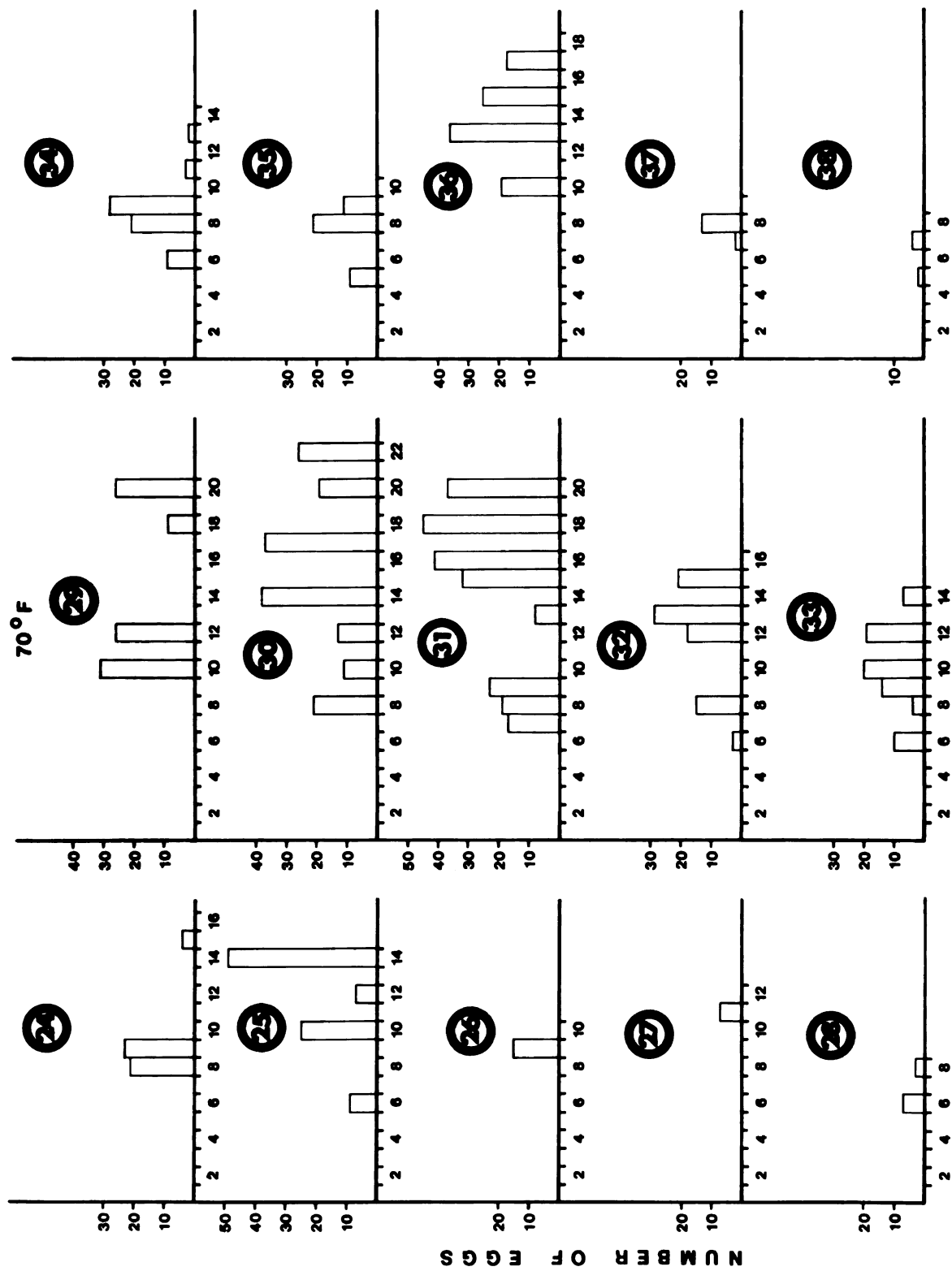
Graph 13. *Onychiurus justiporteri*, average number of eggs laid per female at 60° and 80°F, plotted against instar.

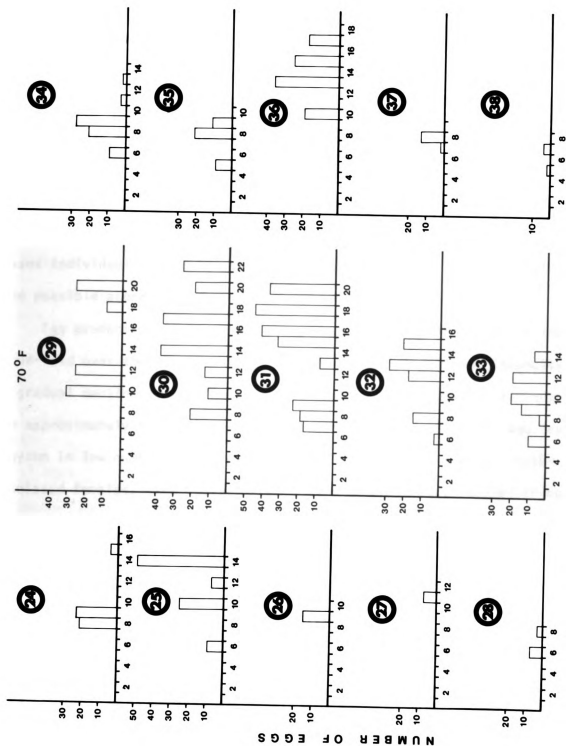


Graphs



Graphs 14 to 23. Onychiurus justiporteri, egg production per instar of 10 females reared at 60°F.





Graphs 24 to 38. *Onychiurus justiporteri*, egg production per instar of 15 females reared at 70°F.

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number of eggs laid was found to decrease with increasing density of the culture. Another important factor was reported by Waldorf (1971 a) for cultures of Sinella curviseta. Yeast or bacteria apparently produce a contaminant in progressively aging cultures, resulting in chemical inhibition of egg production. The influence of crowding and chemical contamination by yeasts and bacteria may thus explain the decrease in egg laying in mass cultures of O. justl porteri. Certainly the crowding effects would be minimized as individuals either died or were sampled from the culture containers. Yet egg production decreased and stopped after 27 weeks at 60°F, 16 weeks at 70°F, and 15 weeks at 80°F. In all cases individuals lived far beyond their productive periods, indicating the possible presence of unanalyzed factors in the mass cultures.

Egg production in low number reared cultures was increased at least four-fold over that in mass cultures. After an initial high fecundity, a gradual decline toward the fourteenth week was succeeded by an increase to approximately the thirty-sixth week (Graphs 9 and 11). The egg laying rhythm in low number reared cultures recalls clearly a similar rhythm in isolated females. The number of eggs laid by individual females in both runs are remarkably close.

The above discussion suggests that egg production is influenced by at least three possible factors: crowding, chemical inhibition, and regulated sexual activity. Waldorf (1971 a) has shown in Sinella curviseta that the males are capable of sensing an impending moult in the females. Immediately after ecdysis, the females are most apt to utilize spermatophores. In mass and low number reared cultures, where males capable of producing sperm are more readily available than in paired cultures, the increased chance of fertilization possibly leads to a higher initial egg production.

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TABLE IX.

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A greater number of females apparently were receptive to fertilization and subsequent egg laying at the beginning of their reproductive life than toward the end of it. Tables VI and VII show that while the average number of eggs per female increased for nine ovipositions, the contributing number of laying females decreased; a decrease not entirely due to death of one of the partners. The combination of many males and receptive females may thus account for an initial high fecundity in the mass and low number reared cultures.

Several females produced eggs over a remarkably long period of time. Graph 9 reflects such long life spans combined with high productivity. A case in point would be a female from a low number reared culture (Table IX) that lived for 366 days at 60°F.

TABLE IX. Egg production of a single female in a low number reared culture for 366 days.

Days on which eggs were laid	63	72	85	103	139	159	172	186	213	231	248	266	283	321
Number of eggs in batch	18	8	9	21	50	57	64	56	42	62	47	60	63	37

In paired cultures the maximum number of eggs laid by one 240 day old female at 60°F was 308 eggs. At 70°F a 120 day old female had laid 222 eggs.

Very little data on onychiurid Collembola are available for comparison. Hale (1965 b) made estimates of fecundity for the following four species: Protaphorura furcifer, P. procampatus, P. latus and P. tricampatus. His culture techniques were similar to the ones in the present study, using yeast as food and an incubation temperature of 15°C (approximately 60°F).

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The data he gathered are summarized below (Table X).

TABLE X. Estimated fecundity for 4 species of Protaphorura cultured by Hale (1965) at 15°C (60°F).

Species	Average no. of eggs/batch	No. of layings	Estimated no. of eggs/life time*
<u>P. furcifer</u>	14.3	2	28
<u>P. procampatus</u>	4.6	2	9
<u>P. latus</u>	15.1	2	30
<u>P. tricampatus</u>	9.7	2	19

According to Hale, "an estimate of the number of eggs laid by a female during life can be obtained by multiplying the average batch size by the number of laying periods."

Drawing a parallel to the data collected for O. justl porterl at 60°F (Table VI) with an average batch size of 15.1, the result is an estimate of 135,9 eggs for a total of nine ovipositions. Adding together the averages of the nine actual ovipositions results in 269 eggs, or almost half again as many eggs. These figures suggest that fecundity estimates of other investigators have been conservatively low when dealing with euedaphic species. A singular case in point is Folsomia candida. Milne (1960) indicates 9-36 eggs per batch at 12°C. Marshall and Kevan (1962) cite 13.2 eggs as their highest average at 24°C. Green (1964 a) gives a mean total of 167.5 eggs in a life time at 25°C, the highest average per batch being 61.7 eggs. Green (1964 b) states that the mean fecundity per female in a culture of 10 individuals was 12.6 eggs. Snider (In Press) has shown that F. candida can lay a maximum of 1654 eggs in a life time of 193 days. In 65 replicates of single females the average number of eggs laid in life amounted to 1011 eggs. The average number of batches produced per female was 12.98, with a mean of 77.9 eggs per oviposition.

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IX. POSTEMBRYONIC DEVELOPMENT

Introduction

Investigations on the postembryonic development of Collembola have been reviewed by Christiansen (1964), Schaller (1970) and Butcher, Snider and Snider (1971). Most authors agree that after hatching, a collembolan passes through three main life stages: juvenile, postmaturity growth, and senile moults (Christiansen, 1964). Information available in the literature indicates that variation in the number of moults to maturity, longevity, size, and anatomical changes are species dependent (Lindenmann, 1950; Uchida and Hongo, 1962; Milne, 1962; Sharma and Kevan, 1963 a,b; Green, 1964 a; Hale, 1965 c, 1966, 1968; Sharma, 1967 a; Ashraf, 1969; and Thibaud, 1969).

Collembola continue to moult throughout their life history (Britt, 1951; Green, 1964 a). In previous investigations, it has consistently been stated that as the individuals pass from juvenile to maturity, a size increase takes place with each moult, until attainment of maximum size. Thereafter there is no change in over-all body size with succeeding moults (Britt, 1951; Green, 1964 a; Sharma and Kevan, 1963 a; Hale, 1965 c; Ashraf, 1969). Healy (1967) found instar measurements too variable to be applied to field animals and used weight classes to determine age structure in a population. Recently, Petersen (1970 In Press) has based an investigation on secondary production of Protaphorura furcifer on the relationship between age and total body length. His work was conducted with laboratory reared specimens and field released individuals tagged with P-32 for recapture.

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Methods

The cultures of O. justiporteri previously described also furnished data on postembryonic development. Again, three temperature regimes, 60°, 70° and 80°F, and varied population densities (mass, low number, pairs and singles), provided a basis for comparison of the results.

The following Table (XI) presents the number of individuals observed in each experimental run.

TABLE XI. Number of individuals observed at three constant temperatures in each experimental run.

Culture category	Temp.	Number of individuals	Length of rearing time from hatching (in days)
Mass	60°F	440	315
Mass	70°F	663	238
Mass	80°F	315	140
Low number reared	60°F	27	336
Low number reared	70°F	32	280
Low number reared	80°F	30	196
Single male and female	60°F	28	267
Single male and female	70°F	56	154
Single male and female	80°F	14	154
Two females	60°F	30	150
Two females	70°F	16	154
Two males	60°F	18	144
Two males	70°F	18	152
Single females	60°F	42	145
Single females	70°F	20	154
Single females	80°F	23	147
Single males	60°F	26	150
Single males	70°F	13	154
Single males	80°F	30	150
		<u>1841</u>	
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The data derived from these observation series provided information on: instar duration; instar size, head width and length, over-all body length; size structure of males and females; mortality; longevity; influence of density and sex on growth; and senility.

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All observations were made daily over a two year period. Each individual series was removed from its respective incubation chamber, and each replicate examined under a dissecting microscope as quickly as possible. In mass cultures periodic samples of each instar were randomly selected and killed, mounted and measured. At the termination of each run, all surviving specimens were killed and preserved.

Individuals were killed by pouring hot 95% ethyl alcohol over them. This treatment prevented contraction of the animals, thus providing good preparation of specimens that were to be measured. Once the alcohol had cooled, the specimens were transferred to vials with fresh 95% alcohol and stored until measurement and subsequent mounting.

It was felt that this method of preservation gave a more natural size measurement. Placing the animals on slides and pressing on a coverslip expands sutures and head capsule beyond their normal size. The alcohol preserved individuals were therefore measured before mounting under a dissecting microscope at 16x, using an ocular micrometer with 100 divisions per millimeter. The data thus obtained were converted to microns carried to the second decimal place.

Permanent slide mounts were made using CMC-10*. The mounting procedure was similar to that reported by Snider (1967). All specimens were mounted ventral side up, allowing rapid sex determination. As the slide preparation "cured," the CMC-10 penetrated the specimens and all external anatomical characters were easily observed.

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X. INSTAR DURATION

Mass Cultures

The duration of the stages of O. justi porteri is clearly influenced by temperature (Table XII). While animals reared at 70° and 80°F remain in each instar for a somewhat similar length of time, individuals at 60°F show a greatly extended duration of the stages. At the same time the range of variability in duration increases with rising temperature (Appendices XIV, XV and XVI). Graph 39 presents the duration of each instar in mass culture at three temperatures. While the 70° and 80°F cultures follow a gradual fluctuation in instar duration over long periods of time, the animals at 60°F begin to exhibit a definite rhythm after the 25th instar. It should be pointed out that daily samples taken from the time period shown on the graph reduced the number of individuals in each culture.

Low Number Cultures

Cultures containing five or less individuals (Table XIII) again show similar instar durations at 70° and 80°F. Here, as in the mass reared series, the 60°F populations exhibit longer instar durations. The range of variation between individual instars is less in these cultures (Appendices XVII, XVIII and XIX). Graph 40 illustrates clearly that the 70° and 80°F populations depict the same gradual fluctuation of instar duration shown previously in Graph 39. The 60°F cultures, from the sixth to the thirty-eighth instar, definitely show a time rhythm of alternating long and short periods.

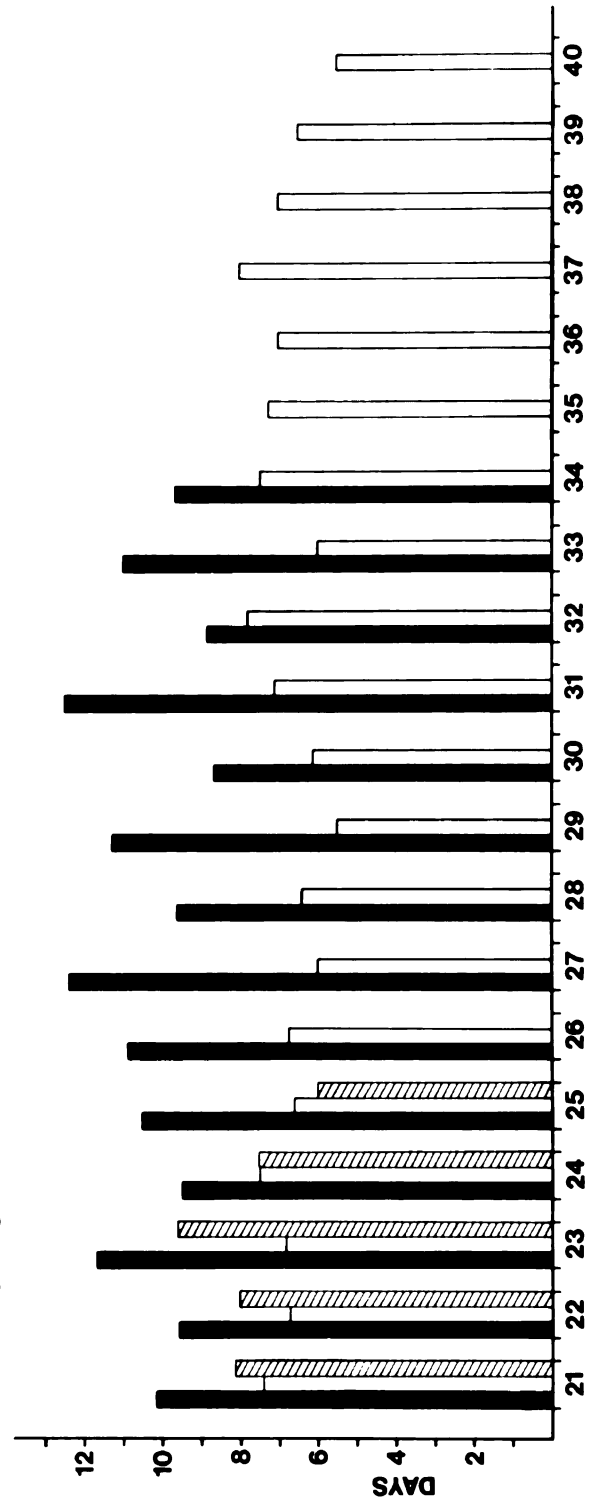
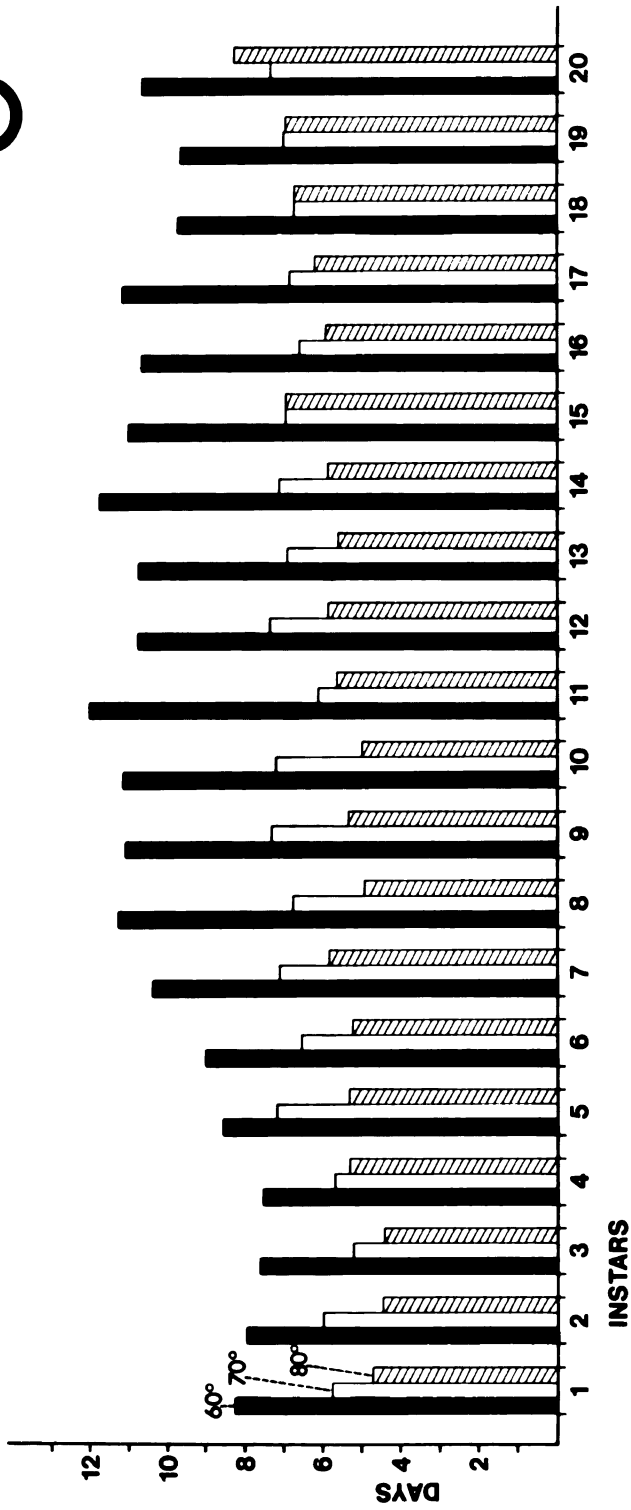
TABLE XII. Summary of instar duration averages at 60°, 70° and 80°F, for mass reared cultures of Onychiurus justus porteri.

Instar	Average in days		
	60°F	70°F	80°F
1	8,27	5,75	4,72
2	7,94	6,00	4,44
3	7,61	5,17	4,44
4	7,55	5,68	5,33
5	8,38	7,20	5,33
6	9,00	6,58	5,22
7	10,38	7,10	5,83
8	11,22	6,75	4,94
9	11,05	7,32	5,33
10	11,16	7,21	5,00
11	12,00	6,10	5,66
12	10,76	7,37	5,83
13	10,77	6,91	5,61
14	11,76	7,16	5,94
15	11,00	6,95	6,96
16	10,64	6,59	5,93
17	11,17	6,84	6,21
18	9,73	6,72	6,72
19	9,66	7,00	6,90
20	10,66	7,37	8,30
21	10,13	7,40	8,11
22	9,57	6,71	8,00
23	11,64	6,81	9,60
24	9,46	7,40	7,50
25	10,50	6,62	6,00
26	10,90	6,75	
27	12,40	6,00	
28	9,62	6,42	
29	11,28	5,71	
30	8,66	6,14	
31	12,50	7,16	
32	8,83	7,80	
33	11,00	6,00	
34	9,66	7,50	
35	(16,00)	7,25	
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37		8,00	
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40		5,50	

TABLE XIII. Summary of instar duration averages at 60°, 70° and 80°F, for cultures containing five or less individuals of Onychiurus justus porteri.

Instar	Average in days		
	60°F	70°F	80°F
1	8,37	6,00	2,70
2	8,12	5,75	4,30
3	8,25	,537	4,90
4	8,37	5,75	4,00
5	8,62	6,87	6,00
6	10,25	7,75	5,80
7	8,00	6,12	5,55
8	12,12	8,12	6,00
9	8,62	8,37	5,75
10	12,25	7,42	6,50
11	9,00	7,28	6,62
12	11,75	7,85	6,37
13	8,87	7,28	5,85
14	11,00	7,28	7,85
15	10,12	6,42	6,85
16	10,12	7,28	7,14
17	10,75	7,28	8,00
18	8,14	6,57	8,00
19	9,57	9,00	6,66
20	7,28	6,85	6,66
21	10,57	7,57	6,80
22	9,00	9,00	6,20
23	10,57	7,71	9,00
24	7,42	7,14	6,00
25	11,66	6,71	6,80
26	8,33	6,57	9,66
27	12,66	7,40	8,50
28	8,00	6,50	
29	11,83	5,33	
30	8,33	7,33	
31	12,00	7,00	
32	8,33	6,66	
33	13,00	7,00	
34	8,83	6,00	
35	12,66	7,33	
36	8,83	7,00	
37	11,33	6,50	
38	8,66	8,00	

39



Graph 39. *Onychiurus justus porteri*, instar duration (in days) of mass reared individuals at 60°, 70° and 80°F.

Cultures of Pairs

Cultures containing one male and one female eventually established a clearer picture of instar duration. Table XIV demonstrates that at 70°F the animals behaved in a basic pattern similar to the mass and low number reared cultures. The 80°F cultures did not exhibit any particular rhythm, and could be best described as erratic. Animals kept at 60°F, after the sixth instar, displayed the long-short rhythm of the low number reared series (Graph 41). The range of variation in instar duration was greater than in the two previous experiments (Appendices XX, XXI and XXII).

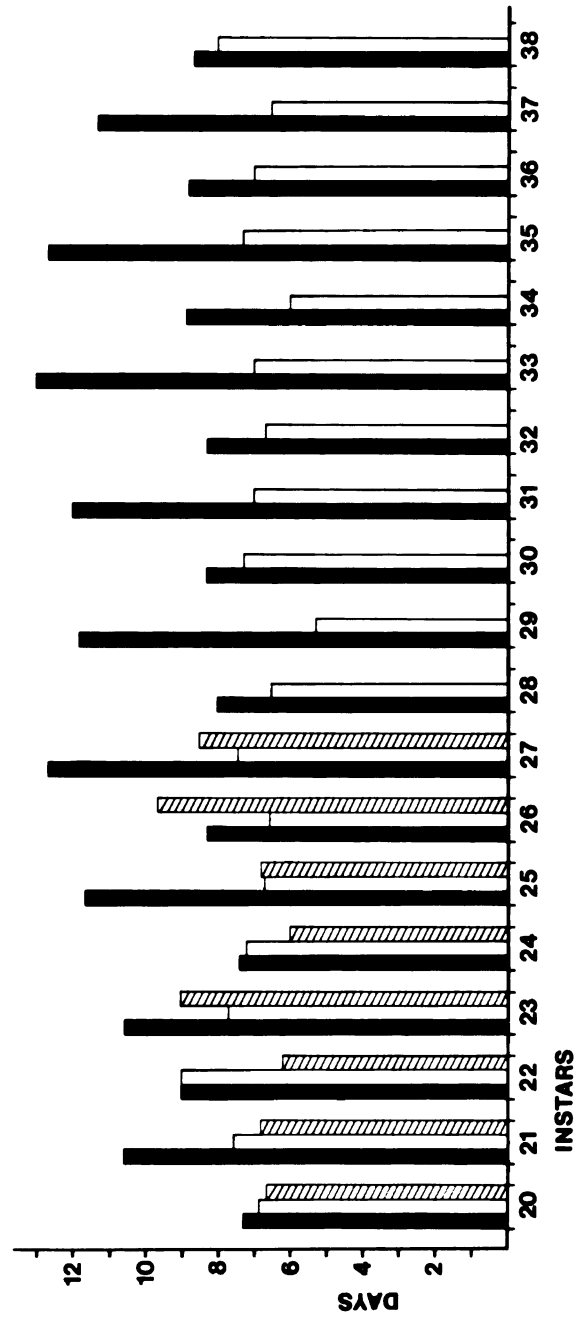
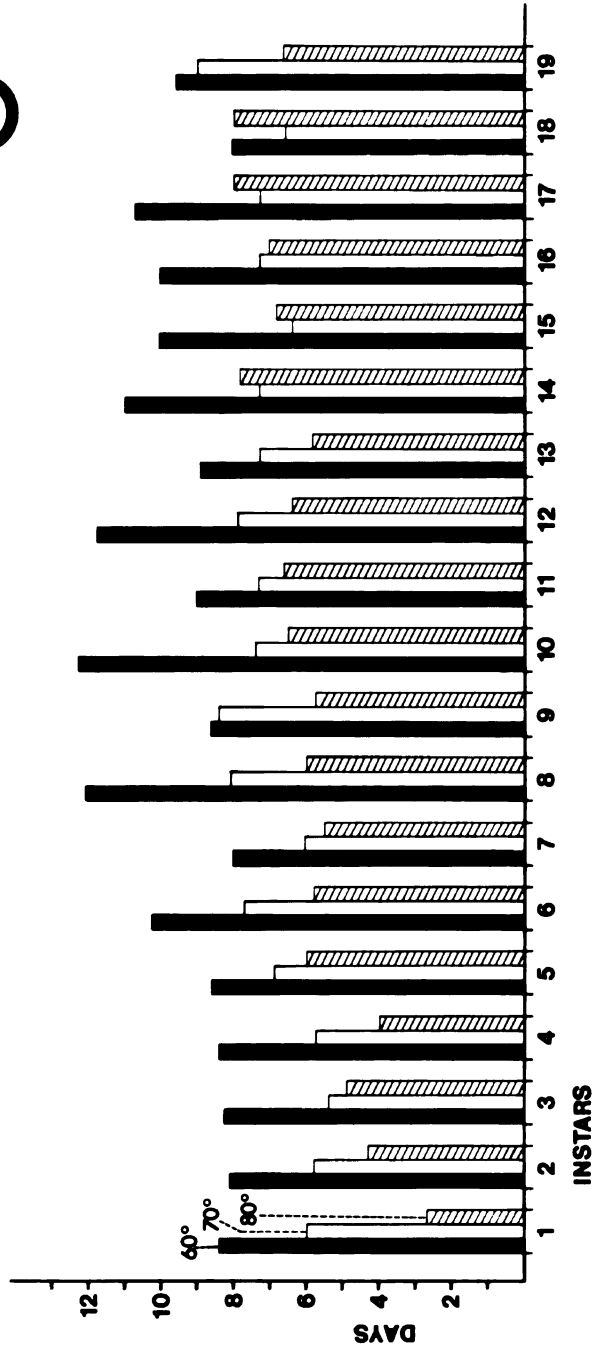
TABLE XIV. Average instar duration, in days, for pairs of male and female of Onychiurus justus porteri.

Instar	Pairs		
	60°F	70°F	80°F
1	9,14	5,53	6,00
2	9,57	5,64	6,00
3	11,14	5,89	6,14
4	10,85	6,14	5,57
5	10,07	6,21	9,57
6	11,92	6,67	13,57
7	10,78	7,00	12,66
8	12,42	7,21	16,00
9	10,69	6,44	9,83
10	11,33	6,69	7,40
11	10,70	6,38	13,66
12	9,90	7,05	14,66
13	11,60	7,22	12,50
14	10,60	7,17	7,00
15	12,40	7,85	(9,00)
16	11,11	7,91	(9,00)
17	12,00	6,18	
18	11,00	8,28	
19	13,00	5,60	
20	9,00	7,00	
21	12,50		
22	9,50		
23	13,50		
24	12,00		
25	(8,00)		
26	(10,00)		

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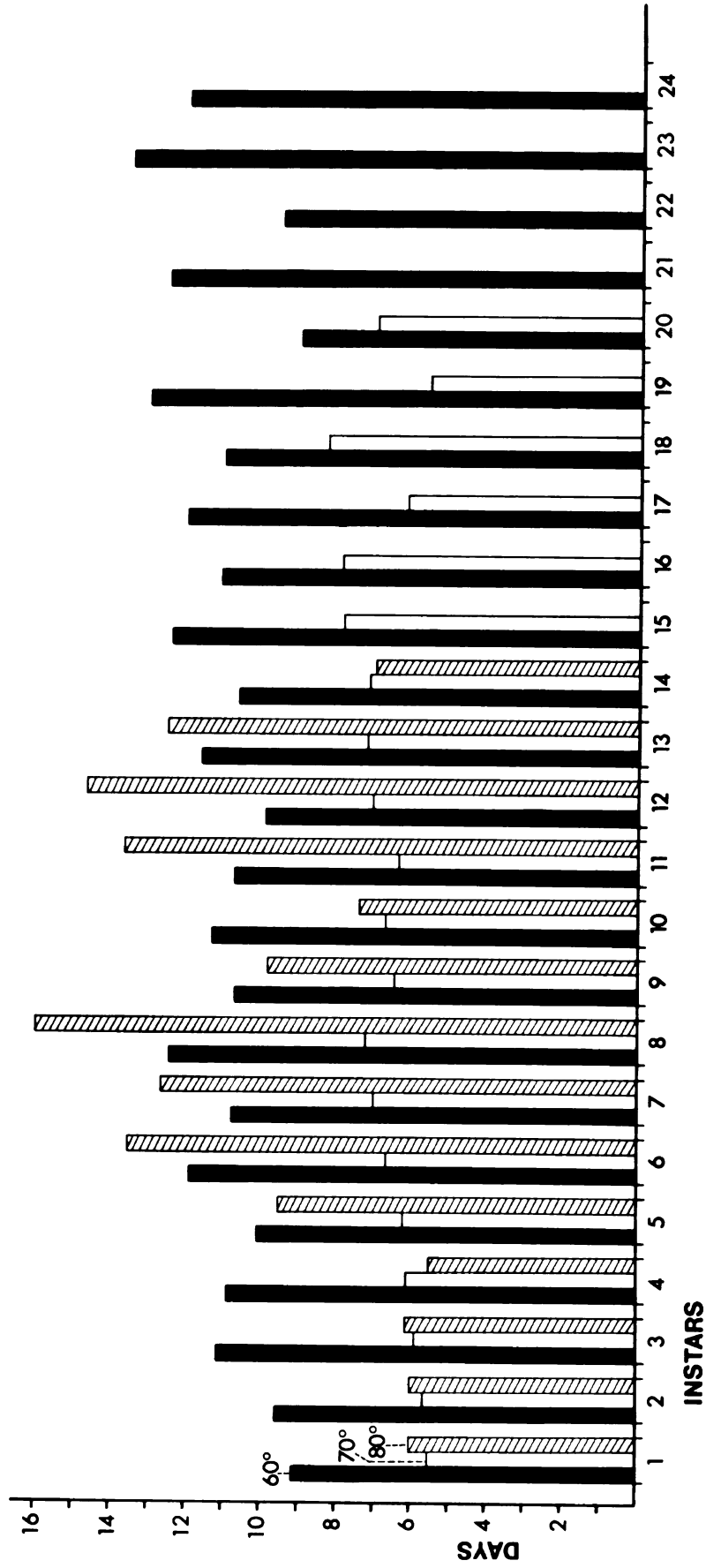
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Graph 40. *Onychiurus justii porteri*, instar duration (in days) of low number reared individuals at 60°, 70° and 80°F.

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Graph 41. *Onychiurus justus porteri*, instar duration (in days) of pairs of males and females reared at 60°, 70° and 80°F.

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It is essential to comment here on what appears to be a clearcut rhythm in instar duration. Recalling the data presented so far, both the temperature and the population density seem to influence the duration of the stages. Another important factor is the sex ratio. The following series of experiments were conducted to determine what role, if any, the influence of members of the opposite sex played in instar duration.

Instar Duration of Single Males and Females

Cultures of single males and single females were set up at 60°, 70° and 80°F and checked daily. Table XV summarizes the instar duration data for these individuals at three temperatures. At all temperatures and in both sexes the length of the stages increased over the figures given for pairs (Table XIV). The range of variation was also very wide (Appendices XXIII, XXIV, XXV, XXVI, XXVII, and XXVIII). Graphs 42, 43 and 44 illustrate the fluctuation in the stages of single males and females at three temperatures. No particular rhythm can be detected other than a gradual fluctuation over long periods of time. Duration of the instars in the female is in most cases longer than in the male.

Instar Duration in Pairs of Males and Pairs of Females

To eliminate the possibility that companionship may produce a rhythmical variation in the length of the stages, pairs of males and pairs of females were observed at 60° and 70°F. Table XVI exemplifies the similarity in the duration of the instars in male and female pairs (Appendices XXIX, XXX, XXXI and XXXII). Clearly there appears no distinct periodicity (Graphs 45 and 46).

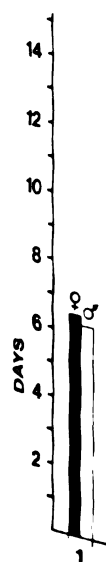
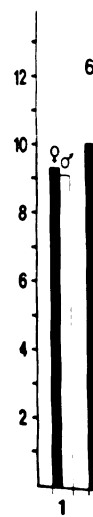
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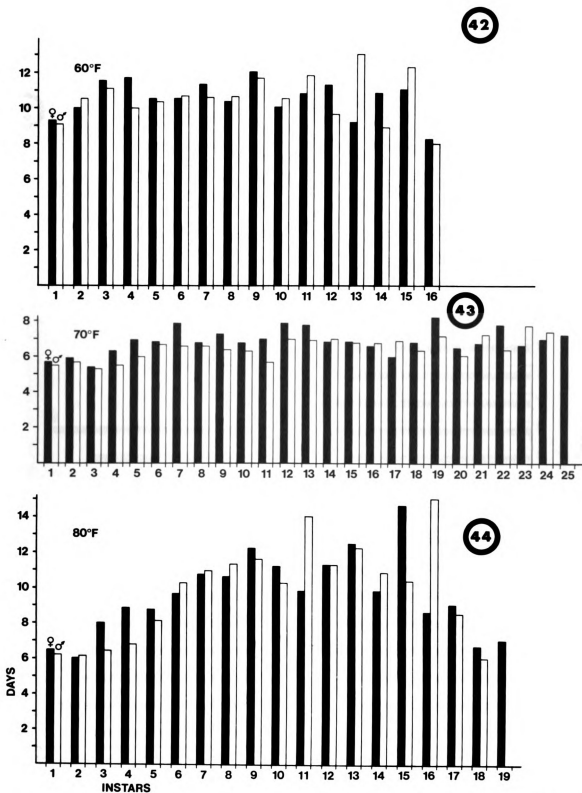
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TABLE XV. Average instar durations, in days, for isolated males and females of Onychiurus justus porteri.

Instar	Single females			Single males		
	60°F	70°F	80°F	60°F	70°F	80°F
1	9,30	5,70	6,47	9,11	5,50	6,30
2	10,04	5,90	6,00	10,55	5,70	6,13
3	11,57	5,40	8,00	11,11	5,30	6,43
4	11,71	6,30	8,86	10,00	5,50	6,80
5	10,54	6,95	8,78	10,38	6,00	8,13
6	10,56	6,85	9,63	10,69	6,70	10,24
7	11,34	7,90	10,72	10,61	6,60	10,96
8	10,39	6,80	10,59	10,65	6,60	11,33
9	12,05	7,31	12,22	11,68	6,40	11,61
10	10,07	6,78	11,21	10,54	6,36	10,26
11	10,82	7,00	9,82	11,94	5,72	14,10
12	11,33	7,92	11,25	9,62	7,00	11,23
13	9,20	7,80	12,46	13,07	6,94	12,21
14	10,83	6,85	9,77	8,91	7,00	10,80
15	11,16	6,83	14,62	12,33	6,80	10,37
16	8,25	6,60	8,60	(8,00)	6,77	15,12
17		6,00	9,00		6,88	8,50
18		6,80	6,66		6,35	6,00
19		8,25	7,00		7,18	(5,00)
20		6,50	(6,00)		6,06	(8,00)
21		6,75			7,26	
22		7,75			6,40	
23		6,66			7,73	
24		7,00			7,40	
25					7,23	
26					6,57	
27					7,60	
28					7,00	



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Graphs 42 to 44. *Onychiurus justus porteri*, instar duration of single males and single females reared at 60°, 70° and 80°F.

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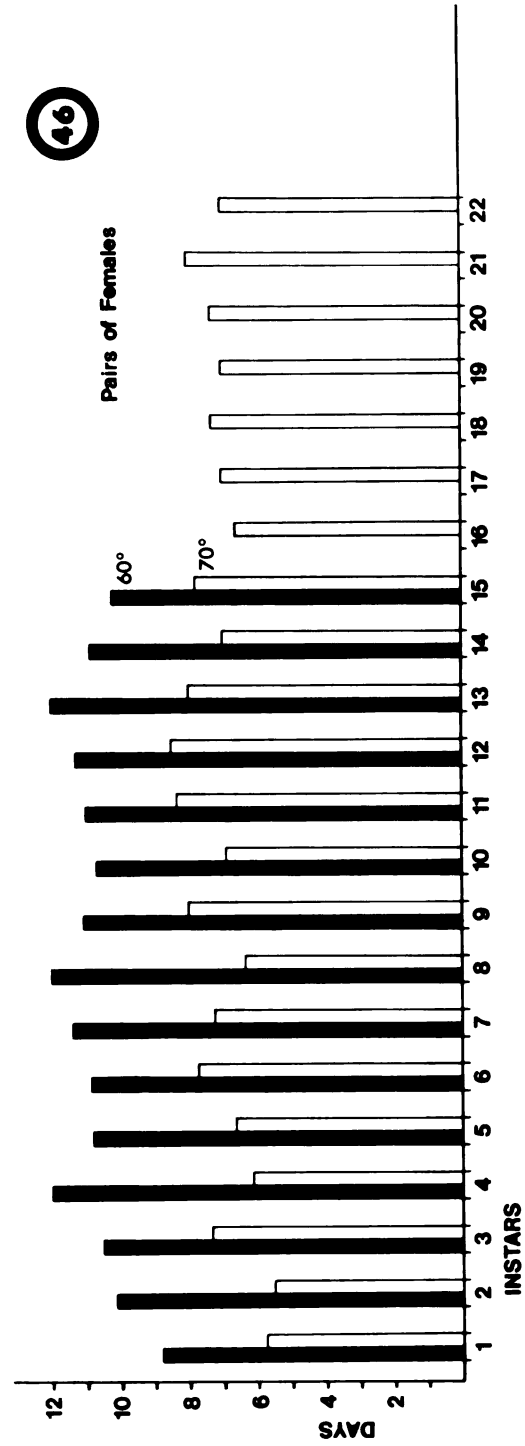
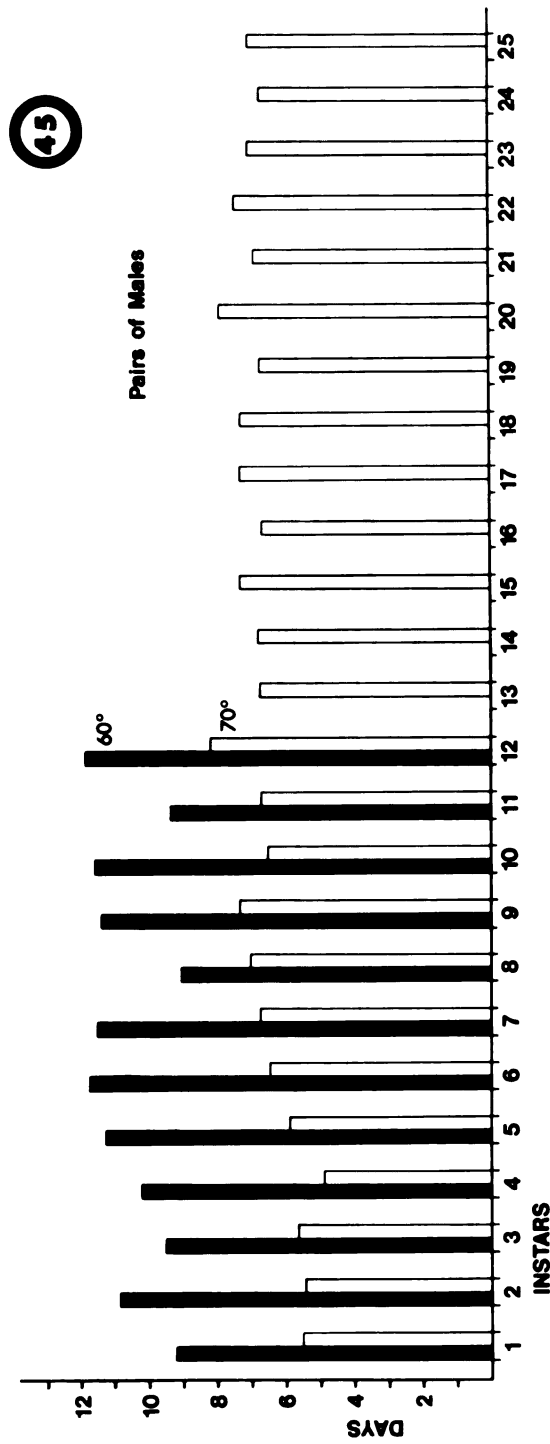
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Graph 45. Onychiurus justii porteri, instar duration of pairs of males reared at 60° and 70°F.
 Graph 46. Onychiurus justii porteri, instar duration of pairs of females reared at 60° and 70°F.

TABLE XVI. Average instar durations, in days, for pairs of males (2) and pairs of females (2), of Onychiurus justus porteri.

Instar	Two males		Two females	
	60°F	70°F	60°F	70°F
1	9,22	5,55	8,80	5,75
2	10,88	5,44	10,13	5,50
3	9,55	5,66	10,53	7,37
4	10,22	4,88	12,00	6,12
5	11,25	5,88	10,80	6,62
6	11,75	6,44	10,86	7,75
7	11,50	6,77	11,40	7,25
8	9,00	7,00	12,00	6,37
9	11,37	7,33	11,07	8,00
10	11,57	6,44	10,66	6,87
11	9,33	6,66	11,00	8,37
12	11,80	8,11	11,27	8,50
13	12,80	6,66	12,00	8,00
14	(10,00)	6,77	10,87	7,00
15	(9,50)	7,25	10,20	7,80
16	(8,00)	6,62	(11,00)	6,60
17		7,25		7,00
18		7,25		7,33
19		6,66		7,00
20		7,83		7,33
21		6,83		8,00
22		7,40		7,00
23		7,00		
24		6,66		
25		7,00		
26		7,00		
27		6,50		

Discussion

The data dealing with instar duration at constant temperatures have depicted three possible factors controlling the length of the stages. The obvious one is temperature, followed by population density and sexual responses. In large mass cultures no particular rhythm is apparent after the first six instars, not until the density of the populations has decreased. As previously mentioned, Green (1964 b) has

related crowding to fecundity. In addition, Waldorf (1971 a) found that males were responsive to females by their instinctive ability to sense when a female was about to moult. Mayer (1957) discovered that females of Orchesella villosa (Geoffroy) had inter-moult periods of uniform length, but that the males exhibited alternating long and short periods. This rhythm was said to be associated with spermatophore deposition. In low number reared and paired cultures of O. justi porteri, the rhythm of long and short instar duration was most apparent at 60°F. Subsequent observations demonstrated that neither single nor paired males and females produce such a rhythm. In none of the 70° and 80°F cultures were definitely alternating long and short periods observed.

These data lead to the belief that the optimum temperature for O. justi porteri lies near 60°F. And that the presence of males in whatever ratio may induce in the females, as well as in themselves, long and short instar durations correlated with reproduction. Upon re-examination of Graphs 9 to 13, it appears that egg laying occurs at the same time as a long period in instar duration.

According to Hale (1965 c) there is a gradual increase in the duration of successive instars from the first instar to maturity. He presents data for Protaphorura latus, P. procampatus, P. tricampatus and P. furcifer, all of which exhibited that trend. Choudhuri (1961) presents similar data for P. fimatus, P. parthenogeneticus and P. imperfectus. In the present investigation, O. justi porteri does not gradually increase the duration of its stages from the first instar on. On the contrary, the first instar is longer than the second. In the case of mass cultured individuals, duration averages decrease until the fourth instar and then gradually increase to the eighth instar. This same trend was observed in the low number and paired cultures. For O. bhattii Yosii, Ashraf (1969) reported

a longer duration of the first instar as compared to the following instars. In two other cases this pattern was noted; for Hypogastrura manubrialis by Vail (1965) and for Isotoma notabilis by Sharma and Kevan (1963 a).

XI. GROWTH

Introduction

Most of the literature discussing collembolan growth is concerned with the first four to six instars (Ashraf, 1969; Milne, 1960; Davis and Harris, 1936; Britt, 1951; Vail, 1965; Sharma, 1967 a; Marshall and Kevan, 1962; Sharma and Kevan, 1963 a,b; MacLagan, 1932; Ripper, 1930; Uchida and Chiba, 1958; Agrell, 1948; Strebel, 1932; James, 1933; South, 1961; Falkenhan, 1932; Handschin, 1926; Thibaud, 1968 a,b, 1969; Hale 1965 c; Pedigo, 1967). Only a few exceptions are to be found (Hale, 1965 c; Green, 1964 a; Uchida and Hongo, 1962). In a majority of the above cited investigations, growth was not observed beyond the adult instar. By definition, that would be the instar where egg laying and spermatophore deposition begin. Petersen (1970, In Press) did not use instar designation in the presentation of his data on the growth of Protaphorura furcifer. He considered the instars to be too variable and instead used total body length in his measurements. His study was concluded after approximately 100 days at 15°C (60°C).

Methods

All measurements of body length, head width and head length were made with an ocular micrometer, using specimens taken from mass cultures. Later,

slide preparations of the same specimens were examined to determine sex and morphological characteristics. Both anatomical and size criteria were established to classify the first six instars; thereafter only measurements and sample data were used to recognize a given instar. Since samples were taken daily, it was relatively easy to remove freshly moulted specimens from the cultures.

Head Length and Width of the First Six Instars

Table XVII gives a summary of data for the first six instars in O. justl porteri until attainment of maximum size in the head capsule. Comparison of standard deviation figures indicates that head width measurements are more reliable than head length.

TABLE XVII. Mean head length and head width, in microns, for the first six instars of mass reared individuals of Onychiurus justl porteri. (Standard deviation in parenthesis below, $\log_{10}N$ above each figure).

INSTAR	1	2	3	4	5	6
60°F	2,00 101,96 (8,94)	2,23 171,28 (17,62)	2,32 213,55 (21,90)	2,40 252,83 (12,07)	2,43 272,53 (19,23)	2,49 314,59 (19,27)
70°F	2,06 116,15 (9,03)	2,21 162,72 (11,95)	2,31 204,22 (16,41)	2,39 246,92 (16,45)	2,44 279,54 (19,93)	2,48 306,89 (19,33)
80°F	2,07 119,95 (14,71)	2,20 160,67 (13,48)	2,26 184,01 (18,68)	2,36 230,44 (17,95)	2,41 258,68 (16,86)	2,44 278,52 (18,07)
60°F	2,12 132,16 (2,46)	2,28 192,81 (17,25)	2,36 230,28 (15,17)	2,44 280,07 (13,61)	2,49 311,33 (18,45)	2,54 347,10 (12,90)
70°F	2,14 140,40 (5,41)	2,24 175,84 (9,86)	2,35 225,72 (10,30)	2,42 267,71 (11,65)	2,48 306,29 (13,96)	2,52 338,56 (11,28)
80°F	2,15 144,10 (7,26)	2,23 173,60 (12,49)	2,32 210,30 (11,56)	2,41 261,57 (9,80)	2,45 283,08 (16,45)	2,49 311,07 (16,03)

The range of individual variation increases with temperature (Appendices XXXIII, XXXIV, and XXXV).

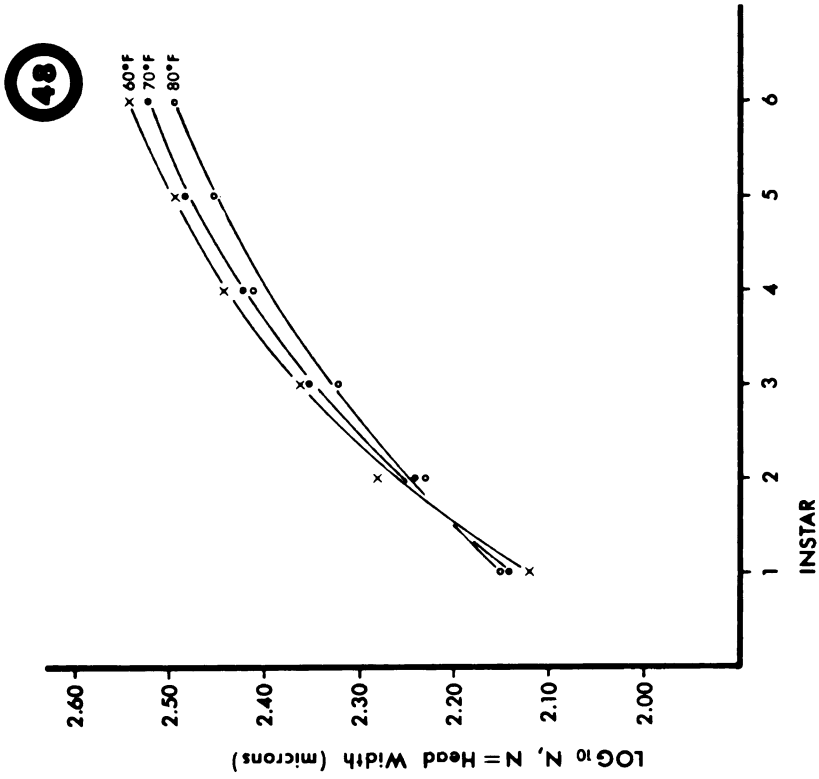
Hale (1965 c), Ashraf (1969) and Thibaud (1969) have presented their data on the first six instars in logarithmic form. Agrell (1948) proved that three species studied by him conformed to Dyar's Rule (1890). Graphs 47 and 48 illustrate the linear growth of the first six instars of O. justi porteri. The curves obtained are similar to those given by Thibaud (1969) for Typhlogastrura balazuci Delamare-Deboutteville. It would appear that Dyar's Rule is valid for the first six instars of O. justi porteri.

Hale (1965 c) states for four species of Protaphorura that egg laying did not begin until they had reached maximum size (based on head capsule measurements). Ashraf (1969) indicates that Onychiurus bhattii passes through four instars before reaching sexual maturity and maximum head width in the fifth. In the present study the concept of maximum size coinciding with sexual maturity does not hold true. Graphs 6, 7, and 8 show that egg production begins in the fifth instar at 60°F and in the fourth instar at 70° and 80°F, at a time when growth is far from complete.

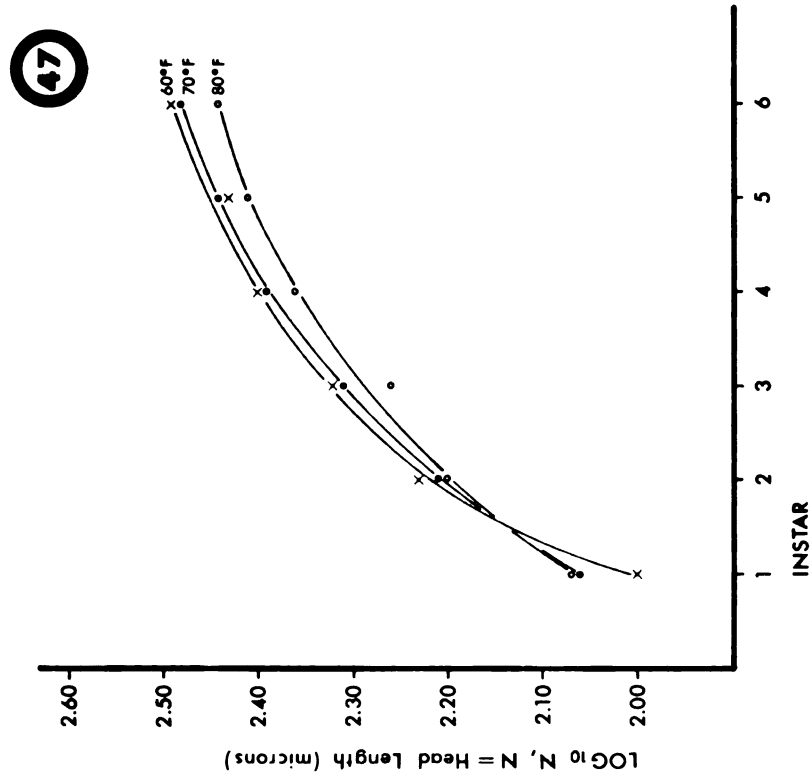
Growth: Over-all Length

The size of each instar in total body length was obtained by adding the figures for head length and body length for each individual. Graphs 49, 50 and 51 illustrate over-all length at three temperatures for cultures of mixed sex, and includes the ranges at each instar. It should be noted that with progressing age size variation increases with each instar (Appendices XXXVI, XXXVII and XXXVIII).

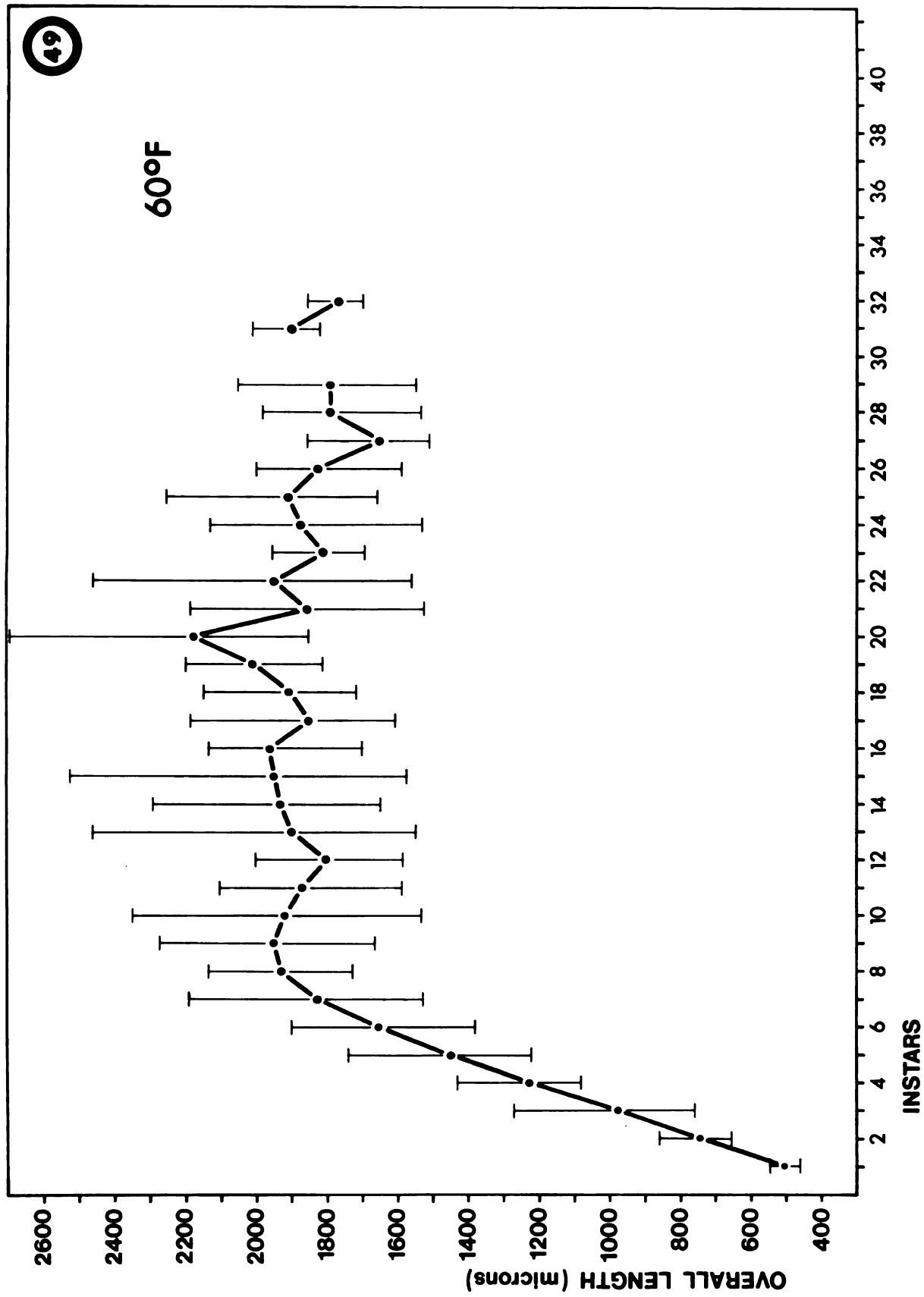
Petersen (1970 In Press) described a significant difference in growth



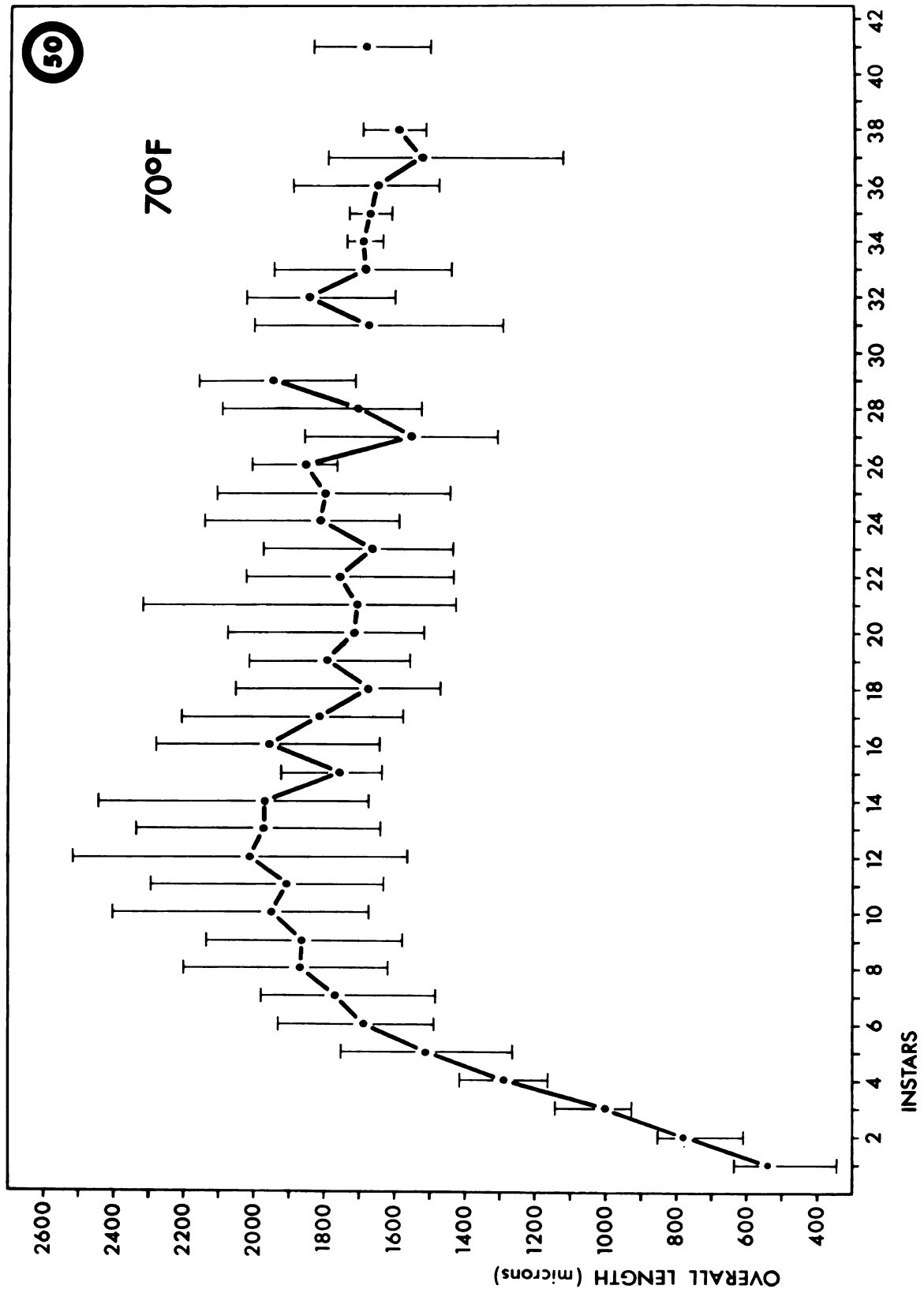
Graph 48. Onychiurus justus porteri, $\text{Log}_{10} N$ of the head width for the first six instars reared at 60°, 70° and 80°F.



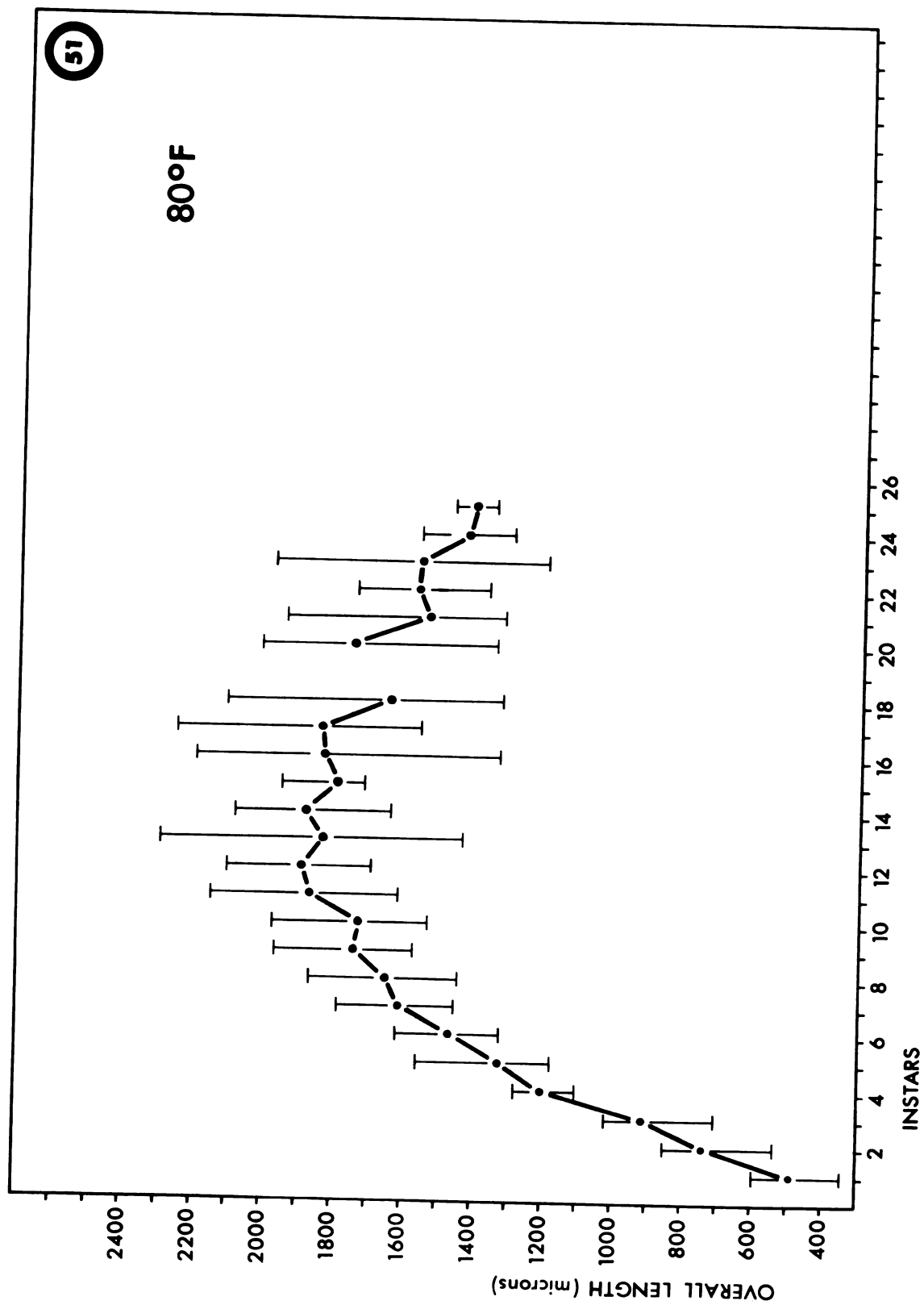
Graph 47. Onychiurus justus porteri, $\text{Log}_{10} N$ of the head length for the first six instars reared at 60°, 70° and 80°F.



Graph 49. *Onychiurus justiporleri*, overall length (in microns) per instar of individuals reared in mass culture at 60°F.



Graph 50. *Onychiurus justus porteri*, overall length (in microns) per instar of individuals reared in mass culture at 70°F.



Graph 51. *Onychiurus justii porteri*, overall length (in microns) per instar of individuals reared in mass culture at 80°F.

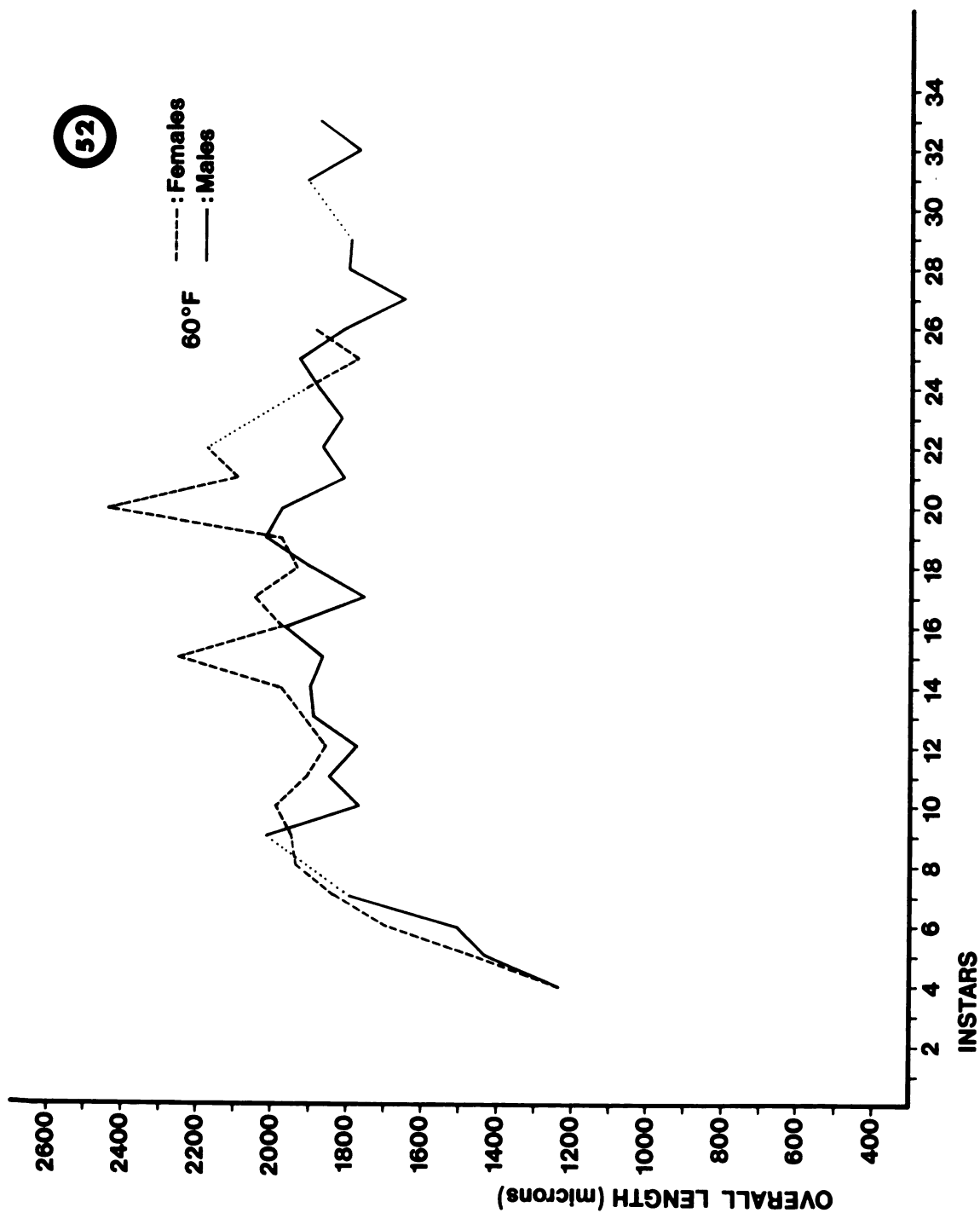
rate between males and females of Protaphorura furcifer. When the data for O. justl porteri were separated according to sex, the same divergence in the growth patterns was found. Graphs 52, 53 and 54 indicate male and female growth. Compared with the graphs for combined sexes, separation of the sexes in the analysis of the data led to narrower size ranges at each instar (Appendices XXXIX, XL, and XLI).

Discussion

In the literature there is frequent reference to the attainment of maximum size together with sexual maturity (Hale 1965 c; Ashraf, 1969). From the data gathered in this investigation, maximum size apparently is not reached until a later instar, irregardless of head capsule size. Previous investigators have based their statements on head capsule measurements and a limited observation of the animal's life history. Petersen (1970 In Press) demonstrated for P. furcifer a growth pattern similar to the one in O. justl porteri. He states that it took 100 days to reach maximum body size at 15°C (60°F), a time period corresponding to the 12th instar of O. justl porteri at 60°F, and in particular relating to the females. At the same time, the males undergo a decrease in average size (Graph 52).

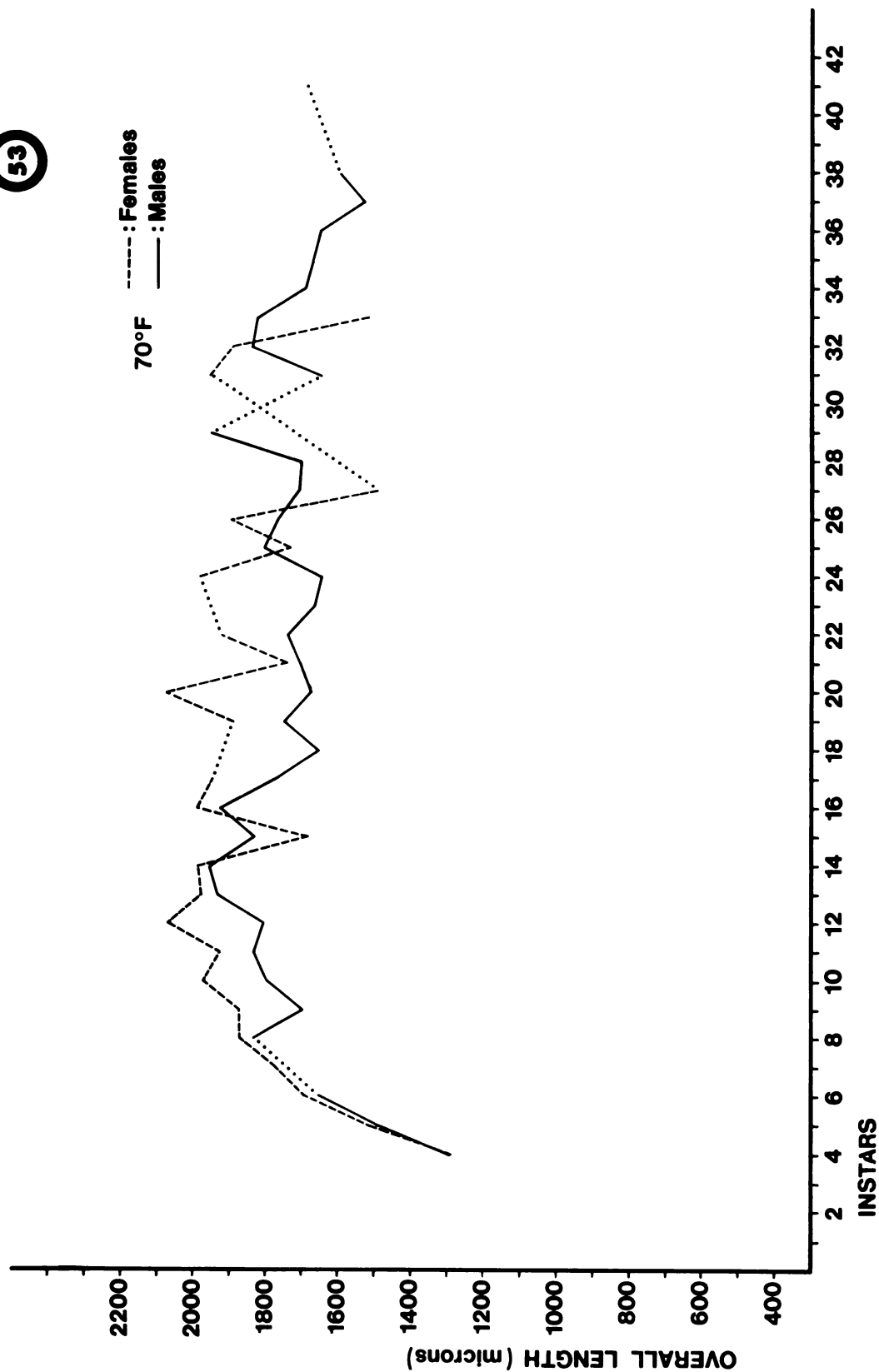
Maximum size in O. justl porteri is reached in the 12th to 14th instar. Thereafter there is a gradual decrease in size of both male and female individuals at all temperatures. The females develop more rapidly than the males and attain a larger size. Graphs 52 and 53 indicate that the males live longer than the females. At 80°F the life history ends in the 26th instar, probably due to the lethal influence of the temperature.

One aspect of growth not observed in other studies is retrograde



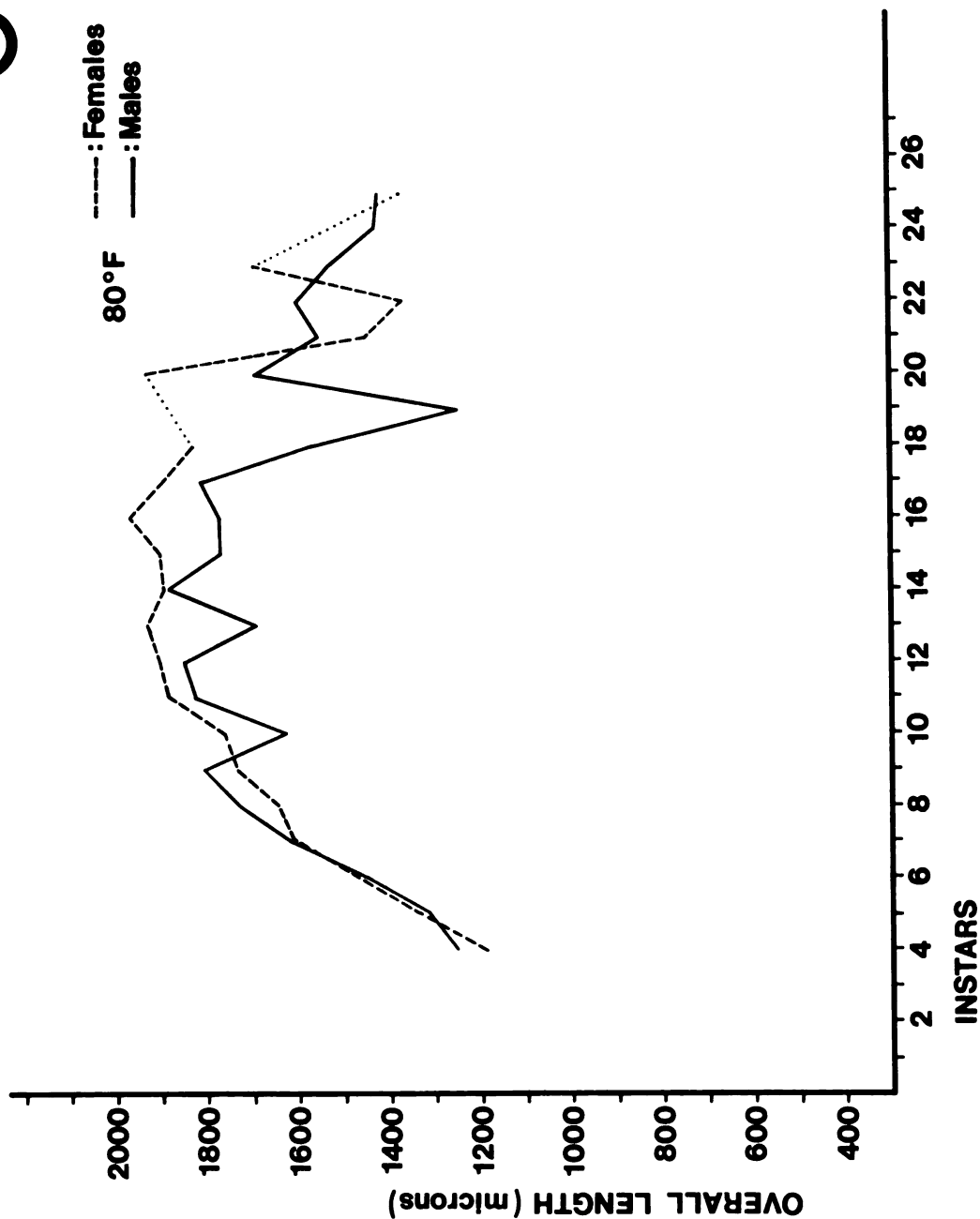
Graph 52. Onychiurus justiporterii, overall length (in microns) per instar of males and females reared in mass culture at 60°F

53



Graph 53. Onychiurus justiporteri, overall length (in microns) per instar of males and females reared in mass culture at 70°F.

54



Graph 54. Onychiurus justus porteri, overall length (in microns) per instar of males and females reared in mass culture at 80°F.

development. Data for O. justi porteri at all three temperatures prove that after the attainment of maximum size there is a steady decline in body length with successive instars. This phenomenon is most apparent at 70° and 80°F. At 60°F (Graph 52) size decrease in the female does not occur until after the 20th instar. It is known that clothes moths and carpet beetles will continue to moult under starvation conditions (Frost, 1942). However, in this study, food was provided throughout the life of the animals.

There is a possible correlation between egg production and retrograde development in O. justi porteri. Graphs 9, 11 and 12 for egg production show the peak periods in egg laying. As fecundity decreases, the average body length of the animals decreases as well (Graphs 49, 50 and 51). There appears to be a relationship between sexual activity, metabolism and age.

The information presented leads to the conclusion that the use of size categories for the assessment of age groups in field populations of Collembola could result in erroneous data. The method described by Healey (1967) for estimating age structure in field populations could lead to the inclusion of young adults and senile adults in the same age category.

XII. DEVELOPMENT OF INSTAR CHAETOTAXY

Dorsal Setae of the Fifth Abdominal Segment

The only work considering the development of collembolan chaetotaxy has been furnished by Hale (1965 c). Chaetotaxy and arrangement of the pseudocelli on the fifth abdominal segment had been used by Gisin (1952) in dividing up the Onychiurus armatus group. Gisin (1952) developed a

labelling method for key setae of the fifth abdominal segment; his notation is followed in this study. Figures 41 to 51 illustrate the successive changes in setal pattern for each instar up to the seventh. Solid black illustrated setae are those found on the instar indicated. Open illustrated setae are those lying under the exoskeleton in animals about to moult. Dotted setae are those that appear infrequently in random individuals.

Figures 41 to 51 indicate the addition of setae up to the 5th instar. From that instar on, the normal pattern and the number remain constant. Some variation occurs as to number and position; figures 45, 49 and 51 show possible setal additions. Salmon (1959) points out that the setal pattern of Onychiuridae may vary in number from one side of the body to the other. A similar situation exists in O. justi porteri. Figures 52 and 53 indicate the occurrence of an unequal number of setae on the two sides of the same segment. Likewise the number of pseudocelli may be unequal. Figure 54 shows the three pseudocelli typical of O. justi. This arrangement appeared in only two specimens of O. justi porteri in over 2000 examined during the investigation.

Hale (1965 c) noted that P. furcifer had the fifth abdominal pseudocelli arranged at an angle to the line joining M and M' and not parallel as in the "armatus" group. The same arrangement was found in O. justi porteri (Fig. 51). Hale also indicates that seta s is short in the first instar and becomes increasingly longer with each moult. The first instar of O. justi porteri exhibits a very long seta s which is then reduced in the second instar (Figs. 41, 42 and 43).

Dorsal Setae of the First Thoracic Segment

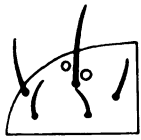
In a taxonomic study evaluating anatomical characteristics, Hale (1968)

Onychiurus just porteri n. ssp. - list of figure captions

Fifth abdominal segment dorsal setal pattern*

41. First instar
42. First instar about to moult
43. Second instar
44. Second instar about to moult
45. Third instar
46. Third instar about to moult
47. Fourth instar
48. Fourth instar about to moult
49. Fifth instar
50. Sixth instar
51. Seventh instar
52. Atypical fifth abdominal segment setal pattern showing unequal number of setae on the same individual.
53. Atypical third abdominal segment setal pattern.
54. Seventh instar individual illustrating the pseudocellar pattern typical of the species.

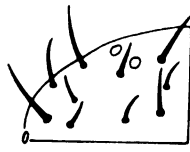
*/ Black setae - typical of the instar indicated; open setae - setal pattern of next instar; dotted setae - setae that can be present or absent.



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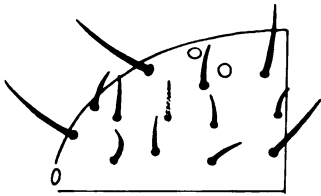
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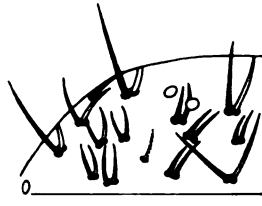
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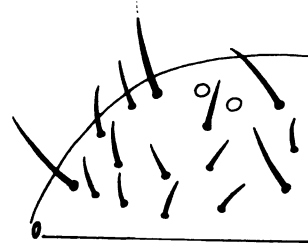
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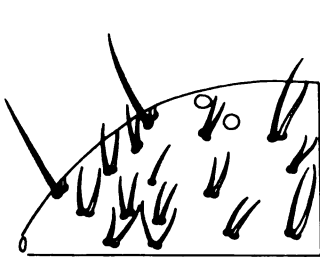
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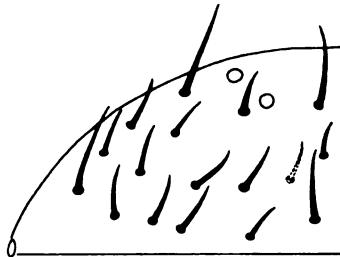
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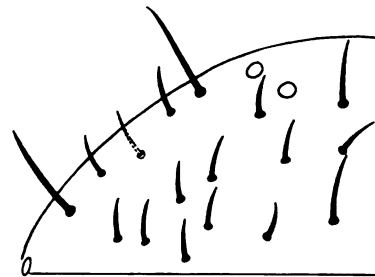
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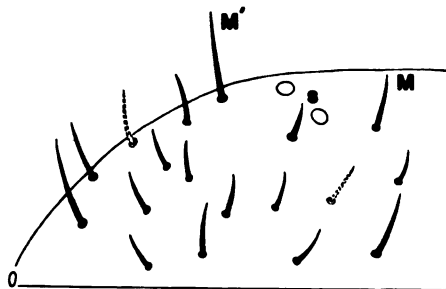
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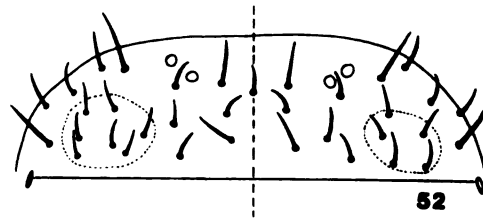
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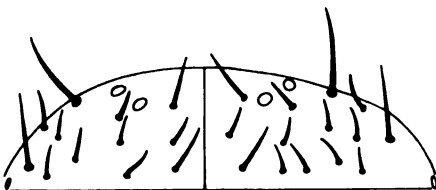
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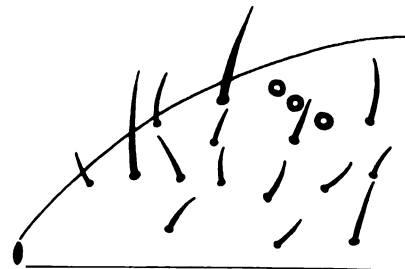
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described the dorsal setae of the first thoracic segment as being too variable for species determination. During this investigation it was thought that the setal pattern of the first thoracic segment might be instar specific, at least to the seventh instar. Figures 55 to 69 illustrate the thoracic setae of the first seven instars of O. justiporteri.

The illustrations indicate that variation from instar to instar and within instars is too great to be of significance. However, the patterns for instars one and two remain characteristic and are used in helping to determine instar number on a morphological basis. Figure 67 illustrates the variations of setae from one side of the body to the other.

Chaetotaxy of the Male and Female Genital Plates

The plates surrounding the genital openings do not develop until the fourth instar, in either of the sexes. Figures 70 to 75 illustrate the development of the setae on the female genital plate from the fourth to the seventh instar. Figures 76 to 81 illustrate the development of the male genital plate setae. Figure 76 shows the male third instar juvenile. A pore is located where, in the next instar, the genital plate will be developed. Figure 77 shows a third instar juvenile about to moult; the fourth instar structures can be seen lying underneath.

The number of setae on the female genital plate increases from the fourth to the seventh instar. Table XVIII indicates the average number of setae per instar, from the fourth to the seventh, and their ranges, demonstrating a certain degree of overlapping between instars; and proving that the number of setae on the genital plates can only be used in conjunction with other morphological criteria in the determination of

Onychiurus just i porteri n. ssp. - list of figure captions

First dorsal thoracic segment setae:

55. First instar

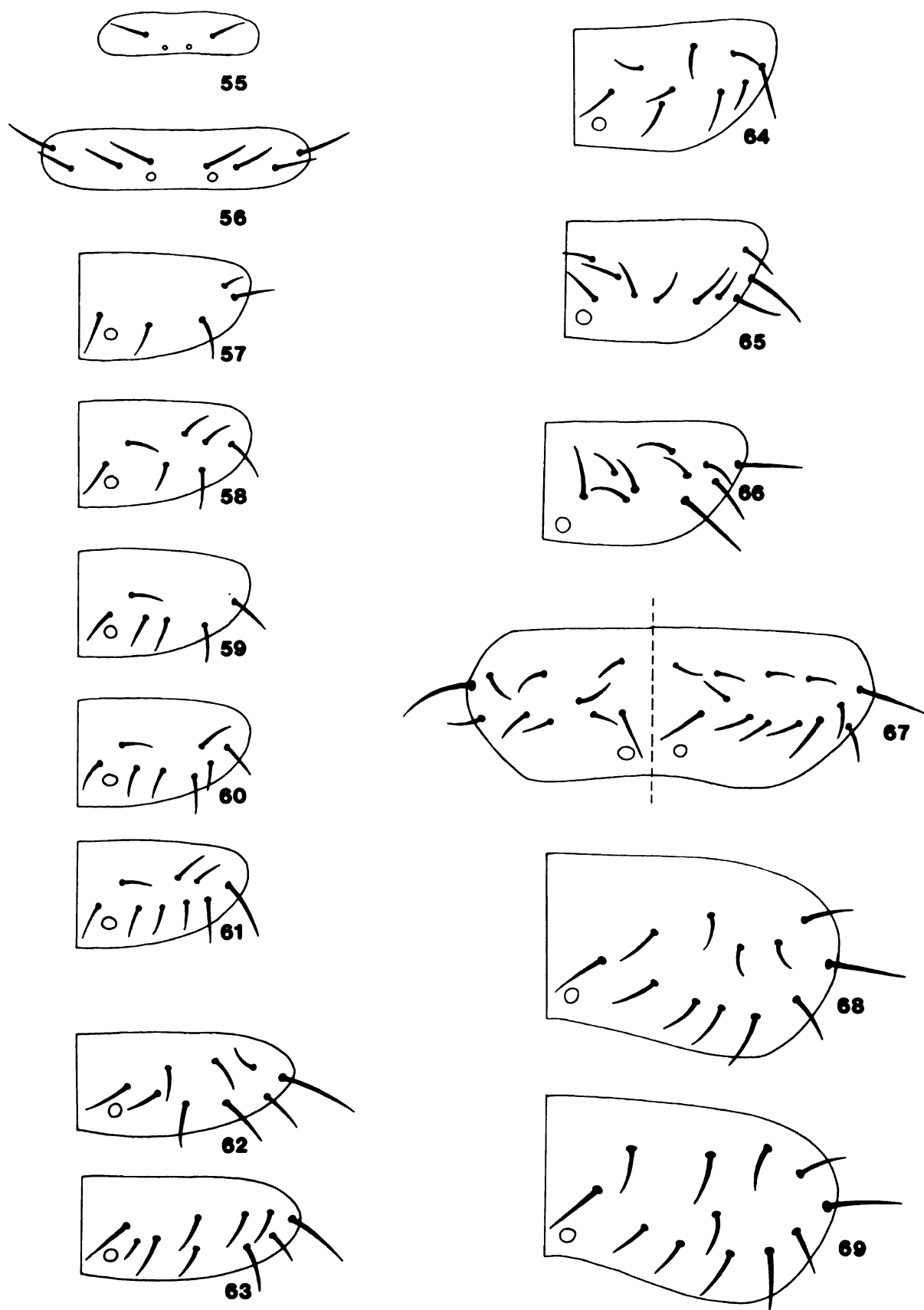
57. - 61. Third instar

62. - 63. Fourth instar

64. - 66. Fifth instar

67. Atypical fifth instar showing unequal number of setae from one side of the body to the other.

68., 69. Sixth instar



Onychiurus just porteri n. ssp. - list of figure captions

Female genital plate setal pattern*

- 70. Fourth instar
- 71. Fourth instar about to moult
- 72. Fifth instar
- 73. Sixth instar
- 74. Sixth instar about to moult
- 75. Seventh instar

Male genital plate setal pattern*

- 76. Third instar (oil)
- 77. Third instar about to moult (oil)
- 78. Fourth instar (oil)
- 79. Fifth instar
- 80. Fifth instar about to moult
- 81. Sixth instar

*/ Black setae represent setal patterns typical of the instar indicated;
open setae represent setal patterns of the next instar.

the first six or seven instars.

TABLE XVIII. Number of setae per instar on the genital plate of Onychiurus justi porteri.

Instar (FEMALES)	4	5	6	7
Average	8,52	16,05	25,10	32,41
Individuals observed	19	34	37	12
Range	6-18	12-20	21-30	30-38
Instar (MALES)	4	5	6	7
Average	24,20	38,75	50,50	-
Individuals observed	15	16	10	-
Range	15-30	36-48	42-57	-

Chaetotaxy of the Male Ventral Organ
of Abdominal Segment II.

The male ventral organ of O. justi porteri is located on the ventral surface of the second abdominal segment. It consists of four (rarely five) setae, larger in diameter than body setae, and arranged in a transverse row. The type of male ventral setae found on O. justi porteri consists of a seta-like thick median shaft, wrapped in a broad cover which is slit longitudinally on one side.

Stach (1954), in his revision of Onychiuridae, did not mention any morphological changes in the male setae. As a result his description and illustrations typify setae of certain size and shape for certain species. The present study shows that the male ventral setae undergo changes from instar to instar. And as the individual reaches senility, bizarre dichotomy of the setae takes place. Figures 76 to 81 illustrate the

changes in shape adopted by the male ventral setae at various instars.

Figures 16, 17, 18 and 19 illustrate setae of two 339 day old individuals reared at 60°F. The general outline is markedly different from fourth instar setae (Fig. 82). Figures 83 to 90 show the variation of the male ventral setae at various instars between the fifth and seventeenth. Figure 91 shows an individual about to moult. The eighteenth instar seta is tightly rolled and long, while the nineteenth instar seta lying underneath is short and lamellate. Figures 92, 93, 94, 95 and 96 show 25th instar male ventral setae, with their outer wrapping split into fragments. This condition is always seen in older individuals.

The examples presented here negate the use of any general description of the male ventral setae for specific identification. Variation within a population is directly related to age of the individual. Stach (1954) did not recognize any such variation in the thousands of samples examined while revising Onychiurus. His specimens were field collections. It would appear that individuals of the age category in which setal variation occurs were not collected; leading to the question whether or not individuals of the 25th to 34th instar occur in nature.

XIII. DIETARY INFLUENCE ON GROWTH AND FECUNDITY

Introduction

Most laboratory studies have attempted to simulate field conditions or at least provide natural foods while manipulating temperature and humidity factors. As a result it is common to use foods such as fungi, yeasts, spores, leaf material and detritus. The influence of specific diets on growth has been, for the most part, a neglected area of investigation. Knight and Angel (1967) cultured Tomocerus flavescens (Tullberg)

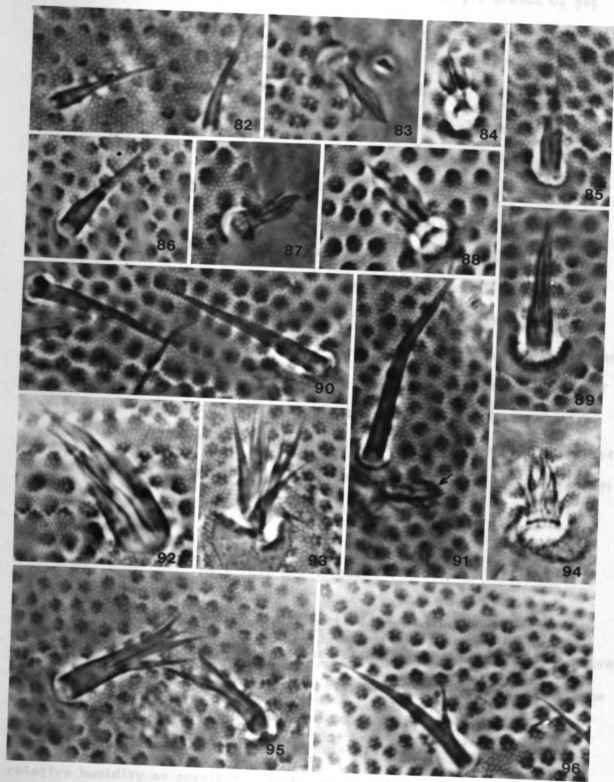
Onychiurus just porteri n. ssp. - list of figure captions

Male ventral setae of the second abdominal segment:

- 82. Fourth instar, lanceolate setae
- 83. Fifth instar, spatulate setae
- 84. Fifth instar, spatulate setae
- 85. Fifth instar, lanceolate setae
- 86. Sixth instar, lanceolate setae
- 87. Sixth instar, spatulate split seta
- 88. Eleventh instar, spatulate seta
- 89. Twelfth instar, lanceolate split seta
- 90. Seventeenth instar, lanceolate setae
- 91. Eighteenth instar about to moult; note (arrow) spatulate seta
formed under lanceolate seta
- 92. - 96. Twenty-fifth instar, split setae typical of senile adults.

on fungi found in Texas

larval preferences by host



selective humidity as possible. The larva was kept in a moist environment of its eggs at 70°F. the eggs hatched. The larva was kept in a moist environment. The larva was reared with a fine needle in a moist environment of its eggs. The larva was reared with a fine needle in a moist environment of its eggs.

on fungi found in forested areas and classified food preference by gut content analysis. However, no studies were pursued to determine the effect of those foods on growth. While studying cellulose decomposition by several species of Collembola, Törne (1967) showed that the population dynamics of the species were regulated by microbial influence on food material in the gut. The effects on fecundity and general biology of Hypogastrura manubrialis (Tullberg) by feeding yeast, liver, mushroom, banana, algae and blood agar base were noted by Vail (1965). He demonstrated that H. manubrialis was a general feeder, but did best on yeast.

Up to the time this investigation commenced, brewer's yeast was used as a basic food source in all the cultures. Where other species in culture were observed, it became increasingly evident that not all of them survive well on yeast. Some populations died out after a brief period of growth, others would not reproduce. It was soon apparent that readily available and uniform food sources needed to be tried. A preliminary testing of food materials other than fungi that might influence growth and fecundity was undertaken.

Materials and Methods

Laboratory cultures of O. justii porteri were maintained at 70°F and used as a source of eggs. The eggs were transferred from the stock cultures with a needle to small containers with plaster-charcoal substrates, of the type previously described. The culture containers were moistened with distilled water at daily intervals to maintain them as close to 100% relative humidity as possible. After an incubation period of 14 days at 70°F, the eggs hatched. The juveniles were floated on water and transferred with a fine needle in groups of 10 to fresh containers. In all,

77 containers with 10 individuals per container (770 individuals) were set up.

The diets used consisted of brewer's yeast, commonly used in many investigations, and two commercially prepared foods designated here as diet "A"* and diet "B"*. A control was set up with no food at all. Diet "A" has the following ingredients: fish meal, fish roe meal, fish liver and glandular meal, typical crayfish meal, dehydrated kelp meal, insect larvae meal, mussel meal, brine shrimp meal, wheat germ and cod liver oil." The ingredients of diet "B" are as follows: "egg yolk, .03% cod liver oil, tapioca, wheat and corn flower and corn starch." Table XIX indicates the guaranteed analysis by the manufacturer for both diets.

TABLE XIX. Constituents of diets "A" and "B" as provided by the manufacturer.

	DIET "A"	DIET "B"
Crude protein	not less than 45%	not less than 3,4%
Crude fat	not less than 4%	not less than 0,9%
Crude fiber	not more than 9%	not more than 0,5%
Ash	not more than 15%	not more than 10%

Small amounts of yeast, diet "A" and diet "B" were added to the cultures each day as required. Food not eaten within 24 hours was removed. If the food showed signs of contamination, it was removed and replaced. As the cultures were examined each day during the 100 days of the experiment, it was a simple matter to scrape the substrate surface to keep it relatively free of molds.

*/ Diets "A" and "B" were manufactured by Hartz Mountain Products Corp., New York, N.Y. 10003

Ultimately, then, there were four runs in the experiment, designated as yeast (15 replicates), diet "A" (25 replicates), diet "B" (30 replicates) and control (7 replicates). The number of individuals observed is indicated in Table XX.

TABLE XX. Number of individuals of Onychiurus justus porteri used per diet.

Diet "A"	250
Diet "B"	300
Yeast (brewer's)	150
Control (no food)	70

Total individuals = 770

As deaths occurred, the bodies were removed and their number noted. Ecdyses were recorded by counting and removing the exuviae. The number of eggs laid were recorded by batch. Once the eggs hatched, the juveniles were counted and killed. All individuals surviving to the end of the experiment were preserved in hot 95% ethanol for later measurement with an ocular micrometer.

Results

As previously mentioned, the eggs took 14 days to hatch at 70°F. The following table (XXI) shows the duration of instars for each of the four runs.

TABLE XXI. Instar duration in days (average of all replicates per diet)

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Control	6,9	8,4	10,6	8,3	8,4	9,9	8,4	7,9	9,6	7,4	7,6	8,4	7,8	8,4	7,0
Diet "B"	7,3	7,0	7,1	7,8	8,4	9,3	8,9	8,0	9,0	8,8	9,2	8,8	8,6	9,2	9,1
Diet "A"	6,0	5,8	5,5	5,8	7,2	8,7	8,8	8,5	8,0	7,0	7,6	7,5	8,4	7,5	7,6
Yeast	5,9	6,6	5,8	5,5	6,9	6,9	6,9	7,6	7,7	7,3	7,5	6,7	7,1	7,0	7,2

There is an obvious similarity of effect between the individuals reared on yeast and those reared on diet "A." Both resulted in a more rapid rate of growth as indicated by instar duration. After the fifth instar, there is a marked similarity between the control and diet "B" in instar duration. This may be the result of bacterial build-up in the substrate of the control cultures. Control specimens were seen eating the substrate and the black contents of the gut were clearly visible through the body walls.

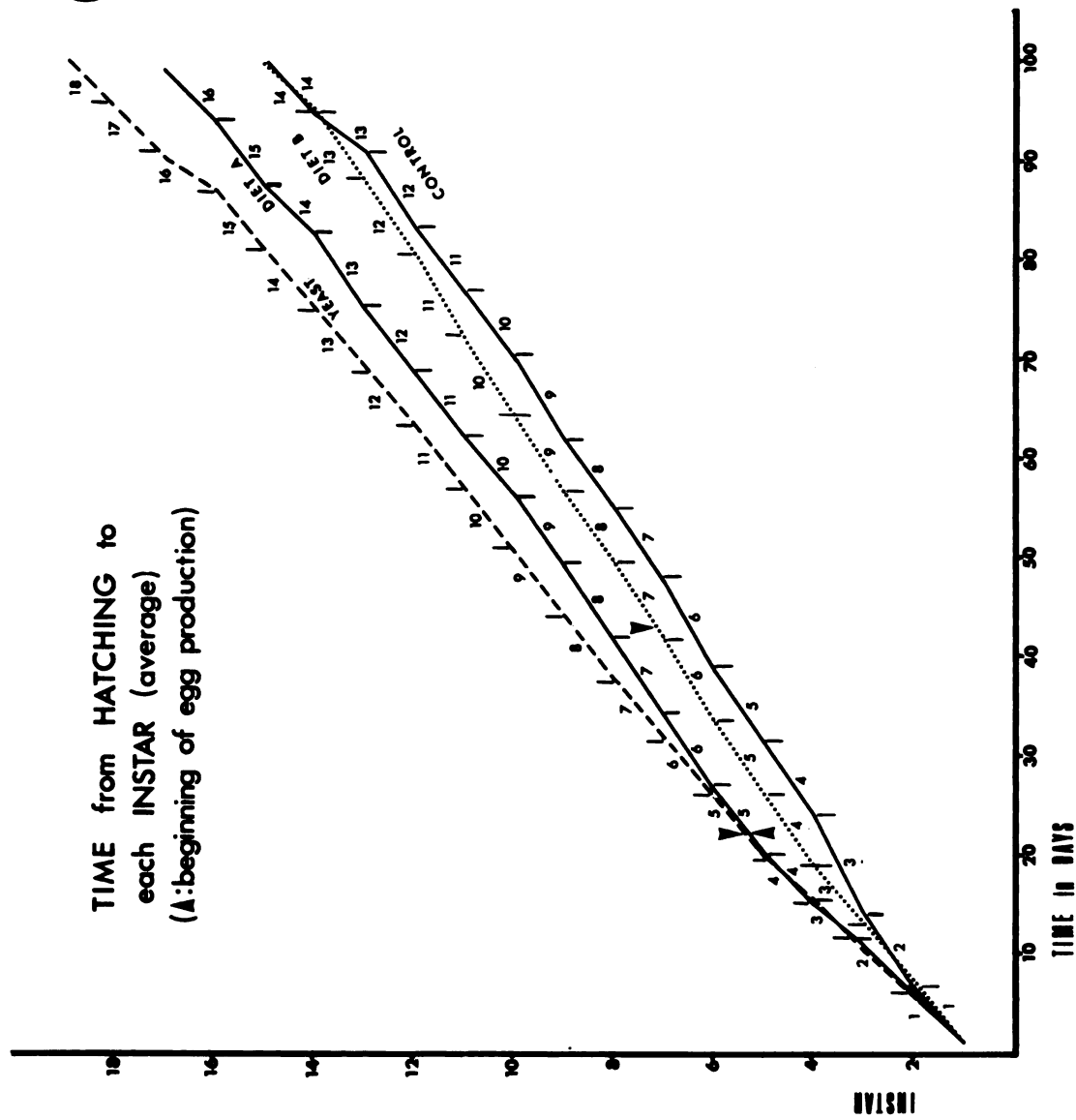
The similarities in growth rate can also be graphically shown by calculating the number of days lived through from the day of hatching to the beginning of each instar. Graph 55 clearly shows the diversity of growth rate between yeast, diet "A," control, and diet "B." Here the lag in instar duration shows up after the first two instars.

Mortality can be inferred from figures for percent survival of the total population. The following table (XXII) shows the survival rate of each run after periods of 25, 50, 75 and 100 days.

TABLE XXII. Influence of various diets on the percent survival of Onychiurus justii porteri.

	Age in days			
	25	50	75	100
Control	78,6	61,4	34,3	27,1
Diet "B"	87,6	77,0	73,3	71,3
Diet "A"	96,0	92,4	78,8	61,6
Yeast	89,3	83,3	67,3	56,6

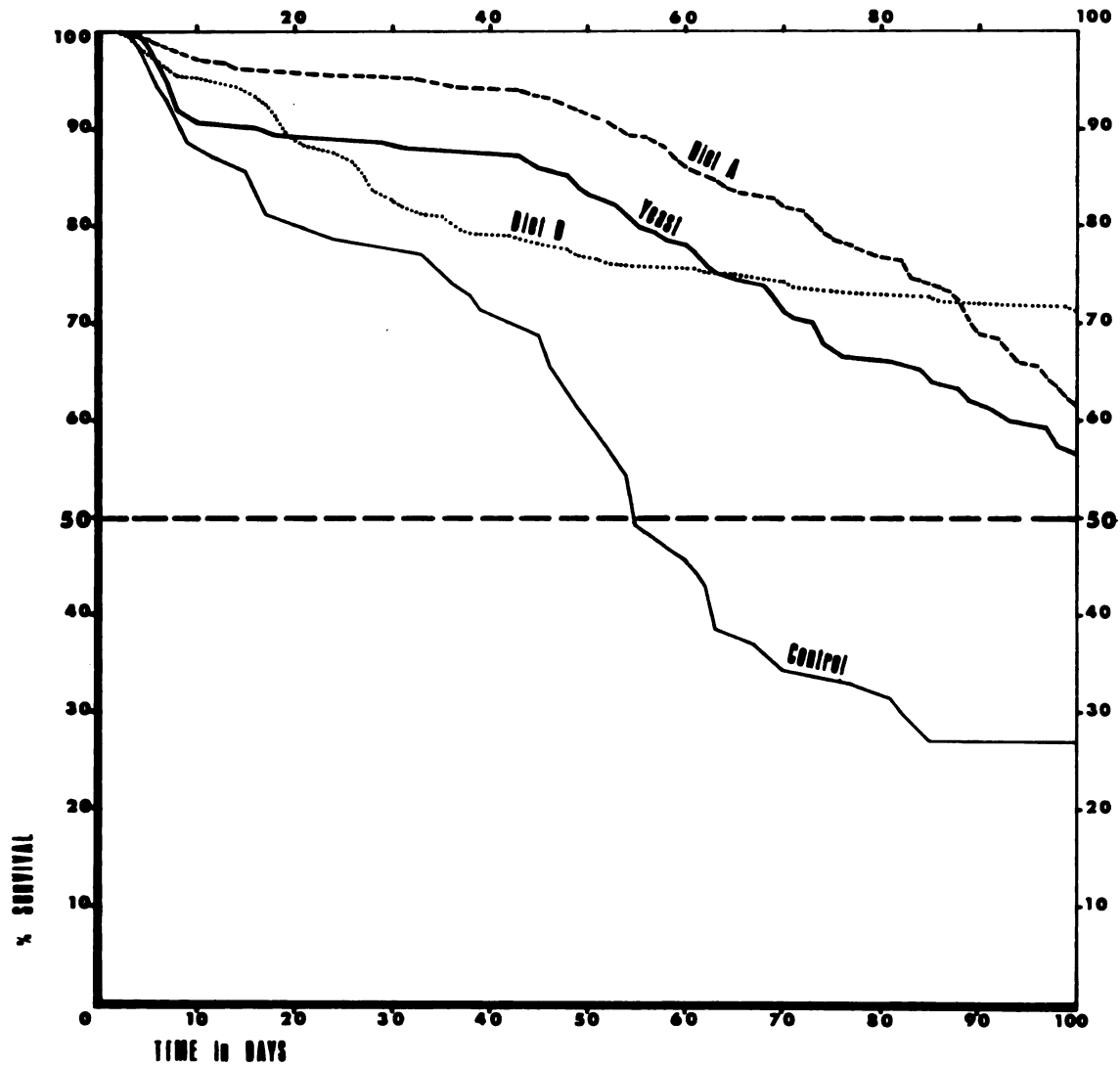
By calculating survival on a daily basis (Graph 56), the expected downward slope of the control populations, reaching 50% after about 55 days, becomes exceedingly clear. It is interesting to note that with



Graph 55. Onychiurus justus porteri, time required for each instar in cultures reared on yeast, diet A, diet B, and control, at 70°F.

56

% Survival at 70°F (21.11°C)



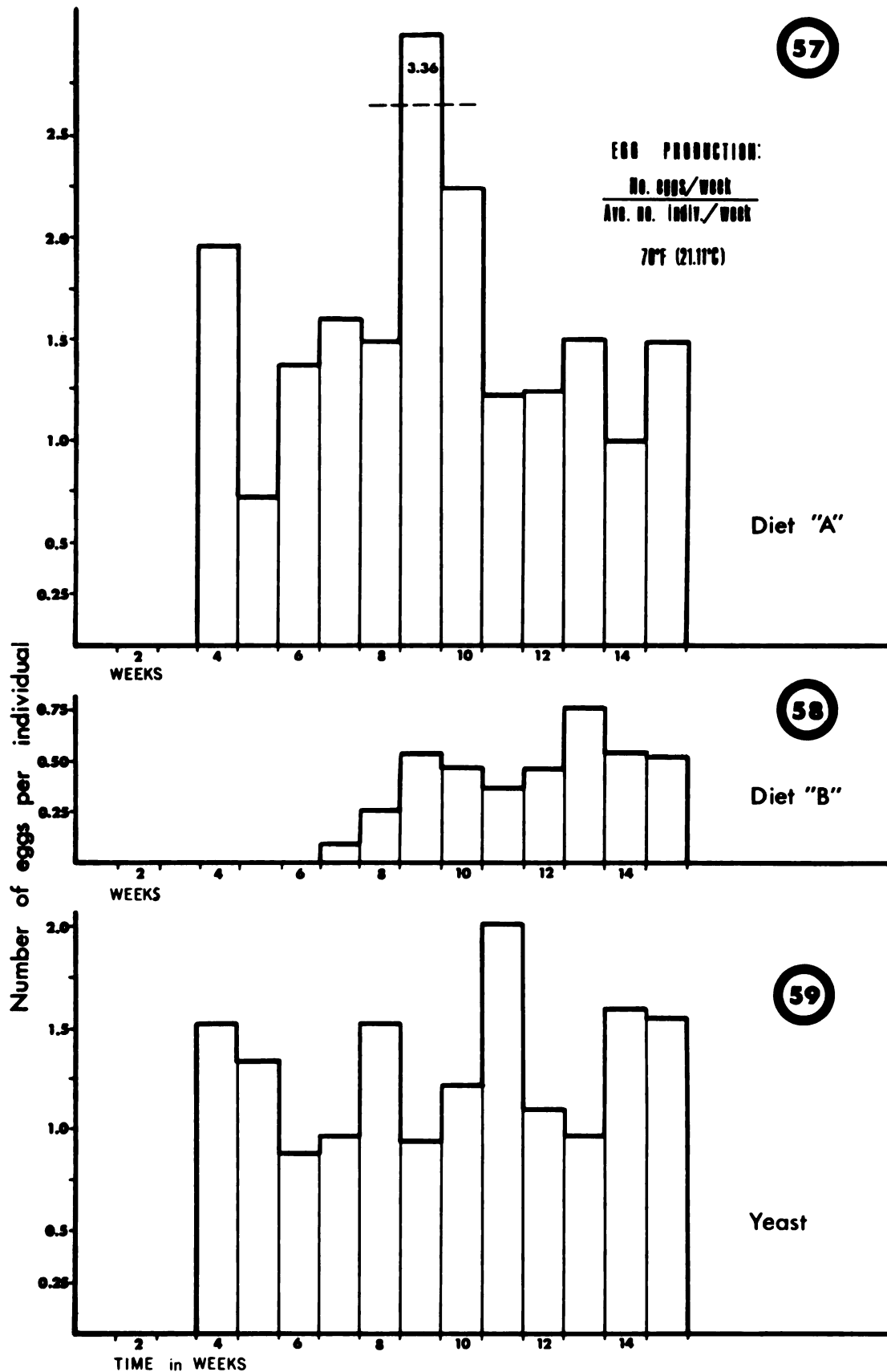
Graph 56. Onychiurus justus porteri, percent survival of individuals reared at 70°F for 100 days and fed yeast, diet A, diet B, and control.

diet "B," not the best diet for growth, survival stabilizes out after approximately 50 days and mortality is at a minimum. On the other hand, both yeast and diet "A" produce similar trends of survival, gradually sloping downward between 50 and 100 days.

Egg production was recorded for each of the four runs. The control did not produce eggs at any time during the 100-day period. However, egg production was observed in the other three runs. Since the cultures were each started with 10 individuals, it was impossible to consider egg production on a per female basis. Therefore average weekly egg production was calculated by using the average number of individuals surviving each week. It must be noted that this figure, as in the mass rearing experiment, includes the males present in each run. Graphs 57, 58, and 59 indicate egg production according to the formula:

$$\text{Egg production per individual} = \frac{\text{Number of eggs/week}}{\text{ave. number individuals/week}}$$

Fecundity appeared highest among individuals cultured on diet "A." Yeast fed individuals were next, followed by those kept on diet "B." Egg laying started during the 5th instar, occurring in the fourth week after hatching in both the diet "A" and yeast fed runs. It is interesting to note that individuals reared on diet "B" did not begin egg laying until the seventh week, at a time when the seventh instar had been reached. Of equal significance is the relatively low fecundity in the diet "B" fed individuals. While diet "A" induced the laying of as many as 50 eggs per clutch, and yeast fed individuals produced nearly as many, those fed diet "B" never laid more than 17 eggs per clutch. On the average, the diet "B" run produced 5-8 eggs per clutch.



Graphs 57 to 59. *Onychiurus justis porteri*, average number of eggs laid per week by individuals reared on diet A, diet B, and yeast at 70°F.

Egg viability was lowest in the run fed on diet "A." Of the 2991 eggs laid that were observed, 2359, or 78%, hatched. In the case of diet "B," of 562 eggs observed, 476 were viable, or 84%. Yeast showed 81% viability for 1373 eggs observed with 1114 hatching. The juveniles were not reared and no figures are available for their survival.

At the end of the 100-day period, the individuals of each run were killed and slide mounted for measurement. Not all runs were killed at the same time. Some replicates were still producing eggs, and it was necessary to allow some clutches of eggs to hatch before killing the parent individuals. Table XXIII indicates the average size of individuals killed at various time periods after 100 days.

When the egg hatches, the 1st instar juvenile is on the average 545 microns in length. The figures in table XXIII indicate that the controls grow very little throughout the experiment. In fact, their size after 100 days lies between 840-1066 microns, which is the average size of 3rd instar juveniles fed yeast. The control individuals were actually in the 14th instar at the time of killing. They underwent ecdysis even though no appreciable size change was attained after reaching the 3rd instar size.

Diet "A" and yeast produced individuals of approximately equal size after 100 days. Diet "B" fed individuals were small by comparison. Their size compares with yeast-fed 4th to 5th instar individuals raised at the same temperature. The figures in table XXIII indicate size fluctuations between 105 and 145 days. This condition seems to be quite normal for individuals after the 7th instar. Previously presented data indicate that after the 7th instar, size (length) fluctuates. An apparent rhythm in size increase and decrease continues until the animals reach senility, when they finally decrease a small amount with each instar until death.

TABLE XXIII. Mean over-all lengths (in microns), at the end of various time periods, of Onychiurus just porteri reared on various diets.

		Diet "A"	Diet "B"	Yeast	Control
Day replicates were killed	105	(12)* 1722,4	(62) 1280,5	(18) 1632,6	----
	107	(18) 1489,1	----	(22) 1737,1	----
	108	----	(55) 1349,6	----	(5) 870,3
	112	(54) 1583,2	----	----	(1) 1066,8
	113	(16) 1602,0	(33) 1257,2	----	----
	114	(24) 1852,9	----	(24) 1800,8	(7) 840,7
	145	----	(16) 1254,3	(32) 1659,6	----

*/ Number contributing to the mean

Discussion

The results of this preliminary study indicate that the type and quality of diet can influence growth and fecundity of O. just porteri. The amount of protein and fat in diets "A" and "B" probably are, to an extent, responsible for these differences. It should be noted that no biochemical analysis has yet been performed on any of the diets. Therefore, it cannot be stated with accuracy whether a specific protein(s) was responsible for the resultant growth and fecundity patterns.

Considering the differences in protein content as a whole, we can rank the three food runs on the basis of high protein to low: diet "A"

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(45% protein), yeast (approx. 40% protein), diet "B" (3,4% protein).

Referring to Graph 55 showing rate of growth, and Table XXI indicating instar duration, differences are apparent. Diet "B" has the longest instar durations, followed by diet "A," and yeast the shortest. Even though yeast contains somewhat less protein than diet "A," the yeast's protein may be easier to assimilate by the Collembola.

Survival, as indicated in Graph 56 and Table XXII, presents some interesting aspects. After an initial decline up to 35 days, diet "B" fed individuals stabilize through the rest of the 100 day period. Meanwhile, both diet "A" fed and yeast fed individuals begin a steady decline after 42 days. These survival patterns may be due to a multiplicity of factors. Perhaps diet "B" fed animals adjusted to the low protein food, with higher assimilation efficiency under stress conditions. It may be that the animals reacted much like dermestid larvae placed on starvation or near starvation diets (Dr. Stanley Beck, in litt.)

One of the most interesting developments was the discrepancy in egg production. As expected, the controls (starved) produced no eggs. Diet "B," low protein, produced few eggs compared to diet "A" and yeast-fed individuals. Moreover, diet "B"-fed cultures lagged in egg production until the 7th week of the experiment. Diet "A"-fed cultures had the highest rate of egg production followed by cultures reared on yeast. But eggs in diet "B"-fed cultures showed the highest viability, followed by yeast and diet "A"-fed cultures.

Finally, there is a marked difference in size between the four runs after 100 days on their respective diets. For over-all size, the diet "A"-fed individuals were largest, followed by yeast-fed, diet "B"-fed and the control.

As has previously been mentioned, every attempt was made to keep the

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cultures as clean as possible throughout the duration of the experiment. Food was not left in the containers for more than 24 hours, after which it was replaced by fresh. Fungal growth was kept at a minimum by scraping the substrate surface whenever the food was replaced. However, no control of bacteria was feasible; and it is possible that such contamination may have supplemented the diets. In the case of the control, it is very probable that contamination allowed some of the individuals to survive the 100 days of the experiment. But it is still striking that they survived at all and continued to moult without appreciable size increase at regular intervals.

The data presented here make it evident that food quality as well as temperature and humidity play an important role in collembolan growth and fecundity. Type of food and its availability must be taken into account in studies of biomass and age structure of collembolan populations in laboratory and field. As previously pointed out, the size of individuals, however advanced in age, bears no relation to the instar they are in, if maintained on an insufficient diet. For instance, the control and diet "B"-fed individuals produced a similar growth rate pattern, but were of different sizes in the 14th instar. If we were to categorize the 14th instar on the basis of biomass or size, we would determine it to be the 4th or 5th instar. A similar situation is reflected in the data presented on growth rate at three different temperatures.

In addition to size differences, food quality affects egg production and may be a decisive factor in population dynamics of a given species. As seen from the data presented here, *Collembola* will live and reproduce on both high and low protein foods. But the constituents of these foods may determine their survival and fecundity.

XIV. SURVIVAL AT 60°O, 70°O AND 80°O

Introduction

The influence of temperature on the activity of Collembola has been documented both in the laboratory and in the field. Some species become inactive between +4°O and -4°O (Nosek, 1959; An Der Lan, 1963; Janetschek, 1963). Others may survive between -5°O and -50°O (Paclt, 1956; Pryor, 1962; Agrell, 1941; Kuhlmann, 1958; An Der Lan, 1961). Temperature regimes between 8°O and 24°O have commonly been used in life-cycle studies (Britt, 1951; Ripper, 1930; Hale, 1965 a,b,c; Choudhuri, 1961; Milne, 1962; Davis and Harris, 1936; Sharma and Kevan, 1963 a,b; Vail, 1965; Marshall and Kevan, 1962).

Very little comparative work exists on longevity of individuals or small populations at selected temperatures. Hale (1966) states that the only precise information he could obtain on longevity concerned Onychiurus latus. In the field the average time from hatching to egg laying was 10 to 11 months. Adults of O. latus, put into culture at 8°O at the time of egg laying, lived for another 120 days; giving a life span of over 400 days.

Recent work by Thibaud (1968 a,b; 1969) has been centered on lethal temperatures and the effects of temperature on postembryonic development. Ashraf (1971) investigated the effect of nine different temperatures on O. bhattii Yosii, with ranges from 0°O to 50°O. His experiments were conducted over a 24 hour period.

Survival in Mass Culture

Mass cultures of O. just porteri were observed for a year (from hatching to death). Periodic samples were taken for growth studies; in

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addition, deaths occurred in the populations. The ensuing changes in population densities were recorded and later tabulated on a weekly basis.

In order to determine the mortality or percent survival of the mass cultures, a theoretical mortality of the individuals sampled each week has to be calculated. I am indebted to Dr. Ralph Pax, who helped derive a formula for the theoretical mortality of sampled individuals. The following is the procedure used to determine the mortality of cultures being sampled on a weekly basis:

- a) Count the total number of individuals on day 1 of the week (including deaths and samples taken out on this same day, if any);
- b) Count the number of deaths in the week;
- c) Calculate the percent mortality;
- d) Count the total number of individuals sampled during the week;
- e) Calculate the "theoretical percent mortality" of the samples:

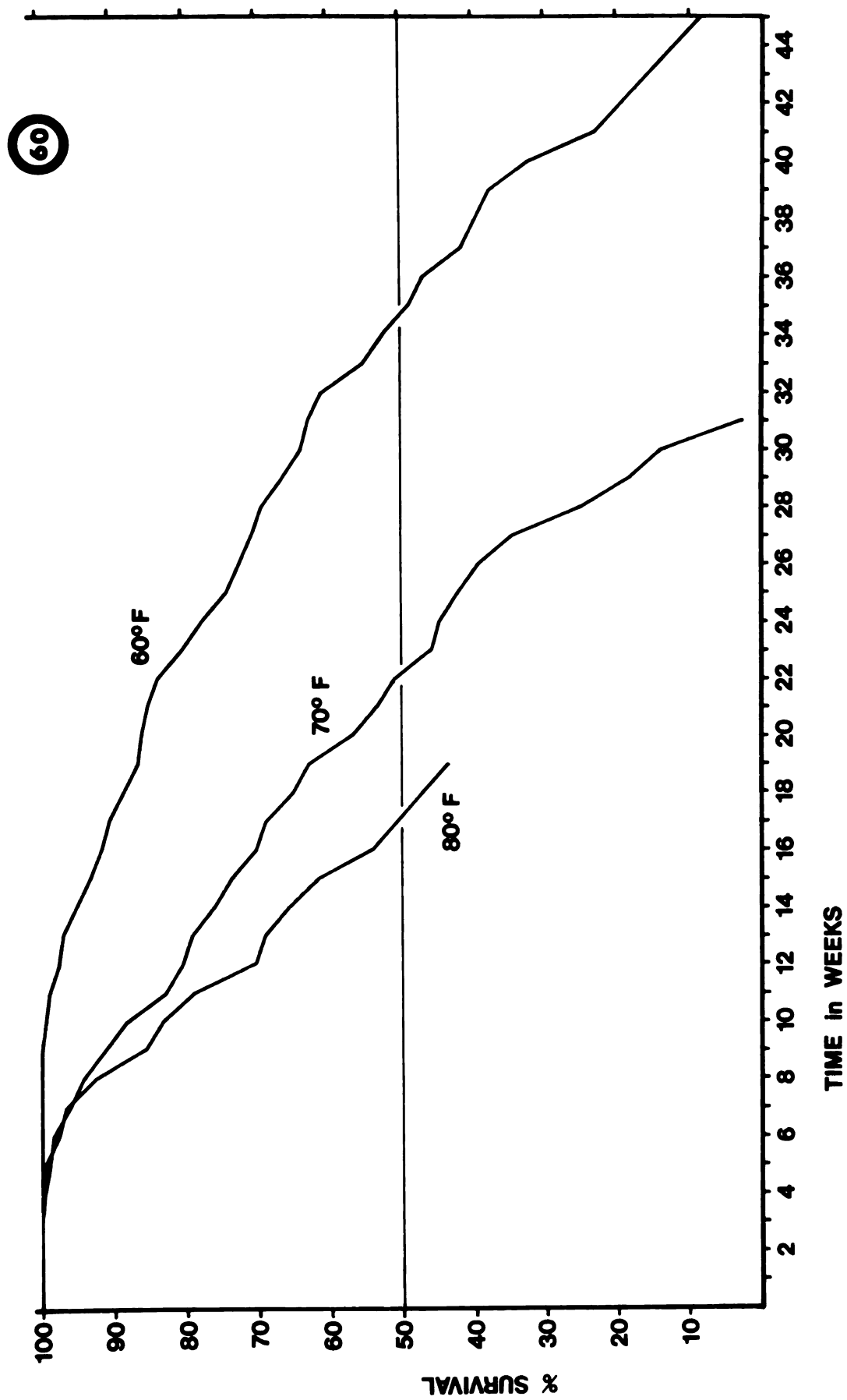
$$\text{No. of sampled individuals} \times \frac{\text{percent total mortality}}{100}$$

= percent mortality in samples;

- f) Add the mortality of the total population to the mortality of the samples.

Note: Both the mortality of the total population and the theoretical mortality of the samples were cumulated for the duration of the experiment (Appendices XLII, XLIII and XLIV).

Graph 60 illustrates the percent survival of O. justl porteri at three temperatures. At 80°F, 50% of the animals survived to the 17th week; extinction was reached in the 19th week (133 days). At 70°F, 50% survival



Graph 60. *Onychiurus justii porteri*, percent survival of mass reared cultures at 60°, 70°, 80°F.

occurred in the 22nd week and death by the 31st week (224 days). Survival at 60°F was much higher, with 50% living to the 34th week and finally reaching a low in the 45th week (315 days). At all three of these temperatures, there were individuals that lived longer. At 70°F a few lived for 237 days, while at 60°F some survived 365 days.

Survival in Low Number Reared Cultures

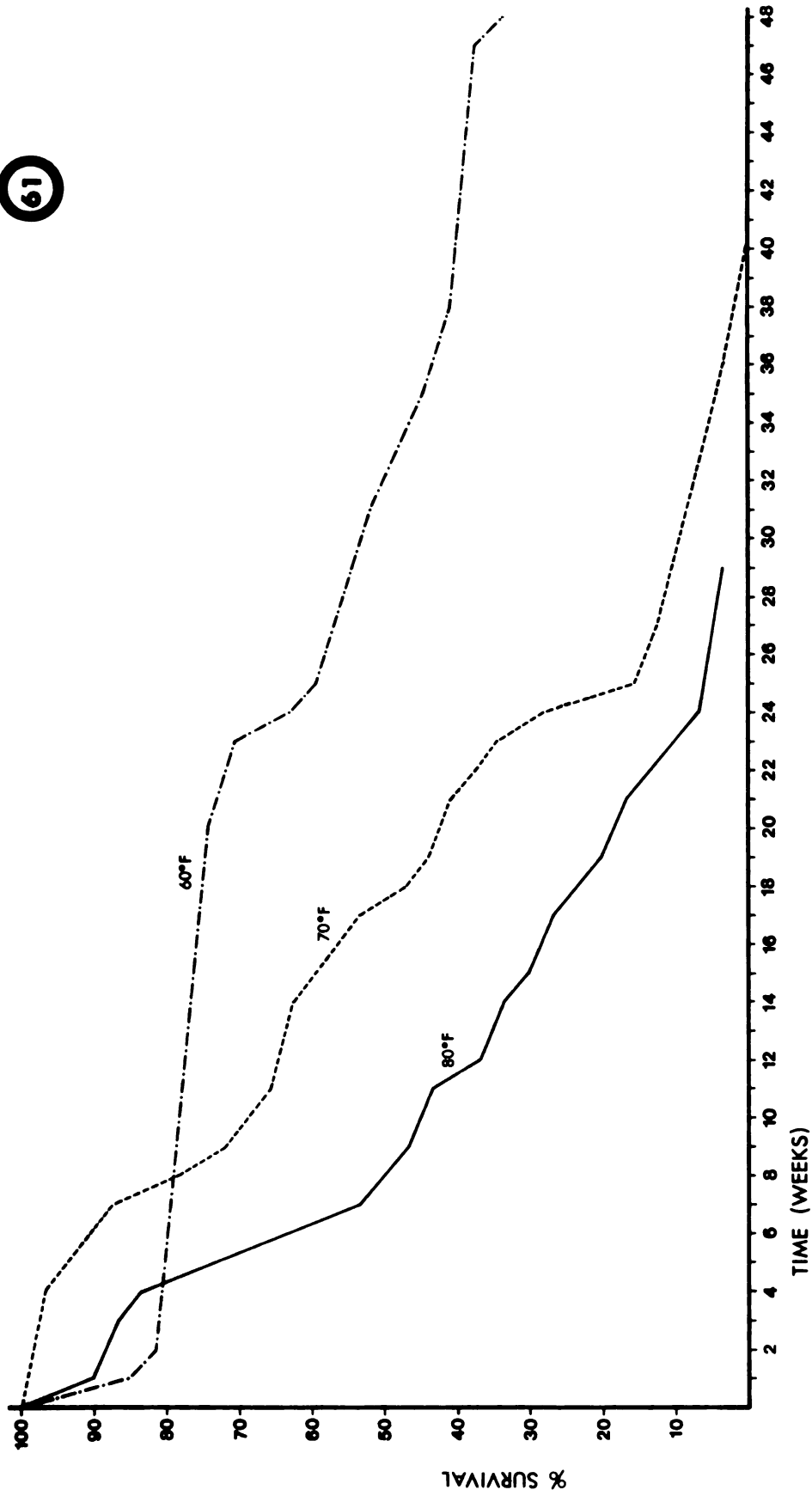
In cultures of five or less individuals, no samples were taken. As a result, mortality could be calculated in the customary way (Appendices XLV, XLVI and XLVII). Graph 61 illustrates the percent survival at three temperatures. Compared to the mass cultures, mortality is initially more pronounced. At 70° and 80°F, the low number reared individuals reach 50% mortality much sooner than the mass reared cultures. Even at 60°F, mortality among juveniles is higher than in mass cultures.

Survival in Cultures Containing Single Individuals and Pairs

In cultures of single males, single females, pairs of male and female, pairs of males and pairs of females, the pattern of survival in the 15 week run is similar to that in low number reared cultures (Tables XXIV, XXV and XXVI).

It is apparent that at 70°F an unknown factor is producing high mortality in the cultures containing pairs of male and female. At 70° and 80°F single males and females show a higher mortality rate than at 60°F. Of similar interest is the high mortality in pairs of males over that of pairs of females at 60° and 70°F.

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Graph 61. *Onychiurus justus porteri*, percent survival of low number reared cultures at 60°F, 70°F and 80°F.

TABLE XXIV. Percent mortality at 60°F in cultures containing single and paired individuals of Onychiurus justus porteri.

WEEK	PERCENT MORTALITY				
	Single males	Single females	Pairs of males	Pairs of females	Pairs of male+female
1	-	-	-	-	-
2	-	-	-	-	-
3	-	-	-	-	-
4	-	-	-	-	-
5	-	-	-	-	-
6	-	-	-	-	3,57
7	-	-	-	-	-
8	3,70	-	-	-	-
9	-	-	5,55	3,33	-
10	-	2,38	11,11	6,66	-
11	-	-	-	-	7,14
12	7,40	7,14	-	-	-
13	-	-	16,66	-	-
14	-	-	-	-	-
15	-	-	-	-	-

TABLE XXV. Percent mortality at 70°F in cultures containing single and paired individuals of O. justus porteri.

WEEK	PERCENT MORTALITY				
	Single males	Single females	Pairs of males	Pairs of females	Pairs of male+female
1	-	-	-	-	-
2	-	-	-	-	-
3	-	-	-	-	-
4	-	-	-	-	-
5	-	-	-	-	-
6	-	-	-	-	-
7	-	-	-	-	1,79
8	-	9,09	-	-	8,93
9	7,69	-	-	-	12,50
10	23,07	-	-	-	16,07
11	-	18,18	5,55	6,25	23,21
12	30,77	27,27	11,11	12,50	32,14
13	38,46	45,45	16,67	-	39,28
14	-	-	22,22	-	42,86
15	-	-	-	-	-

TABLE XXVI. Percent mortality at 80°F in cultures containing single and paired individuals of O. justus porteri.

PERCENT MORTALITY			
WEEK	Single males	Single females	Pairs of male+female
1	-	-	-
2	-	-	-
3	-	-	-
4	-	-	-
5	-	-	-
6	3,57	-	-
7	-	-	-
8	7,14	-	-
9	10,71	-	-
10	-	-	-
11	14,28	-	7,14
12	25,00	-	-
13	28,57	14,28	-
14	32,14	-	14,28
15	-	19,05	21,43

Discussion

From the data presented, it appears that mortality is influenced not only by temperature but also by the total number of individuals in a population and possibly by their sex. In mass culture, survival is higher in the initial few weeks, indicating less juvenile mortality. In the low number reared cultures there is a higher juvenile mortality, although the adults exhibit a prolonged survival time.

Cultures of single individuals have an initial high rate of survival, but after the seventh or eighth week, respond in a pattern similar to the low number reared cultures. Males in the first 15 weeks show a high mortality. However, examination of Graphs 52, 53 and 54 for mass culture reveal a corresponding decrease in size of males in the same time period (approximately 11th instar or 105 days at 60°F and 16th instar or 105 days at 70°F).

The information on survival and the data on growth rate suggest that mortality may be directly related to temperature - humidity, population density, sex, age and metabolism. And judging by the data in the previous section, diet certainly plays an important role in the survival of Collembola.

XV. SUMMARY

1. A new subspecies, Onychiurus justi porteri, is described from Michigan.
2. The culture techniques used in this investigation were those described by Snider, Shaddy and Butcher (1969). Two culture container sizes were employed; 50 mm x 37,5 mm and 25 mm x 34 mm. Transfer of individuals from culture to test containers was accomplished by floating the juveniles on water and lifting them with a fine needle.
3. O. justi porteri was subjected to 0, 80, 90, 95 and 100% RH at 50°, 60°, 70° and 80°F, using various concentrations of glycerol. Survival was shown to be highest at 100% RH and a temperature of 50°F. As temperature increased and RH decreased, survival decreased accordingly.
4. The egg laying process of O. justi porteri is described.
5. Egg cannibalism was found to occur in the case of non-developing eggs.
6. The embryonic development of O. justi porteri is described and a time table for 70°F is presented. As temperature decreases, between the temperatures of 50° and 80°F, the time required for development of the egg increases.

7. Fecundity in mass cultures was calculated according to the formula:

$$\text{Average egg production per individual} = \frac{\text{Total number of eggs in that week}}{\text{Average no. of individuals in that week}}$$

In mass cultures the greatest number of eggs per individual was laid at 60°F and egg production lasted until the 27th instar.

Fecundity in low number reared cultures (five individuals or less) was higher than in mass cultures. Egg production continued until the 42nd instar at 60°F.

In general, an increase in temperature lowers the number of eggs produced. Over-all survival of the eggs was greatest at 60°F and decreased at 70° and 80°F. Fecundity was demonstrated to be much higher in O. justi porteri than in any other species of Onychiurus so far observed and reported.

8. Instar duration was shown to be related to temperature. At 60°F a rhythm of alternating long and short instar duration was indicated. Isolated males and females did not produce such a rhythm. It is suggested that the duration of the stages may, in addition to temperature, be governed by the presence or absence of individuals of the opposite sex.
9. Measurements of the head capsule of the first six instars indicate that growth of O. justi porteri conforms to Dyar's Rule.

Over-all body length was observed at 60°, 70° and 80°F in mass culture. A size difference between males and females was shown. Females develop more rapidly than males and attain a larger size. Maximum length of both males and females is reached between the 12th and 14th instar; thereafter a decrease in size occurs at all temperatures investigated.

A possible correlation between egg production and retrograde development is suggested. The size structure of a population of O. just porteri may be determined by a relationship between sexual activity, metabolism, and age.

10. The chaetotaxy of the fifth abdominal segment is described in a manner similar to Hale's (1965 c) investigation. The development of the setal pattern is illustrated from the first to the seventh instar.

The dorsal setal pattern of the first thoracic segment was investigated in the hope of finding a correlation with instar number. However, beyond instars one and two variation was too great to allow its use.

The chaetotaxy of the male and female genital plates is illustrated. Setal patterns of the genital plates of both sexes do not develop until the fourth instar. The maximum number of setae is attained by the seventh instar.

The chaetotaxy of the male ventral organ is described and illustrated. From the present investigation it was possible to negate the use of male ventral setae morphology for specific instar designation.

11. An investigation comparing yeast, a high protein food, a low protein food, and control (no food) was undertaken. Indications are that food quality can influence growth, fecundity and mortality. Retrograde development was observed in the control individuals.
12. Survival at 60°, 70° and 80°F was found to be highest at 60°F. In mass culture, juveniles appear to have a higher survival rate. Whereas in low number reared cultures, the adults exhibit a prolonged survival time.

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APPENDIX I

Onychiurus just porteri n.ssp., 80°F: Percent mortality of adults at various relative humidities.

TIME	PERCENT R.H.				
	0	80	90	95	100
10 min	-				
20	96				
30	100				
40		-			
50		8			
60		47	-		
70		77	10		
80		97	25		
90		100	33		
100			56		
110			80		
120			93		
130			98		
140			100		
3 hrs				-	
6				44	
18				90	-
21				93	1
42				98	1
47				100	1
77					10
140					22
171					30
217					42

APPENDIX II

Onychiurus justus porteri n.ssp., 70°F: Percent mortality of adults at various relative humidities.

TIME	PERCENT R.H.				
	0	80	90	95	100
10 min	-				
20	27				
30	98				
40	100	-			
50		2			
60		10			
70		22			
80		69	-		
90		93	5		
100		100	10		
110			22		
120			48		
130			58		
140			72		
150			85		
160			96		
170			100		
3 hrs				-	
17				68	-
48				87	1
90				94	3
138				96	4
216					6

APPENDIX III

Onychiurus just porteri n.ssp., 60°F: Percent mortality of adults
at various relative humidities.

TIME	PERCENT R.H.				
	0	80	90	95	100
10 min	-				
20	-				
30	32				
40	93				
50	100				
60					
70		-			
80		3			
90		11			
100		49			
110		72			
120		88	-		
130		96	7		
140		100	12		
150			16		
160			30		
170			46		
180			62		
4 hrs			100	-	
17				4	
45				53	-
67				56	1
96				68	1
138				73	2
216					4

APPENDIX IV

Onychiurus justus porteri n.ssp., 50°F: Percent mortality of adults at various relative humidities.

TIME	PERCENT R.H.				
	0	80	90	95	100
10 min	-				
20	-				
30	7				
40	40				
50	94				
60	100	-			
2 hrs		3			
3		34			
4		90	-		
5		100	12		
6			28		
7			44		
8			65		
9			84		
10			100	-	
18				2	
42				23	
68				42	
90				50	
138				65	-
258				71	-

APPENDIX V

Onychiurus justis porteri, 60°F: Average egg production per week, for individuals reared in mass cultures.

$$\text{Average egg production} = \frac{\text{Total no. of eggs/week}}{\text{Average no. of individuals/week}}$$

WEEK	AVERAGE NO. OF INDIVID.	TOTAL NO. OF EGGS	AVE. EGGS/ INDIVIDUAL
5	550,28	255	0,4634
6	531,00	724	1,3636
7	512,14	741	1,4468
8	482,57	615	1,2744
9	462,00	568	1,2294
10	452,00	227	0,5022
11	441,71	323	0,7312
12	424,85	88	0,2071
13	405,71	216	0,5323
14	384,00	110	0,2864
15	365,85	42	0,1148
16	339,71	150	0,4415
17	326,14	44	0,1349
18	303,71	161	0,5301
19	-	-	-
20	272,71	63	0,2310
21	-	-	-
22	-	-	-
23	236,42	57	0,2410
24	-	-	-
25	212,57	60	0,2822
26	-	-	-
27	197,71	45	0,2276

APPENDIX VI

Onychiurus justus porteri, 70°F: Average egg production per week, for *individuals* reared in mass cultures.

$$\text{Average egg production} = \frac{\text{Total no. of eggs/week}}{\text{Average no. of individuals/week}}$$

WEEK	AVERAGE NO. OF INDIVID.	TOTAL NO. OF EGGS	AVE. EGGS/ INDIVIDUAL
4	645,42	257	0,3981
5	590,42	523	0,8858
6	551,28	302	0,5478
7	511,28	55	0,1075
8	468,28	256	0,5466
9	422,28	107	0,2533
10	378,71	47	0,1241
11	340,28	94	0,2762
12	287,71	65	0,2259
13	268,42	35	0,1303
14	244,28	45	0,1842
15	226,57	12	0,0529
16	207,28	9	0,0434

APPENDIX VII

Onychiurus just *porteri*, 80°F: Average egg production per week, for
individuals reared in mass cultures.

$$\text{Average egg production} = \frac{\text{Total no. of eggs/week}}{\text{Average no. of individuals/week}}$$

WEEK	AVERAGE NO. OF INDIVID.	TOTAL NO. OF EGGS	AVE. EGGS/ INDIVIDUAL
4	338,14	51	0,1508
5	290,71	133	0,4575
6	255,14	71	0,2782
7	230,14	55	0,2389
8	202,71	32	0,1578
9	172,57	43	0,2491
10	145,28	4	0,0275
11	-	-	-
12	-	-	-
13	81,42	6	0,0736

APPENDIX VIII

Onychiurus justus porteri, 60°F: Average egg production per week, for individuals reared in groups of five or less.

$$\text{Average egg production} = \frac{\text{Total no. of eggs/week}}{\text{Average no. of individuals/week}}$$

WEEK	AVERAGE NO. OF INDIVID.	TOTAL NO OF EGGS	AVE. EGGS/ INDIVIDUAL
6	23,00	77	3,3478
7	23,00	21	0,9130
8	23,00	73	3,1739
9	23,00	96	4,1739
10	23,00	45	1,9565
11	-	-	-
12	22,00	35	1,5909
13	22,00	36	1,6363
14	22,00	23	1,0454
15	22,00	28	1,2727
16	-	-	-
17	22,00	85	3,8636
18	22,00	20	0,9090
19	22,00	50	2,2727
20	21,85	36	1,6475
21	21,00	28	1,3333
22	21,00	92	4,3809
23	-	-	-
24	18,42	56	3,0401
25	-	-	-
26	17,00	42	2,4705
27	-	-	-
28	-	-	-
29	16,00	62	3,8750
30	-	-	-
31	15,57	82	5,2665
32	-	-	-
33	14,28	30	2,1008
34	14,00	60	4,2857
35	-	-	-
36	13,00	63	4,8461
37	-	-	-
38	-	-	-
39	-	-	-
40	-	-	-
41	-	-	-
42	12,00	37	3,0833

APPENDIX IX

Onychiurus just porteri, 70°F: Average egg production per week, for individuals reared in groups of five or less.

$$\text{Average egg production} = \frac{\text{Total no. of eggs/week}}{\text{Average no. of individuals/week}}$$

WEEK	AVERAGE NO. OF INDIVID.	TOTAL NO. OF EGGS	AVE. EGGS/ INDIVIDUAL
4	31,85	24	0,7535
5	-	-	
6	30,00	27	0,9000
7	28,57	43	1,5050
8	-	-	
9	23,71	42	1,7714
10	-	-	
11	21,42	23	1,0737
12	-	-	
13	21,00	19	0,9047
14	-	-	
15	-	-	
16	-	-	
17	17,28	26	1,5046
18	-	-	
19	-	-	
20	-	-	
21	13,14	20	1,5220
22	-	-	
23	11,85	21	1,7721

APPENDIX X

Onychiurus justii porteri, 60°F: Egg production per week, for pairs of male and female reared in isolation. (9 reps)

WEEK	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
TOTAL NO. OF EGGS	18	-	13	18	29	27	18	142	27	-	55	67	106	53	89	86
NO. FEMALES LAYING	1	-	2	1	2	2	1	5	1	-	3	2	4	2	4	2
AVERAGE	(18)	-	6,5	(18)	14,5	13,5	(18)	28,4	(27)	-	18,3	33,5	25,1	26,5	22,2	43,0
RANGE	-	-	6-7	-	11-18	10-17	-	8-43	-	-	13-26	30-37	22-38	14-39	11-33	40-46

WEEK	22	23	24	25	26	27	28	29	30	31	32	33	34	35
TOTAL NO. OF EGGS	18	91	29	57	-	-	47	-	41	-	42	-	-	31
NO. FEMALES LAYING	1	2	1	2	-	-	1	-	1	-	1	-	-	1
AVERAGE	(18)	45,5	(29)	28,5	-	-	(47)	-	(41)	-	(42)	-	-	(31)
RANGE	-	37-54	-	19-38	-	-	-	-	-	-	-	-	-	-

APPENDIX XI

Psychiurus justii porteri, 700F: Egg production per week, for pairs of male and female reared in isolation. (21 reps)

WEEK	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
TOTAL NO. OF EGGS.	49	40	192	119	103	101	125	44	46	86	41	-	73	26	63
NO. FEMALES LAYING	7	3	13	7	8	4	6	4	2	3	1	-	3	1	2
AVERAGE	7,0	13,3	14,7	17,0	12,8	25,2	20,8	11,0	23,0	28,6	(41)	-	24,3	(26)	31,5
RANGE	2-10	2-21	3-26	11-28	2-23	3-49	2-29	4-25	21-25	17-37	-	-	9-45	-	26-37

APPENDIX XII

Onychiurus justus porteri, 60°F: Egg production per instar, for pairs of male and female reared in isolation. (9 reps)

INSTAR	NO. EGGS TOTAL	NO. FEMALES LAYING	AVERAGE PER FEMALE	RANGE
5	18	1	(18)	-
6	25	2	12,5	7-18
7	34	3	11,3	6-17
8	28	2	14,0	10-18
9	110	4	27,5	18-43
10	77	3	25,6	8-42
11	93	3	31,0	26-37
12	39	2	19,5	16-23
13	140	5	28,0	13-39
14	70	3	23,3	14-33
15	151	5	30,2	11-46
16	101	3	33,6	18-54
17	38	1	(38)	-
18	66	2	33,0	19-47
19	41	1	(41)	-
20	-	-	-	-
21	42	1	(42)	-
22	-	-	-	-
23	31	1	(31)	-

APPENDIX XIII

Onychiurus justus porteri, 70°F: Egg production per instar, for pairs
of male and female reared in isolation. (21 reps)

INSTAR	NO. EGGS TOTAL	NO. FEMALES LAYING	AVERAGE PER FEMALE	RANGE
5	11	2	5,5	2-9
6	38	5	7,6	3-10
7	36	4	9,0	2-17
8	147	10	14,7	3-21
9	167	9	18,5	11-28
10	106	5	21,2	11-31
11	12	3	4,0	2-7
12	83	5	16,6	7-26
13	75	4	18,7	2-36
14	94	3	31,3	7-49
15	82	4	20,5	4-32
16	41	1	(41)	-
17	54	2	27,0	17-37
18	54	2	27,0	9-45
19	-	-	-	-
20	82	3	27,3	19-37
21	-	-	-	-
22	26	1	(26)	-

Onychiurus justii porteri, 60°F: Instar duration averages, in days, for mass reared cultures.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12
NO. OF CULTURES	18	18	18	18	18	18	18	18	18	18	18	17
AVERAGE	8,27	7,94	7,61	7,55	8,38	9,00	10,38	11,22	11,05	11,16	12,00	10,76
RANGE	8-10	7-11	6-9	6-11	5-11	6-13	7-17	7-18	6-16	7-18	6-17	7-14

INSTAR	13	14	15	16	17	18	19	20	21	22	23	24
NO. OF CULTURES	18	17	17	17	17	15	15	15	15	14	14	13
AVERAGE	10,77	11,76	11,00	10,64	11,17	9,73	9,66	10,66	10,13	9,57	11,64	9,46
RANGE	6-16	5-16	8-17	7-15	8-14	5-14	6-16	9-14	7-16	6-16	8-16	7-12

INSTAR	25	26	27	28	29	30	31	32	33	34	35
NO. OF CULTURES	12	11	10	8	7	6	6	6	4	3	1
AVERAGE	10,50	10,90	12,40	9,62	11,28	8,66	12,50	8,83	11,00	9,66	(16,00)
RANGE	7-14	8-15	8-16	8-13	7-14	8-10	9-15	8-10	6-14	8-12	-

Onychiurus justipoteri, 70°F: Instar duration averages, in days, for mass reared cultures

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14
NO. OF CULTURES	29	29	29	29	29	29	29	28	28	28	28	29	23	24
AVERAGE	3,75	6,00	5,17	5,68	7,20	6,58	7,10	6,75	7,32	7,21	6,10	7,37	6,91	7,16
RANGE	5-6	4-8	4-8	4-8	5-9	5-9	5-10	5-9	5-9	5-9	5-8	5-11	5-10	5-12

INSTAR	15	16	17	18	19	20	21	22	23	24	25	26	27	28
NO. OF CULTURES	23	22	19	18	17	16	15	14	11	10	8	8	7	7
AVERAGE	6,95	6,59	6,84	6,72	7,00	7,37	7,40	6,71	6,81	7,40	6,62	6,75	6,00	6,42
RANGE	4-10	4-9	5-10	5-11	5-11	6-11	4-9	4-9	4-11	6-9	5-8	6-7	5-7	5-8

INSTAR	29	30	31	32	33	34	35	36	37	38	39	40
NO. OF CULTURES	7	7	6	5	4	4	4	4	3	2	2	2
AVERAGE	5,71	6,14	7,16	7,80	6,00	7,50	7,25	7,00	8,00	7,00	6,50	5,50
RANGE	4-8	5-8	5-9	7-8	5-7	5-10	7-8	6-8	7-10	6-8	6-7	5-6

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APPENDIX XVI

onychiurus justii porteri, 80°F: Instar duration averages, in days, for mass reared cultures.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13
NO. OF CULTURES	18	18	18	18	18	18	18	18	18	18	18	18	18
AVERAGE	4.72	4.44	4.44	5.33	5.33	5.22	5.83	4.94	5.33	5.00	5.66	5.83	5.61
RANGE	4-6	4-6	3-6	4-7	4-9	4-7	4-7	4-8	4-7	4-6	4-7	4-8	5-7

INSTAR	14	15	16	17	18	19	20	21	22	23	24	25
NO. OF CULTURES	18	18	16	14	11	11	10	9	7	5	4	2
AVERAGE	5.94	6.96	5.93	6.21	6.72	6.90	8.30	8.11	8.00	9.60	7.50	6.00
RANGE	4-9	5-9	5-9	4-8	5-9	4-10	5-12	5-13	5-10	5-10	6-8	6-6

APPENDIX XVII

Onchirus justii porterii, 60°F: Average instar duration, in days, for cultures containing five or less

individuals.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13
NO. OF CULTURES	8	8	8	8	8	8	8	8	8	8	8	8	8
AVERAGE	8,37	8,12	8,25	8,37	8,62	10,25	8,00	12,12	8,62	12,25	9,00	11,75	8,87
RANGE	8-9	8-9	8-9	7-10	6-11	8-12	7-10	9-14	5-13	11-15	6-14	7-18	6-11

INSTAR	14	15	16	17	18	19	20	21	22	23	24	25	26
NO. OF CULTURES	8	8	8	8	7	7	7	7	7	7	7	6	6
AVERAGE	11,00	10,12	10,12	10,75	8,14	9,57	7,28	10,57	9,00	10,57	7,42	11,66	8,33
RANGE	7-16	7-17	6-16	8-16	8-12	5-15	5-10	8-14	6-12	7-14	6-10	10-14	7-10

INSTAR	27	28	29	30	31	32	33	34	35	36	37	38
NO. OF CULTURES	6	6	6	6	6	6	6	6	6	6	5	3
AVERAGE	12,66	8,00	11,83	8,33	12,00	8,33	13,00	8,83	12,66	8,83	11,33	8,66
RANGE	11-16	7-10	9-14	7-12	10-14	8-10	11-15	8-13	11-16	8-9	11-17	6-11

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Onychiurus justis porter, 70°F: Average instar duration, in days, for cultures containing five or less individuals.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13
NO. OF CULTURES	8	8	8	8	8	8	8	8	8	7	7	7	7
AVERAGE	6.00	5.75	5.37	5.75	6.87	7.75	6.12	8.12	8.37	7.42	7.28	7.85	7.28
RANGE	6-6	5-6	5-6	5-6	5-8	6-9	4-8	6-10	5-14	4-11	4-14	6-8	5-7

INSTAR	14	15	16	17	18	19	20	21	22	23	24	25	26
NO. OF CULTURES	7	7	7	7	7	7	7	7	7	7	7	7	7
AVERAGE	7.28	6.42	7.28	7.28	6.57	9.00	6.85	7.57	9.00	7.71	7.14	6.71	6.57
RANGE	6-8	5-7	6-10	5-9	6-8	5-14	4-9	5-13	6-13	6-10	5-10	5-8	5-9

INSTAR	27	28	29	30	31	32	33	34	35	36	37	38
NO. OF CULTURES	5	4	3	3	3	3	3	3	3	3	2	2
AVERAGE	7.40	6.50	5.33	7.33	7.00	6.66	7.00	6.00	7.33	7.00	6.50	8.00
RANGE	5-10	5-8	5-6	5-9	6-8	6-8	6-8	4-9	6-8	6-8	6-7	7-9

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Onychiurus justii porterl, 80°F: Average instar duration, in days, for cultures containing five or less

individuals.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14
NO. OF CULTURES	10	10	10	10	10	10	9	9	8	8	8	8	7	7
AVERAGE	2,70	4,30	4,90	4,00	6,00	5,80	5,55	6,00	5,75	6,50	6,62	6,37	5,85	7,85
RANGE	2-3	3-5	4-5	4-4	4-8	5-7	4-6	5-8	5-6	5-9	5-10	5-8	5-8	6-10

INSTAR	15	16	17	18	19	20	21	22	23	24	25	26	27
NO. OF CULTURES	7	7	6	6	6	6	5	5	5	5	5	3	2
AVERAGE	6,85	7,14	8,00	8,00	6,66	6,66	6,80	6,20	9,00	6,00	6,80	9,66	8,50
RANGE	6-12	4-11	6-10	6-13	5-11	6-8	6-8	4-8	5-12	5-7	4-10	7-14	6-11

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APPENDIX XX

Onychiurus justii porteri, 60°F: Instar duration, in days, for pairs of male and female.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12
NO. OF REPLICATES	14	14	14	14	14	14	14	14	13	12	10	10
AVERAGE	9,14	9,57	11,14	10,85	10,07	11,92	10,78	12,42	10,69	11,33	10,70	9,90
RANGE	8-10	7-11	8-14	8-16	8-16	8-17	8-13	10-16	6-16	7-15	9-13	8-13

INSTAR	13	14	15	16	17	18	19	20	21	22	23	24
NO. OF REPLICATES	10	10	10	9	6	5	4	2	2	2	2	2
AVERAGE	11,60	10,60	12,40	11,11	12,0	11,0	13,0	9,0	12,50	9,50	13,50	12,0
RANGE	9-15	8-13	8-19	8-22	11-15	9-15	11-18	8-10	10-15	9-10	10-17	11-13

APPENDIX XXI

Onychiurus justus porteri, 70°F: Instar duration, in days, for pairs of male and female.

INSTAR	NO. OF REPLICATES	AVERAGE	RANGE
1	28	5,53	5-7
2	28	5,64	4-7
3	28	5,89	4-9
4	28	6,14	4-9
5	28	6,21	3-10
6	28	6,67	5-10
7	28	7,0	4-10
8	28	7,21	5-12
9	27	6,44	4-11
10	26	6,69	4-10
11	21	6,38	4-9
12	18	7,05	4-11
13	18	7,22	4-11
14	17	7,17	5-10
15	14	7,85	4-11
16	12	7,91	6-11
17	11	6,18	5-11
18	7	8,28	6-12
19	5	5,60	4-7

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APPENDIX XXII

Onychiurus justl porteri n.ssp. 80°F: Instar duration, in days, for pairs of male and female.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12
NO. OF REPLICATES	7	7	7	7	7	7	6	6	6	5	3	3
AVERAGE	6,0	6,0	6,14	5,57	9,57	13,57	12,66	16,0	9,83	7,40	13,66	14,66
RANGE	5-7	4-9	5-9	4-9	6-14	7-33	5-24	8-24	9-12	6-11	8-17	7-20

APPENDIX XXIII

Onychiurus justl porteri n.ssp., 60°F: Instar duration, in days, for isolated females.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
O. OF EPLICATES	42	42	42	42	42	41	41	41	38	28	23	18	16	12	6	4
AVERAGE	9,30	10,04	11,57	11,71	10,54	11,56	11,34	10,39	12,05	10,07	10,82	11,33	9,20	10,83	11,16	8,25
RANGE	8-11	8-13	8-18	6-17	6-17	7-20	5-20	7-17	6-17	6-14	7-17	8-17	8-14	8-15	8-13	8-9

APPENDIX XXIV

Onychiurus justii porteri n.ssp., 70°F: Instar duration, in days, for isolated females.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12
NO. OF REPLICATES	20	20	20	20	20	20	20	20	19	19	18	14
AVERAGE	5,70	5,90	5,40	6,30	6,95	6,85	7,90	6,80	7,31	6,78	7,00	7,92
RANGE	5-7	5-9	5-7	5-8	4-12	4-9	5-12	5-10	5-10	5-10	5-10	5-11

INSTAR	13	14	15	16	17	18	19	20	21	22	23
NO. OF REPLICATES	10	7	6	5	5	5	4	4	4	4	3
AVERAGE	7,80	6,85	6,83	6,60	6,00	6,80	8,25	6,50	6,75	7,75	6,66
RANGE	5-13	4-10	6-8	4-8	5-8	5-10	6-12	5-8	5-9	4-11	4-9

APPENDIX XXV

Onychiurus just i porteri n.ssp., 80°F: Instar duration, in days, for isolated females.

INSTAR	NO. OF REPLICATES	AVERAGE	RANGE
1	23	6,47	5-7
2	23	6,0	3-8
3	23	8,0	4-41
4	23	8,86	4-29
5	23	8,78	5-26
6	22	9,62	5-22
7	22	10,72	5-34
8	22	10,59	5-19
9	22	12,22	7-34
10	19	11,21	5-24
11	17	9,82	5-34
12	16	11,25	5-28
13	13	12,46	6-27
14	9	9,77	7-15
15	8	14,62	6-32
16	5	8,60	4-14
17	5	9,0	7-12
18	3	6,66	5-8

APPENDIX XXVI

Onychiurus justl porteri n.ssp., 60°F: Instar duration, in days, for isolated males.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
NO. OF REPLICATES	27	27	27	27	26	26	26	26	25	24	18	16	14	12	6	3
AVERAGE	9, 11	10, 55	11, 11	10, 0	10, 38	10, 69	10, 61	10, 65	10, 68	10, 54	11, 94	9, 62	13, 07	8, 91	12, 33	8, 0
RANGE	8-10	8-14	8-16	7-17	7-15	7-22	6-16	7-19	7-18	7-17	8-17	6-19	8-23	6-13	8-14	7-9

APPENDIX XXVII

Onychiurus justii porteri n.ssp., 70°F: Instar duration, in days, for isolated males.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14
NO. OF REPLICATES	10	10	10	10	10	10	10	10	10	11	11	15	17	15
AVERAGE	5,50	5,70	5,30	5,50	6,0	6,70	6,60	6,60	6,40	6,36	5,72	7,0	6,94	7,0
RANGE	4-6	5-7	4-6	5-6	4-8	5-8	5-9	5-9	5-9	5-9	4-7	4-11	5-11	5-10

INSTAR	15	16	17	18	19	20	21	22	23	24	25	26	27
NO. OF REPLICATES	15	18	17	17	16	16	15	15	15	15	13	7	5
AVERAGE	6,80	6,77	6,88	6,35	7,18	6,06	7,26	6,40	7,73	7,40	7,23	6,57	7,60
RANGE	5-10	4-8	6-8	5-11	5-11	4-8	5-9	4-9	4-12	5-11	5-11	5-8	7-8

APPENDIX XXVIII

Onychiurus just porteri n.ssp., 80°F: Instar duration, in days, for isolated males.

INSTAR	NO. OF REPLICATES	AVERAGE	RANGE
1	30	6,20	5-9
2	30	6,13	4-12
3	30	6,43	5-10
4	30	6,80	4-11
5	30	8,13	4-24
6	29	10,24	4-25
7	29	10,96	5-32
8	27	11,33	6-27
9	26	11,61	5-29
10	23	10,26	5-23
11	20	14,10	5-38
12	17	11,23	6-22
13	14	12,21	5-23
14	10	10,80	5-28
15	8	10,37	7-22
16	8	15,12	9-29
17	4	8,50	6-11
18	3	6,0	6

APPENDIX XXIX

Onychilurus justl porteri n.sp., 60°F: Instar duration, in days, for pairs of males.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14
NO. OF REPLICATES	9	9	9	9	8	8	8	8	8	7	5	5	5	3
AVERAGE	9,22	10,88	9,55	10,22	11,25	11,75	11,50	9,0	11,37	11,57	9,33	11,80	12,80	10,0
RANGE	9-10	9-13	8-11	7-14	8-18	10-16	8-18	7-12	8-14	8-17	8-16	9-17	10-14	9-11

APPENDIX XXX

Onychiurus justii porteri n.ssp., 70°F: Instar duration, in days, for pairs of males.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13
NO. OF REPLICATES	9	9	9	9	9	9	9	9	9	9	9	9	9
AVERAGE	5,55	5,44	5,66	4,88	5,88	6,44	6,77	7,00	7,33	6,44	6,66	8,11	6,66
RANGE	5-6	5-6	5-6	4-6	5-7	5-9	4-10	5-9	6-8	5-9	5-9	6-10	5-10

INSTAR	14	15	16	17	18	19	20	21	22	23	24	25	26
NO. OF REPLICATES	9	8	8	8	8	6	6	6	5	3	3	3	3
AVERAGE	6,77	7,25	6,62	7,25	7,25	6,66	7,83	6,83	7,40	7,00	6,66	7,00	7,00
RANGE	5-9	4-9	5-8	5-11	5-9	5-10	6-11	5-9	6-8	6-8	6-8	5-9	5-8

APPENDIX XXXI

Onychiurus justii porteri n.sp., 60°F: Instar duration, in days, for pairs of females.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
NO. OF REPLICATES	15	15	15	15	15	15	15	14	13	12	11	11	10	8	5
AVERAGE	8,80	10,13	10,53	12,0	10,80	10,86	11,40	12,0	11,07	10,66	10,0	11,27	12,0	10,87	10,20
RANGE	8-11	8-11	9-13	8-21	8-19	8-20	9-19	8-20	8-15	7-15	8-14	9-13	9-15	8-12	9-12

APPENDIX XXXII

Onychiurus justii porteri n.ssp., 70°F: Instar duration, in days, for pairs of females.

INSTAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NO. OF REPLIC.	8	8	8	8	8	8	8	8	8	8	8	6	6	5	5	4	3	3	3	3
AVERAGE	5,75	5,50	7,37	6,12	6,62	7,75	7,25	6,37	8,0	6,87	8,37	8,50	8,0	7,0	7,80	6,60	7,0	7,33	7,0	7,33
RANGE	5-7	4-8	5-10	4-9	5-9	6-10	6-9	5-7	5-11	5-9	6-12	8-10	7-9	4-9	6-11	5-8	5-10	5-10	6-8	7-8

APPENDIX XXXIIII

Onychiurus justii porteri n.ssp., 60°F: Head length and head width in the first six instar of individuals reared in mass culture.

INSTAR	1	2	3	4	5	6
NO. OF REPLICATES	3	16	7	19	36	20
LENGTH AVERAGE	101,96	171,28	213,55	252,83	272,53	314,59
RANGE	94,8-112,0	137,9-189,6	181,0-236,9	215,4-267,2	245,5-318,9	275,8-344,8
S.D.	8,94	17,62	21,90	12,07	19,23	19,27
WIDTH AVERAGE	132,16	192,81	230,28	280,07	311,33	347,10
RANGE	129,3-133,6	159-4-228,3	211,1-254,1	245,5-301,7	288,7-336,1	318,9-366,3
S.D.	2,46	17,25	15,17	13,61	18,45	12,90

APPENDIX XXXIV

Onychiurus justii porteri n.ssp., 70°F: Head length and head width in the first six instars of individuals reared in mass culture.

INSTAR	1	2	3	4	5	6
NO. OF REPLICATES	22	25	25	41	55	30
LENGTH AVERAGE	116,15	162,72	204,22	246,92	279,54	306,89
RANGE	103,4-137,9	129,3-172,4	172,4-241,2	206,8-280,1	245,5-327,5	262,9-344,8
S.D.	9,03	11,95	16,41	16,45	19,93	19,33
WIDTH AVERAGE	140,40	175,84	225,72	267,71	306,29	338,56
RANGE	129,3-146,5	155,1-194,3	215,4-241,2	249,8-301,7	275,8-336,1	318,9-357,7
S.D.	5,41	9,86	10,30	11,65	13,96	11,28

APPENDIX XXXV

Onychiurus justiporterii n.ssp., 80°F: Head length and head width in the first six instars of individuals reared in mass culture.

INSTAR	1	2	3	4	5	6
NO. OF REPLICATES	20	24	27	10	26	22
LENGTH AVERAGE	119,95	160,67	184,01	230,44	258,68	278,52
RANGE	99,1-137,9	120,6-172,4	146,5-215,4	206,8-258,6	228,3-228,7	241,2-310,3
S.D.	14,71	13,48	18,68	17,95	16,86	18,07
WIDTH AVERAGE	144,10	173,60	210,30	261,57	283,08	311,07
RANGE	129,3-155,1	150,8-189,6	181,0-236,9	245,5-275,8	249,8-318,9	267,2-331,8
S.D.	7,26	12,49	11,56	9,80	16,45	16,03

APPENDIX XXXVI

Onychiurus just porteri n.ssp., 60°F: Over-all length in microns.

INSTAR	NO. OF REPLICATES	AVERAGE	RANGE
1	3	507,3	461,4-545,0
2	16	743,3	654,6-861,4
3	23	975,5	760,7-1270,3
4	21	1231,8	1803,4-1433,8
5	41	1449,8	1225,1-1744,1
6	21	1659,3	1384,6-1902,9
7	46	1829,2	1531,3-2195,6
8	17	1930,7	1728,5-2138,5
9	17	1950,1	1665,4-2276,4
10	27	1922,7	1535,1-2347,0
11	18	1872,2	1594,9-2105,1
12	30	1804,5	1590,0-2054,5
13	21	1902,6	1556,6-2466,9
14	12	1930,9	1654,7-2293,1
15	12	1956,3	1579,8-2529,9
16	6	1965,4	1708,5-2139,0
17	19	1849,2	1611,6-2188,6
18	9	1907,5	1721,5-2152,5
19	12	2012,2	1817,3-2201,5
20	9	2181,3	1855,1-2698,8
21	12	1856,9	1527,5-2189,7
22	10	1956,9	1566,3-2464,7
23	12	1814,7	1695,6-1959,0
24	16	1878,9	1536,1-2134,7
25	15	1918,4	1661,7-2256,2
26	8	1825,0	1594,9-2001,0
27	10	1645,4	1511,4-1855,6
28	6	1792,3	1537,2-1984,3
29	6	1790,1	1553,0-2054,5
30	-	-	-
31	3	1901,3	1820,6-2012,6
32	4	1764,5	1700,0-1855,0
33	1	(1870,0)	-

APPENDIX XXXVII

Onychiurus just i porteri n.ssp., 70°F: Over-all length in microns.

INSTAR	NO. OF REPLICATES	AVERAGE	RANGE
1	22	540,7	345,1-637,3
2	26	780,2	611,7-855,1
3	30	1000,2	927,8-1141,1
4	44	1293,0	1166,4-1417,3
5	59	1511,7	1264,5-1752,2
6	42	1689,3	1493,6-1927,7
7	30	1766,5	1483,9-1977,6
8	12	1869,2	1619,1-2199,9
9	29	1861,2	1577,5-2136,9
10	25	1953,1	1669,7-2404,4
11	34	1906,7	1628,3-2292,4
12	27	2013,1	1561,5-2513,4
13	41	1967,0	1640,6-2334,6
14	18	1970,8	1674,0-2441,3
15	12	1755,3	1636,3-1923,9
16	16	1954,1	1645,0-2278,9
17	19	1810,8	1577,6-2204,8
18	14	1674,3	1469,5-2053,4
19	9	1795,7	1558,8-2011,4
20	10	1715,5	1519,4-2076,0
21	13	1709,9	1427,7-2318,4
22	10	1758,1	1435,5-2021,3
23	11	1665,1	1437,4-1970,1
24	6	1814,6	1586,8-2139,0
25	12	1799,5	1444,2-2104,6
26	3	1854,2	1766,7-2004,0
27	7	1553,9	1310,3-1855,4
28	9	1700,0	1524,3-2088,9
29	3	1943,7	1712,8-2155,2
30	-	-	-
31	12	1674,9	1299,0-2000,2
32	8	1844,9	1603,5-2021,8
33	9	1684,4	1443,1-1945,0
34	3	1690,5	1638,0-1737,6
35	3	1673,3	1612,1-1729,0
36	6	1653,0	1478,2-1894,9
37	7	1525,5	1125,6-1795,3
38	3	1596,1	1519,4-1695,1
39	-	-	-
40	-	-	-
41	5	1687,0	1503,5-1837,3

APPENDIX XXXVIII

Onychiurus justus porteri n.ssp., 80°F: Over-all length in microns.

INSTAR	NO. OF REPLICATES	AVERAGE	RANGE
1	20	490,6	345,3-595,5
2	26	742,8	538,3-847,0
3	30	913,8	705,8-1019,4
4	9	1204,5	1107,2-1281,0
5	28	1325,6	1179,3-1558,8
6	22	1469,1	1325,9-1618,0
7	21	1609,9	1455,3-1786,1
8	23	1650,4	1446,7-1869,5
9	16	1743,3	1572,8-1966,5
10	12	1726,6	1535,1-1978,2
11	21	1871,7	1618,0-2154,3
12	15	1896,6	1699,7-2104,0
13	13	1836,9	1439,4-2297,3
14	15	1887,6	1640,6-2085,8
15	8	1794,2	1718,8-1949,3
16	21	1828,4	1325,9-2195,6
17	15	1842,8	1560,4-2253,4
18	17	1644,1	1327,0-2116,4
19	3	1249,6	1193,4-1303,3
20	11	1754,2	1343,7-2016,9
21	14	1539,3	1323,5-1945,0
22	8	1572,7	1373,3-1745,2
23	14	1562,4	1209,1-1978,2
24	6	1434,7	1301,7-1561,5
25	10	1415,2	1357,1-1468,3

APPENDIX XXXIX

Onychiurus justii porteri n.ssp., 60°F: Average over-all length, in microns, for males and females.

INSTAR	M A L E S			F E M A L E S		
	AVERAGE	REPL.	RANGE	AVERAGE	REPL.	RANGE
4	1233,7	4	1167,7-1308,0	1231,4	17	1083,4-1433,8
5	1428,5	10	1267,2-1609,4	1456,6	31	1225,1-1744,1
6	1502,7	4	1425,9-1577,1	1696,1	17	1384,6-1902,9
7	1788,2	2	1702,6-1873,8	1831,0	44	1531,3-2195,6
8	-	-	-	1930,7	17	1728,5-2138,5
9	(2018,2)	1	1665,4-	1945,8	16	1665,4-2276,4
10	1766,1	8	1535,1-2103,5	1988,6	19	1629,9-2347,0
11	1844,1	10	1669,7-1953,6	1907,4	8	1594,9-2105,1
12	1772,3	21	1590,0-1995,4	1879,5	9	1611,6-2054,5
13	1885,9	9	1556,6-2251,6	1918,5	12	1611,6-2466,9
14	1897,3	7	1687,0-2142,3	1978,2	5	1654,7-2293,1
15	1862,9	8	1579,8-2042,3	2243,2	4	1866,3-2529,9
16	1965,3	4	1708,5-2139,0	1965,7	2	1963,8-1967,6
17	1757,5	13	1611,6-1904,6	2047,9	6	1779,1-2188,6
18	1899,1	7	1755,4-2067,4	1937,0	2	1721,5-2152,5
19	2019,1	10	1817,3-2201,5	1977,8	2	1962,7-1992,9
20	1977,3	5	1855,1-2112,6	2436,4	4	2254,9-2698,8
21	1808,8	10	1527,5-1967,6	2097,8	2	2005,8-2189,7
22	1862,4	7	1566,3-2074,9	2177,3	3	2021,3-2464,7
23	1814,7	12	1695,6-1959,0	-	-	-
24	1874,6	14	1536,1-2134,7	1909,6	2	1830,3-1988,1
25	1928,8	14	1661,7-2256,2	(1771,0)	1	-
26	1807,2	6	1594,9-2001,0	1882,3	2	1821,7-1942,8
27	1645,4	10	1494,9-1855,6	-	-	-
28	1792,3	6	1537,2-1984,3	-	-	-
29	1790,1	6	1553,0-2054,5	-	-	-
30	-	-	-	-	-	-
31	1901,3	3	1820,6-2012,6	-	-	-
32	1764,5	4	1700,0-1855,0	-	-	-
33	(1870,0)	1	-	-	-	-

APPENDIX XL

Onychiurus just i porteri n.ssp., 70°F: Average over-all length, in microns, for males and females.

M A L E S				F E M A L E S		
INSTAR	AVERAGE	REPL.	RANGE	AVERAGE	REPL.	RANGE
4	1295,4	13	1225,1-1404,2	1292,1	31	1166,4-1417,3
5	1488,5	9	1378,9-1752,2	1515,9	50	1264,5-1702,1
6	1652,8	3	1600,8-1743,5	1692,1	39	1493,6-1927,7
7	-	-	-	1766,5	30	1483,9-1977,6
8	(1835,6)	1	-	1872,2	11	1619,1-2199,9
9	1698,8	2	1577,6-1820,0	1873,3	27	1577,5-2136,9
10	1794,6	3	1669,7-1878,2	1974,7	22	1757,0-2404,4
11	1830,0	6	1711,4-2028,1	1923,1	28	1628,3-2292,4
12	1801,7	6	1561,5-2176,2	2073,5	21	1689,7-2513,4
13	1937,7	12	1678,4-2145,2	1979,2	29	1640,6-2334,6
14	1959,0	9	1718,2-2441,3	1982,7	9	1674,0-2351,6
15	1829,3	6	1661,7-1923,9	1681,4	6	1636,3-1759,2
16	1924,3	8	1645,0-2278,9	1984,1	8	1775,3-2214,5
17	1775,4	15	1577,6-1961,5	1943,6	4	1582,5-2204,8
18	1674,3	14	1469,5-2053,4	-	-	-
19	1751,5	6	1558,8-1963,3	1884,2	3	1687,0-2011,4
20	1675,5	9	1519,4-1829,2	(2076,0)	1	-
21	1707,3	12	1427,7-2318,4	(1741,4)	1	-
22	1740,0	9	1434,5-2021,3	(1921,3)	1	-
23	1665,1	11	1437,4-1970,1	-	1	-
24	1647,9	3	1586,8-1711,8	1981,4	3	1834,0-2139,0
25	1820,6	9	1444,2-2104,6	1736,2	3	1628,3-1880,4
26	(1766,7)	1	-	1898,0	2	1792,0-2004,0
27	1706,5	2	1557,7-1855,4	1492,8	5	1310,3-1728,5
28	1700,7	9	1524,3-2088,9	-	-	-
29	1943,7	3	1712,8-2155,2	-	-	-
30	-	-	-	-	-	-
31	1647,3	11	1299,0-2000,2	(1979,4)	1	-
32	1839,7	7	1603,5-2021,8	(1880,9)	1	-
33	1820,4	5	1695,6-1945,0	1514,5	4	1443,1-1670,3
34	1690,5	3	1638,0-1737,6	-	-	-
35	1673,3	3	1612,1-1729,0	-	-	-
36	1653,0	6	1478,2-1894,9	-	-	-
37	1525,5	7	1125,6-1795,3	-	-	-
38	1596,1	3	1519,4-1695,1	-	-	-
39	-	-	-	-	-	-
40	-	-	-	-	-	-
41	1687,0	5	1503,5-1837,3	-	-	-

APPENDIX XLI

Onychiurus justiporteri n.ssp., 80°F: Average over-all length, in microns, for males and females.

M A L E S				F E M A L E S			
INSTAR	AVERAGE	REPL.	RANGE	AVERAGE	REPL.	RANGE	
4	1254,5	2	1233,7-1275,3	1190,2	7	1107,2-1281,0	
5	1321,4	8	1221,3-1446,7	1327,3	20	1179,3-1558,8	
6	1454,8	7	1358,8-1576,9	1475,7	15	1325,9-1618,0	
7	1611,0	2	1609,9-1612,1	1609,9	19	1455,3-1786,1	
8	1728,2	2	1677,3-1779,1	1642,9	21	1446,7-1869,5	
9	1814,6	1	-	1738,5	15	1572,8-1966,5	
10	1625,7	3	1535,1-1719,8	1760,3	9	1577,6-1978,2	
11	1820,6	5	1634,2-2018,9	1887,7	16	1618,0-2154,3	
12	1823,2	1	-	1901,8	14	1699,7-2104,0	
13	1684,7	5	1439,4-1914,8	1932,0	8	1731,7-2297,3	
14	1883,5	6	1790,9-2011,4	1890,2	9	1640,6-2085,8	
15	1768,7	5	1718,8-1865,8	1903,2	3	1778,6-1949,3	
16	1771,7	15	1419,1-1974,4	1970,4	6	1325,9-2195,6	
17	1814,7	10	1560,4-2253,4	1899,3	5	1769,4-2166,5	
18	1619,3	14	1327,0-2116,4	1759,5	3	1536,1-1890,5	
19	1249,6	3	1193,4-1303,3	-	-	-	
20	1691,7	8	1343,7-1945,0	1920,8	3	1787,2-2016,9	
21	1553,4	12	1323,2-1945,0	1454,9	2	1406,7-1502,7	
22	1601,2	7	1445,5-1745,2	1373,3	1	-	
23	1528,1	11	1342,6-1978,2	1698,1	3	1578,2-1761,9	
24	1434,7	6	1301,7-1561,5	-	-	-	
25	1420,4	9	1357,1-1468,3	1368,5	1	-	

APPENDIX XLII

Onychiurus justus porteri n.ssp., 60°F: Percent mortality in mass reared cultures.

WEEK	TOTAL INDIVIDUALS ON 1 DAY OF WEEK	NO. OF DEATHS IN EACH WEEK	TOTAL INDIVIDUALS SAMPLED / WEEK	PERCENT MORTALITY/WEEK	PERCENT MORTALITY /WEEK, CUMULATIVE	PERCENT MORTALITY TOTAL	THEORETICAL MORT. FOR SAMPLED INDIV.	THEORET. MORTALITY /WEEK, CUMULATIVE	MORT./WEEK, CUMUL. +THEORET. MORT. CUM.
1		0		0					
2		0		0					
3		0		0					
4		0		0					
5		0		0					
6		0		0					
7		0		0					
8		0		0					
9		0		0					
10	440	2	6	0,45	0,45	0,45	0,027	0,027	0,48
11	429	2	12	0,46	0,91	0,90	0,055	0,082	0,99
12	414	4	15	0,96	1,87	1,81	0,144	0,226	2,10
13	395	2	15	0,50	2,37	2,27	0,075	0,301	2,67
14	375	6	21	1,60	3,97	3,63	0,336	0,637	4,61
15	351	6	18	1,70	5,67	5,00	0,306	0,943	6,61
16	327	4	21	1,22	6,89	5,90	0,256	1,199	8,09
17	302	3	12	0,99	7,88	6,59	0,118	1,318	9,20
18	287	5	18	1,74	9,62	7,72	0,313	1,631	11,25
19	264	5	9	1,89	11,51	8,86	0,170	1,801	13,31
20	250	1	11	0,40	11,91	9,09	0,044	1,845	13,76
21	238	2	9	0,84	12,75	9,54	0,075	1,921	14,67
22	227	3	6	1,32	14,07	10,22	0,079	2,000	16,07
23	218	7	9	3,21	17,28	11,81	0,288	2,289	19,57
24	202	5	10	2,47	19,75	12,95	0,247	2,536	22,29
25	187	6	6	3,20	22,95	14,31	0,192	2,728	25,68
26	175	3	3	1,71	24,66	15,00	0,051	2,779	27,44
27	169	3	6	1,77	26,43	15,68	0,106	2,885	29,32
28	160	2	9	1,25	27,68	16,13	0,112	2,998	30,68
29	149	4	9	2,68	30,36	17,04	0,241	3,239	33,60
30	136	3	19	2,20	32,56	17,72	0,418	3,657	36,22
31	114	1	6	0,87	33,43	17,95	0,052	3,709	37,14
32	107	2	9	1,86	35,29	18,40	0,167	3,876	39,17
33	96	5	12	5,20	40,49	19,54	0,624	4,500	44,99
34	79	2	10	2,53	43,02	20,00	0,253	4,753	47,77
35	67	2	15	2,98	46,00	20,45	0,447	5,200	51,20
36	50	1	6	2,00	48,00	20,68	0,120	5,320	53,32
37	43	2	9	4,65	52,65	21,13	0,418	5,739	58,39
38	32	0	6	0	-	0	0	-	-
39	26	1	5	3,84	56,49	21,36	0,192	5,931	62,42
40	20	1	8	5,00	61,49	21,59	0,400	6,331	67,82
41	11	1	1	9,09	70,58	21,81	0,090	6,422	77,00
42	10	1	0	10,0	80,58	22,04	-	-	80,58
43	9	0	0	0	-	0	-	-	-
44	9	0	0	0	-	0	-	-	-

APPENDIX XLIII

Onychiurus just porteri n.ssp., 70°F: Percent mortality in mass reared cultures.

WEEK	TOTAL INDIVIDUALS ON 1 DAY OF WEEK	NO. OF DEATHS IN EACH WEEK	TOTAL INDIVIDUALS SAMPLED / WEEK	PERCENT MORTALITY / WEEK	PERCENT MORTALITY /WEEK, CUMULATIVE	PERCENT MORTALITY TOTAL	THEORETICAL MORT. FOR SAMPLED INDIV.	THEORETICAL MORT. /WEEK, CUMULATIVE	MORT./WEEK, CUMUL. +THEORET. MORT., CUM.
1		0		0					
2		0		0					
3		0		0					
4	663	1	54	0,15	0,15	0,15	0,081	0,081	0,23
5	608	3	48	0,49	0,64	0,60	0,235	0,316	0,96
6	557	3	21	0,53	1,17	1,05	0,111	0,427	1,60
7	532	8	39	1,50	2,67	2,26	0,586	1,013	3,68
8	472	7	41	1,48	4,15	3,31	0,607	1,620	5,77
9	437	10	30	2,28	6,43	4,82	0,684	2,304	8,73
10	394	9	24	2,28	8,71	6,18	0,547	2,851	11,56
11	363	14	44	3,85	12,56	8,29	1,694	4,545	17,11
12	305	5	26	1,63	14,19	9,04	0,424	4,969	19,59
13	274	4	12	1,45	15,64	9,65	0,174	5,143	20,78
14	258	7	15	2,71	18,35	10,70	0,407	5,550	23,90
15	236	5	13	2,11	20,46	11,46	0,274	5,824	26,28
16	218	7	14	3,21	23,67	12,51	0,449	6,273	29,91
17	197	2	9	1,01	24,68	12,82	0,091	6,364	31,04
18	186	6	23	3,22	27,90	13,72	0,741	7,105	35,01
19	154	3	13	1,94	29,84	14,17	0,252	7,357	37,20
20	138	8	6	5,79	35,63	15,38	0,347	7,704	43,33
21	123	4	3	3,25	38,88	15,98	0,098	7,802	46,68
22	117	3	3	2,56	41,44	16,44	0,077	7,879	49,32
23	111	5	10	4,50	45,94	17,19	0,450	8,329	54,27
24	96	1	12	1,04	46,98	17,34	0,125	8,454	55,43
25	83	2	6	2,40	49,38	17,64	0,144	8,598	57,98
26	75	2	6	2,66	52,04	17,94	0,160	8,758	60,80
27	67	3	8	4,47	56,51	18,40	0,358	9,116	65,63
28	56	5	6	8,92	65,43	19,16	0,535	9,651	75,08
29	35	2	20	5,71	71,14	19,45	1,142	10,793	81,93
30	23	1	3	4,34	75,48	19,60	0,130	10,923	86,40
31	19	2	6	10,52	86,00	19,90	0,631	11,554	97,55
32	11	0	0	0	-	-	0	-	-
33	11	0	2	0	-	-	0	-	-
34	9	3	6	33,33	119,33	20,36	2,000	13,554	-

APPENDIX XLIV

Onychiurus justus porteri n.ssp., 80°F: Percent mortality in mass reared cultures.

WEEK	TOTAL INDIVIDUALS ON 1.DAY OF WEEK	NO. OF DEATHS IN EACH WEEK	TOTAL INDIVIDUALS SAMPLED / WEEK	PERCENT MORTALITY / WEEK	PERCENT MORTALITY /WEEK, CUMULATIVE	PERCENT MORTALITY TOTAL	THEORETICAL MORT. FOR SAMPLED INDIV.	THEORETICAL MORT. /WEEK, CUMULATIVE	MORT./WEEK, CUMUL. +THEORET. MORT., CUM.
1		0		0					
2		0		0					
3		0		0					
4		0		0					
5	315	1	45	0,31	0,31	0,31	0,140	0,140	0,45
6	269	4	25	1,48	1,79	1,58	0,370	0,510	2,30
7	240	2	21	0,83	2,62	2,22	0,174	0,684	3,30
8	217	7	24	3,22	5,84	4,44	0,773	1,460	7,30
9	185	13	15	7,02	12,86	8,57	0,053	1,510	14,37
10	149	3	25	2,01	14,87	9,52	0,503	2,012	16,88
11	129	5	14	3,87	18,74	11,11	0,542	2,554	21,29
12	110	9	15	8,18	26,92	13,96	0,227	2,781	29,70
13	86	1	14	1,16	28,08	14,28	0,162	2,943	31,02
14	71	2	19	2,81	30,89	14,92	0,534	3,477	34,37
15	50	2	3	4,00	34,89	15,55	0,120	3,597	38,49
16	45	3	12	6,66	41,55	16,50	0,799	4,396	45,95
17	30	0	15	0	-	0	0	-	-
18	15	0	5	0	-	0	0	-	-
19	10	1	6	10,0	51,55	17,00	0,600	4,996	56,55
20	3	0	3	0	-	0	0	-	-

APPENDIX XLV

Onychiurus justii porteri n.ssp., 60°F: Percent mortality, per week, in cultures containing five or less individuals. The series was terminated at the end of the 48 weeks.

WEEK	NO. OF INDIVID. IN CULTURE	DEATHS	PERCENT MORTALITY
1	27	4	14,81
2	23	1	18,51
3	22	0	-
4	22	0	-
5	22	0	-
6	22	0	-
7	22	0	-
8	22	0	-
9	22	0	-
10	22	0	-
11	22	1	22,22
12	21	0	-
13	21	0	-
14	21	0	-
15	21	0	-
16	21	0	-
17	21	0	-
18	21	0	-
19	21	0	-
20	21	1	25,92
21	20	0	-
22	20	0	-
23	20	1	29,62
24	19	2	37,03
25	17	1	40,74
26	16	0	-
27	16	0	-
28	16	1	44,44
29	15	0	-
30	15	0	-
31	15	1	48,14
32	14	0	-
33	14	1	51,85
34	13	0	-
35	13	1	55,55
36	12	0	-
37	12	0	-
38	12	1	59,25
39	11	0	-
40	11	0	-
41	11	0	-
42	11	0	-
43	11	0	-
44	11	0	-
45	11	0	-
46	11	0	-
47	11	0	62,96
48	10	1	66,66

APPENDIX XLVI

Onychiurus justus porteri n.ssp., 70°F: Percent mortality, per week, in cultures containing five or less individuals.

WEEK	NO. OF INDIV. IN CULTURE	DEATHS	PERCENT MORTALITY
1	32	0	-
2	32	0	-
3	32	0	-
4	32	1	3,12
5	31	1	6,25
6	30	0	-
7	30	2	12,52
8	28	3	21,87
9	25	2	28,12
10	23	1	31,25
11	22	1	34,37
12	21	0	-
13	21	0	-
14	21	1	37,50
15	20	0	-
16	20	2	43,75
17	18	1	46,87
18	17	2	53,12
19	15	1	56,25
20	14	0	-
21	14	1	59,37
22	13	1	62,50
23	12	1	65,52
24	11	2	71,87
25	9	4	87,37
26	5	0	-
27	5	1	87,50
28	4	0	-
29	4	0	-
30	4	0	-
31	4	0	--
32	4	0	-
33	4	2	93,75
34	2	0	-
35	2	0	-
36	2	1	96,87
37	1	0	-
38	1	0	-
39	1	0	-
49	1	1	100,00

APPENDIX XLVII

Onychiurus just porteri n.ssp., 80°F: Percent mortality, per week, in cultures containing five or less individuals.

WEEK	NO.OF INDIVID. IN CULTURE	DEATHS	PERCENT MORTALITY
1	30	3	10,00
2	27	0	-
3	27	1	13,33
4	27	1	16,66
5	26	3	26,66
6	23	3	36,66
7	20	3	46,66
8	17	0	-
9	17	2	53,33
10	15	0	-
11	15	1	56,66
12	14	2	63,33
13	12	0	-
14	12	1	66,66
15	11	1	70,00
16	10	0	-
17	10	1	73,33
18	9	0	-
19	9	2	80,00
20	7	0	-
21	7	1	83,33
22	6	1	86,66
23	5	1	90,00
24	4	1	93,33
25	3	0	-
26	3	0	-
27	3	0	-
28	3	0	-
29	3	1	96,66

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