BIOLOGY AND CONTROL OF THE HEAD LOUSE, *PEDICULUS HUMANUS CAPITIS* (ANOPLURA:PEDICULIDAE), IN A SEMI-ARID URBAN AREA

by

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I hereby recommend that this dissertation prepared under my direction by James Delmer Lang

entitled Biology and Control of the Head Louse, Pediculus humanus capitis (Anoplura:Pediculidae), in a Semi-Arid Urban Area

be accepted as fulfilling the dissertation requirement of the degree of Doctor of Philosophy

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SIGNED: James D. Lang

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BIOGRAPHY

James D. Lang was born in Santa Monica, California, on 13 February, 1942. He attended grammar school in Redondo Beach, California, and graduated from Mary Star of the Sea High School, San Pedro, in 1960.

He received the Bachelor of Arts degree in 1969 from the University of North Dakota, Grand Forks. His undergraduate major was biology with a minor in physical sciences.

He entered the U.S. Army in March, 1967, and served in Vietnam for twelve months. Following separation from the service in January, 1969, he began graduate work in entomology at The University of Arizona where he received the Master of Science degree in August, 1971. His thesis dealt with ectoparasites found on ground squirrels. He received a Research Assistantship from 1971-1974 in support of continued studies leading to the Doctor of Philosophy degree. His doctoral dissertation involved the biology and control of the head louse, Pediculus humanus capitis deGeer.

He is married to the former Cheryl Kay Young of New Bavaria, Ohio.

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ABSTRACT

This study examined the biology and control of the head louse, Pediculus humanus capitis deGeer, in Tucson, Arizona, a semi-arid urban area. This was accomplished by developing an improved method for rearing head lice whereby 27 generations of lice and over 57,000 eggs were produced.

The low percentage of infestations (ca. 4.3%) among 24,000 elementary school children in the Tucson study area was attributed to overall good hygienic habits. The higher-than-normal percentage of infestations among male students was probably the result of current long hair styles which provided an ideal louse habitat. The majority of infestations were in lower socio-economic areas of Tucson where all re-infestations occurred. The rarity of head lice noted among Black Tucsonians and their relative frequency among Black Africans was probably reflective of different hair styles.

Lice were transmitted mostly by direct means, but indirect means, such as borrowing infested combs or brushes, were also important.

The seasonal abundance of head lice in Tucson was observed to depend upon peoples' seasonal and social habits rather than on climatic conditions. The location of lice on an individual's head was determined by conditions of the hair which governed the moisture and light to which lice were exposed. Temperature probably had only a slight influence on location since it varied only slightly on individuals' scalps (mean = 29.1 ± 0.15 C) and hair surfaces (mean = 28.56 ± 0.3 C).

Oviposition occurred in the thicker, more sheltered areas of an individual's hair. Egg production occurred more frequently when an individual was less physically active and thus perspired less.

Eggs were first produced 14 ± 3.5 hours following insemination. Females inseminated once produced 56 ± 6.6 viable eggs. Maximum and minimum lethal temperatures for eggs were 39 ± 2 C and 24 ± 2 C, respectively. The maximum number (95-99%) of eggs hatched at 31 ± 2 C. Increased humidity increased eclosion, except that it decreased it at greater than ca. 83% r.h.

First instar nymphs were confined to the scalp surface, while later instars and adults remained in the hair close to the scalp.

Feeding by lice, as with egg production, occurred more readily when an individual remained quiet, especially at night. Minimal feeding time for survival of first and second nymphal instars was four times daily, while third nymphal instars and adults required feeding three times daily. Lice which were fed 3-4 times daily had their biological processes markedly hampered. This was the result of being deprived of a constant blood supply as under natural conditions on the host.

Females could not be inseminated until 14 ± 3.5 hours after ecdysis. The more frequent matings in higher louse populations were detrimental to females so that their numbers decreased in the rearing container (61%), but not in natural populations (76%).

Starved adult head lice survived 24 ± 1.8 hours at 26 ± 2 C, while at 46 ± 2 C they lived 30-35 minutes.

Gregariousness was noted to be caused by lice seeking better conditions of temperature and humidity, rather than to a true clustering behavior.

Prevention is the best means of controlling the head louse. Prevention involves educating people as to this louse's biology and mode of transmission. Experiments showed that lengths of treatment with currently available pediculicides should be changed to assure that these compounds are completely ovicidal. Revising the directions for the experimental use of 1% malathion dust and their translation into Spanish facilitated its use by parents.

Tucson head lice were not resistant to various concentrations of DDT, lindane, and malathion formulated powders.

INTRODUCTION

The occurrence of head lice, Pediculus humanus capitis deGeer, can depend upon the age, sex, ethnicity, customs, and hygienic conditions of a population. Other factors such as climate and general human health may also play a part.

Most workers have noted that younger aged groups are generally more infested than older groups due to their inferior personal hygienic habits. Greenough (1887) recorded that 88% of infestations reported in Boston were 1-15 years of age, while Buxton (1938a) noted that African children 6-15 years of age comprised 63% of reported infestations.

Females have composed the majority of infestations due to their usually longer hair. The percent of head louse infestations among a sample of New York Caucasian school children was 16.5%, of which 83% were girls (Sobel, 1913). Prevalence among some English school children was estimated to be 50% for girls and 30-40% for boys (Mellanby, 1941). Iranian villagers were found to be ca. 40% infested, of which 75% were female (Jalayer, 1967).

Sobel (1913) observed that Black Americans were rarely infested (only 0.5%) with head lice. He found lice more often on Blacks with soft straight hair, among those whose parents had light black skin, or in cases where one parent was Caucasian. He believed the infrequency of lice among Blacks to be due mostly to their habit of frequently combing the hair so as to straighten the kinks. But Buxton (1938a) found a similar percentage of head louse infestations among various

African tribes when compared to Ceylonese and Palestinian prisoners (non-Blacks).

The greater occurrence of head lice among populations whose hygienic habits have deteriorated has been well documented. Individuals of the lower socio-economic levels of society (Nuttall, 1917a; Mellanby, 1941), those under stress as soldiers (Nuttall, 1918), prisoners (Buxton, 1938a), refugees (Mellanby, 1941; Roy and Ghosh, 1944), and those choosing a communal life style (Alexander, 1968) are more susceptible to infestations of head lice.

The changing life styles of young people in the past 10 years have greatly increased the prevalence of head lice in the United States and in other countries (Alexander, 1968; Wexler, 1968). In light of this increase, a need exists to furnish nurses and other public health officials with a reference that will answer questions concerning this pest.

This study examines the biology and control of the head louse in Tucson, Arizona, a semi-arid urban area. It also attempts to resolve questions concerning certain topics examined by past workers who arrived at contradictory results.

HISTORICAL REVIEW OF THE HUMAN LOUSE, *PEDICULUS HUMANUS*

The human louse, *Pediculus humanus* Linnaeus, is an obligate blood-sucking ectoparasite of man. It is taxonomically divided into two subspecies: the body louse, *P. h. humanus* Linnaeus, and the head louse, *P. h. capitis* deGeer. The body louse occurs mostly on the clothing, feeds sporadically, and under natural conditions attaches eggs to the clothing. The head louse is found mainly on the head, but can also infest the body, feeds frequently, and under natural conditions attaches eggs to the hair.

Investigators of the evolution of *Pediculus humanus* on man agree that the body louse descended from the head louse (Nuttall, 1919b; Waterson, 1921; Zinsser, 1935). According to this view, as primitive man began to lose his body hair he adopted clothing, while the lice on his body adapted themselves to these altered conditions. The head louse, not having to adapt to a changing habitat, is considered the primitive form. Nuttall (1919b, p. 345) believed: "that *capitis* is being converted into *corporis* (=*humanus*) today in nature, and that the latter, when man has become hairless, will constitute a species whose birth we are witnessing."

Human lice have played a part in man's superstitions as well as influencing his social and political life. Purported medicinal powers of lice have been reported through the ages. Aegineta and Avicenna (980-1036 A.D.) advocated the use of them in removing "peccant humours" from man, while Linnaeus believed that children were protected from a number of diseases by lice (Zinsser, 1935). Lice were eaten by the

American Indians, Budini, Hottentots, and by the medieval English, for medicinal purposes, especially as a remedy for jaundice (Zinsser, 1935). French mothers placed head lice upon their childrens' heads as a protective and curative measure (Knott, 1905). The uninformed in England, India, and the Far East believed that lice were a sign of fertility (Shipley, 1916). The belief that head lice were beneficial prevailed among the Irish (Knott, 1905). The poor in Scotland (Nuttall, 1918) and certain ethnic groups in New York City (Sobel, 1913) believed that a good head louse population was a sign of good health, a view which today is shared by some Papago and Yaqui Indians (Zempel, 1972).

The statement that with the spread of Christianity "the louse commenced to enjoy most exceptional privileges" (Knott, 1905) is no doubt true (Nuttall, 1918). Certain saints, who practiced self-denial by living in filth and squalor by never washing, and who wore long, unruly hair and beards and dirty rags, were probably morally good examples to their fellow men, but not so physically (Nuttall, 1918). The superior sanitary habits of the Romans were followed in the Dark Ages by a return to poor hygienic conditions which persisted through many centuries. The Dark Ages were consequently "the age of the louse" (Nuttall, 1918).

Living conditions during the Middle Ages were such that aristocrats were almost as susceptible to lice as the poorer classes. Washing was almost out of the question and aristocrats wore a great many clothes which were rarely changed (Zinsser, 1935), thus providing for an ideal louse habitat. This is illustrated by the documented story of Thomas á Beckett's funeral (Zinsser, 1935, p. 185). "As the Archbishop's body grew cold,

lice began to crawl out from his eight layers of clothing: vermin boiled over like water in a simmering cauldron, and the onlookers burst into alternate weeping and laughter."

The custom of shaving the head wholly or partly by ancient and modern people, and among the priesthood, was no doubt an effort to control head lice (Nuttall, 1918). The aristocracy's habit of shaving the head and wearing a wig during the 17th and 18th centuries also was partly due to attempts to control head lice, but the wigs they wore often contained eggs (Zinsser, 1935) which when hatched could again cause infestations.

Improved sanitary practices, such as frequent bathing, during the last 100 years have mostly limited louse populations to the lower socio-economic levels of societies, and to conditions that foster a breakdown in sanitary habits. Although anyone may acquire human lice, their continued presence, to most people, signifies a disregard for cleanliness and health.

The Body Louse, *Pediculus humanus humanus*, as a Disease Vector

The body louse has been proven the natural vector for the agent (*Rickettsia prowazeki*) of epidemic typhus (Nicolle, Comte, and Conseil, 1909; Ricketts and Wilder, 1910), as well as the agents for trench fever (*R. quintana*) (Hurst, 1916; Davies and Weldon, 1917), and relapsing fever (*Borrelia recurrentis*) (Mackie, 1907). With the discovery that the body louse was an effective vector for these pathogenic microorganisms a number of investigations were carried out concerning

its biology (Nuttall, 1917a, 1919a; Buxton, 1947), vector capabilities (Snyder and Wheeler, 1945; Weyer, 1952; Vinson, 1966), and control (Nuttall, 1918; Busvine, 1945; Eddy and Carson, 1948; Steinberg et al., 1971).

Epidemic typhus has afflicted man for centuries. It probably did not become epidemic in Europe until the 15th century (Zinsser, 1935). Before that time it may have remained in pockets as endemic typhus so that its occurrence escaped recognition. Epidemic typhus has devastated cities, driven populations into exile, and turned conquering armies into panic-stricken rabble (Zinsser, 1935). Typhus has repeatedly been a decisive factor in military history. A historian noted that, during Napoleon's campaign against Russia, neither country could effectively wage a battle because the "cootie" won the war. The prevalence of head lice during World War I had never before been equaled in the world's history (Nuttall, 1917a). Epidemic typhus in Russia alone killed three million people from 1917 to 1921 (Zinsser, 1935).

The body louse, and thus louse-borne diseases, have been greatly reduced in the past 30 years, due mostly to the development and use of more effective insecticides. For example, the chlorinated hydrocarbon DDT, first used to suppress a typhus outbreak in Naples, Italy, during the winter of 1943-44 (Wheeler, 1946), prevented a repetition of the post-World War I outbreak of typhus at the end of World War II.

The Head Louse, *Pediculus humanus capitis*, as a Disease Vector

The head louse has never been a proven natural vector of pathogenic microorganisms, although, as depicted in Table 1, it has the potential to vector them. This was evidenced by Busvine (1945), who assigned the major role of the spread of typhus to the body louse, since typhus is almost completely absent from northwestern Europe where the head louse is comparatively frequent and the body louse infrequent in occurrence. The relationship between pathogenic microorganisms and human lice, mostly body lice, is discussed by Weyer (1960).

Dermatitis has frequently been caused by scratching as the result of irritation by head louse feeding (Sobel, 1913; Nuttall, 1917b). Persistent scratching can lead to secondary infections involving the scalp, but they can also occasionally involve the eyes. Scalp and eye diseases attributed to the head louse are depicted in Table 2. Although Hudson (1914) and Hirtenstein (1943) fail to mention how head lice cause eye diseases (Table 2), I believe that they may be initiated via contamination of the eyes by louse fecal material.

The hygienic habits of an individual in this study were found to generally reflect the number of head lice found on him and accordingly the condition of his scalp. The majority of infested individuals examined were mildly infested and were found to have very slight dermatitis of the scalp, while a few heavily infested persons were noted to have plica polonica.

Table 1. Natural infection and experimental transmission of pathogenic microorganisms by the head louse, Pediculus humanus capitis.

Pathogenic Microorganism/ Disease Produced	Natural Infection of Head Lice with Pathogenic Microorganisms	Experimental Transmission of Pathogenic Microorganisms	Source
Mycobacterium leprae/ Leprosy	Infecting two specimens out of many from nodular leprosy patient	Not conducted	McCoy and Clegg (1912)
Yersinia pestis/ Bubonic plague	Infecting specimens from plague patient	Specimens ground in saline sol.; inoculated rats; 5/5 rats died of plague	deRaadt (1916)
Rickettsia prowazeki/ Epidemic typhus	Infecting specimens from epidemic typhus patients	Specimens ground in saline sol.; inoculated monkeys; 5/7 developed typical febrile reactions with subsequent resistance to inoc. of virulent typhus blood	Goldberger and Anderson (1912)
Salmonella typhi/ Typhoid fever	Infecting 75% of specimens from typhoid patient	Not conducted	Abe (1907)

Table 2. Scalp and eye diseases attributed to the head louse, Pediculus humanus capitis.

Disease	Definition of Disease[1]	Source[2]
Scalp		
Favus	Yellowish crusts usually over hair follicles accompanied by musty odor and itching, which may spread to rest of body	Waterson (1921)
Folliculitis	Abnormal quantity of lymph follicles	Sobel (1913)
Furunculosis	Resulting from boils	Sobel (1913)
Impetigo Contagiosa	Inflammation marked by isolated pustules that become crusty and rupture	Brumpt (1910)
Morbus Errorum (Vagabond's Disease)	Frequently bitten area is rough, thickened, and deeply pigmented	Nuttall (1917b)
Plica Polonica	Mat of hair, scabs, and crusts	Sobel (1913)
Eye		
Conjunctivitis	Inflammation of conjunctiva	Hirtenstein (1943)

Table 2. (Continued) Scalp and eye diseases attributed to the head louse, Pediculus humanus capitis.

Disease	Definition of Disease[1]	Source[2]
Eye (Continued)		
Prob. Corneal Infiltration	Penetration of the cornea which usually does not heal	Hirtenstein (1943)
Phlyctenular Keratitis	Inflammation of conjunctiva and cornea accompanied by formation of small projections consisting of accumulations of lymphoid cells	Hudson (1914)

1. From Taber (1964).

2. Disease reported initially by the respective authors.

Studies regarding the head louse, especially its biology, have been meager. The lack of interest in the head louse is principally due to its apparent inability to naturally vector pathogens. One of the better biological works concerning the head louse was conducted by Nuttall (1917a; 1919a). Its occurrence on various races of man was investigated by Buxton (1937, 1938a, 1940a), while a number of studies have examined its prevalence (Sobel, 1913; Mellanby, 1942) and control (Murphy, 1943; Kaiser, 1946; Gardner, 1958) among school children, and among individuals whose hygienic conditions have deteriorated under stress situations (Nuttall, 1918; Buxton, 1938a; Mellanby, 1941; Roy and Ghosh, 1944).

SYNONYMY OF THE HEAD LOUSE, PEDICULUS HUMANUS CAPITIS

The synonymy of the head louse, Pediculus humanus capitis deGeer, is as follows:

1758 Pediculus humanus Linnaeus (in part)

1767 Pediculus humanus var. I Linnaeus

1778 Pediculus humanus capitis deGeer

1804 Pediculus cervicalis Latreille

1816 Pediculus pubescens deOlfers

1818 Pediculus capitis : Nitzsch

(?) 1880 Pediculus consobrinus Piaget

1915 Pediculus capitis angustus Fahrenholz

1915 Pediculus capitis maculatus Fahrenholz

1916 Pediculus friedenthali Fahrenholz

1916 Pediculus oblongus Fahrenholz

1917 Pediculus capitis capitis : Fahrenholz

1919 Pediculus assimilis

1926 Pediculus humanus americanus Ewing

1926 Pediculus humanus humanus : Ewing

Linnaeus originally (1758) used the name Pediculus humanus for both the head and body louse, and later (1767) used variety I for head-infesting forms, and variety II for body-infesting forms. These varieties were later named, respectively, P. h. capitis and P. h. corporis (deGeer, 1778).

P. cervicalis was named for "le pou de tête" (Latreille, 1804). Deeply pigmented specimens from the heads of the Black race were designated P. pubescens (deOlfers, 1816). Nitzsch (1818) used the name P. capitis for the head louse and P. vestimenti for the body louse. P. consobrinus was given specific rank for lice from a spider monkey, Ateles pentadactylus, (Piaget, 1880). The single remaining female in the Piaget Collection was examined and attributed to P. h. capitis by Nuttall (1919b), and later identified as P. h. humanus by Ferris (1951).

Fahrenholz maintained that the head and body louse belonged to separate species and began to supply each race of man with a subspecies. P. c. angustus was named (1915) for lice from Japanese. P. c. maculatus was named (1915) for Hottentot Blacks and later (1917) extended to specimens from Blacks from Cameroon, Africa, and from Blacks from Paramaribo, Surinam. Fahrenholz (1916) named specimens occurring on a gibbon, Hylobates mülleri, locality not given, as P. friedenthali, of which the female was described only as "much resembling the head louse of man." P. oblongus was named (1916) for a single female louse from H. syndactylus. Specimens from Caucasians in the Hamburg Museum were designated (1917) as P. c. capitis. P. assimilis was designated by Fahrenholz (1919) for lice from two gibbon species, H. mülleri, and H. syndactylus, from the Zoological Gardens, Berlin.

Fahrenholz' specimens were carefully compared by Nuttall (1920) to his own specimens in regard to measurements, morphology, and pigmentation. Nuttall commented (p.149) "the worst blunders committed by Fahrenholz are due to his relying upon pigmentation in his diagnoses, this leading to his referring to various structures as "absent" in

some pediculi, and "present" in others." Nuttall consequently placed angustus, maculatus, friedenthali, oblongus, capitis, and assimilis as synonyms of P. h. capitis. He concluded (p. 152) "the evidence adduced in this paper (Nuttall's) points to the imperative necessity for the employment of more scientific method(s) in the description and differentiation of species of Anoplura." Fahrenholz' specimens were also later examined by Ferris (1935), who found no solid evidence for recognizing any of the names except maculatus. He noted that maculatus may represent a genetically defined type, although he rejected it due to its complete intergradation with the more typical forms.

Ewing (1926) supported the opinion that head and body lice of Europeans were a single species but maintained that they represent subspecies. P. h. humanus was restricted to head lice collected from Caucasians in Germany. He recorded the Caucasian race as the type host. He thus tried to establish the head louse as the typical form and ignored the earlier fixation of the name as proposed for "le pou du corps" by Latreille (1804). Specimens from scalps of pre-Columbian American Indian mummies from Surco, Peru, were designated as P. h. americanus (Ewing, 1926). This name was also applied to specimens from Mayan Indians of Yucatan and Guatemala (Ferris, 1935), and later questionably applied to specimens found on two monkeys at the National Zoological Park (Ewing, 1936). No justifiable reason for recognition of this name was found by Ferris (1935).

DESCRIPTION OF THE LIFE STAGES OF THE HEAD LOUSE, *PEDICULUS HUMANUS CAPITIS*

The structural differences that occur during growth of the nymphal instars of the body louse, *Pediculus humanus humanus* Linnaeus were compared by Buxton (1938b). He found it easy to distinguish the first nymphal instar from the others, but more difficult to distinguish the second from the third nymphal instar. The best point of distinction between the instars was found to be the length of tibia III, which increased in size from the first to the third instars. Buxton (1938b) noted that this distinction also applied to the head louse, *P. h. capitis* deGeer. He found that the only difference observed between the nymphal instars of the body and head louse was the slightly smaller size of the latter's second and third instars. The descriptions of the nymphal instars and adults of the head louse, given below, are after Buxton (1938b).

The term "nymphal instars" will be used throughout this study to designate the hatched, non-adult stages of the head louse.

Egg

Length ranging from 0.7 to 1.0 mm. Width, at widest diameter, 0.3 to 0.5 mm. Operculum at distal end. Light to dark brown in color depending upon viability or non-viability, and developmental period.

Nymph

First Instar (Fig. 1A)

Length ranging from 1.0 to 1.3 mm. Setae on dorsum of abdomen few, long, and in longitudinal lines; one median pair being on most segments. Paratergal plates (bearing spiracle) absent. Mean length tibia III, 0.192 mm. Ratio of head to thorax and abdomen ca. 1:2.8.

Second Instar (Fig. 1B)

Length ranging from 1.4 to 2.0 mm. Setae of dorsum of abdomen in one transverse row, containing two to three setal pairs. Paratergal plates present, as in third instar. Mean length tibia III, 0.264 mm. Ratio of head to thorax and abdomen ca. 1:3.5.

Third Instar (Fig. 1C)

Length ranging from 2.1 to 2.6 mm. Setae on dorsum of abdomen not in one row, but somewhat irregular; a pair of minute supplementary setae being present on segments VII and VIII close to midline. Mean length tibia III, 0.358 mm. Ratio of head to thorax and abdomen ca. 1:4.3.

Adult

The following general description of the adult male and female head louse is in part after Ferris (1935). Shape usually elongate and swollen with pigmentation varying from pale to dark. Antennae usually shorter than head. Abdominal setae more or less arranged in rows. Thoracic spiracles varying in size. Paratergal plates vary in pigmentation and extent, but never with dorsal and ventral lobes.

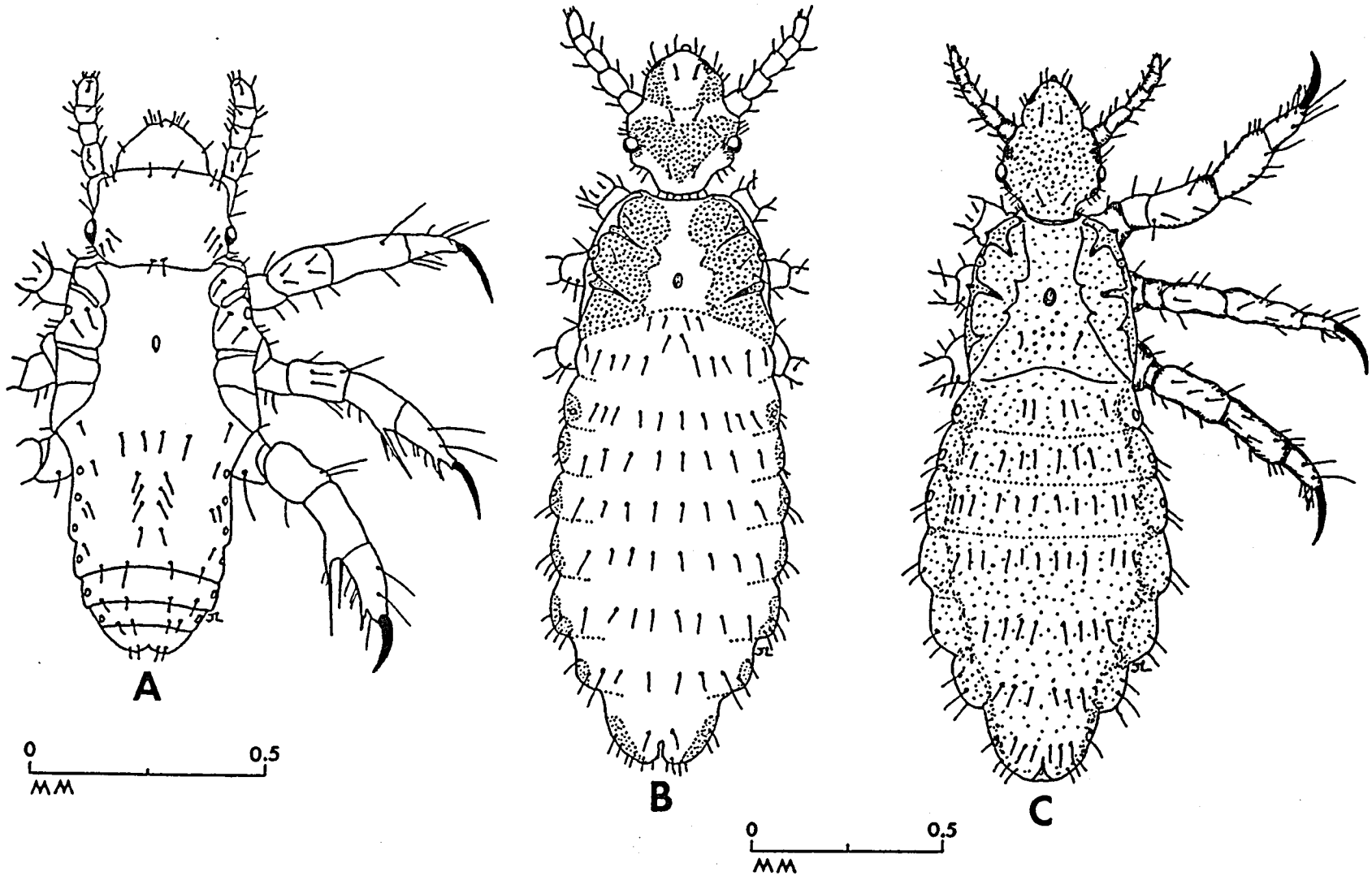

Fig. 1. Dorsal view of the first (A), second (B), and third (C) nymphal instars of the body louse, Pediculus humanus humanus (undistinguishable from the head louse, P. h. capitis) (after Keilin and Nuttall, 1930).

Male (Fig. 2)

Length ranging from 2.3 to 2.6 mm. Leg I with tibio-tarsus stouter than in female. Abdomen with tergal plates of variable pigmentation and extent, and normally present on segments III to VIII. There are two additional plates on segments III to VI which are occasionally more or less fused. Occasionally a tergal plate is present on segment II and an additional plate on segment VIII. Genitalia presenting no specific peculiarities. Genital plate always present, it being small and variable.

Female (Fig. 2)

Length varies from 2.9 to 3.5 mm. Gonapophyses short and blunt. Genital plate variable. Femur III with very strong ventral spur.

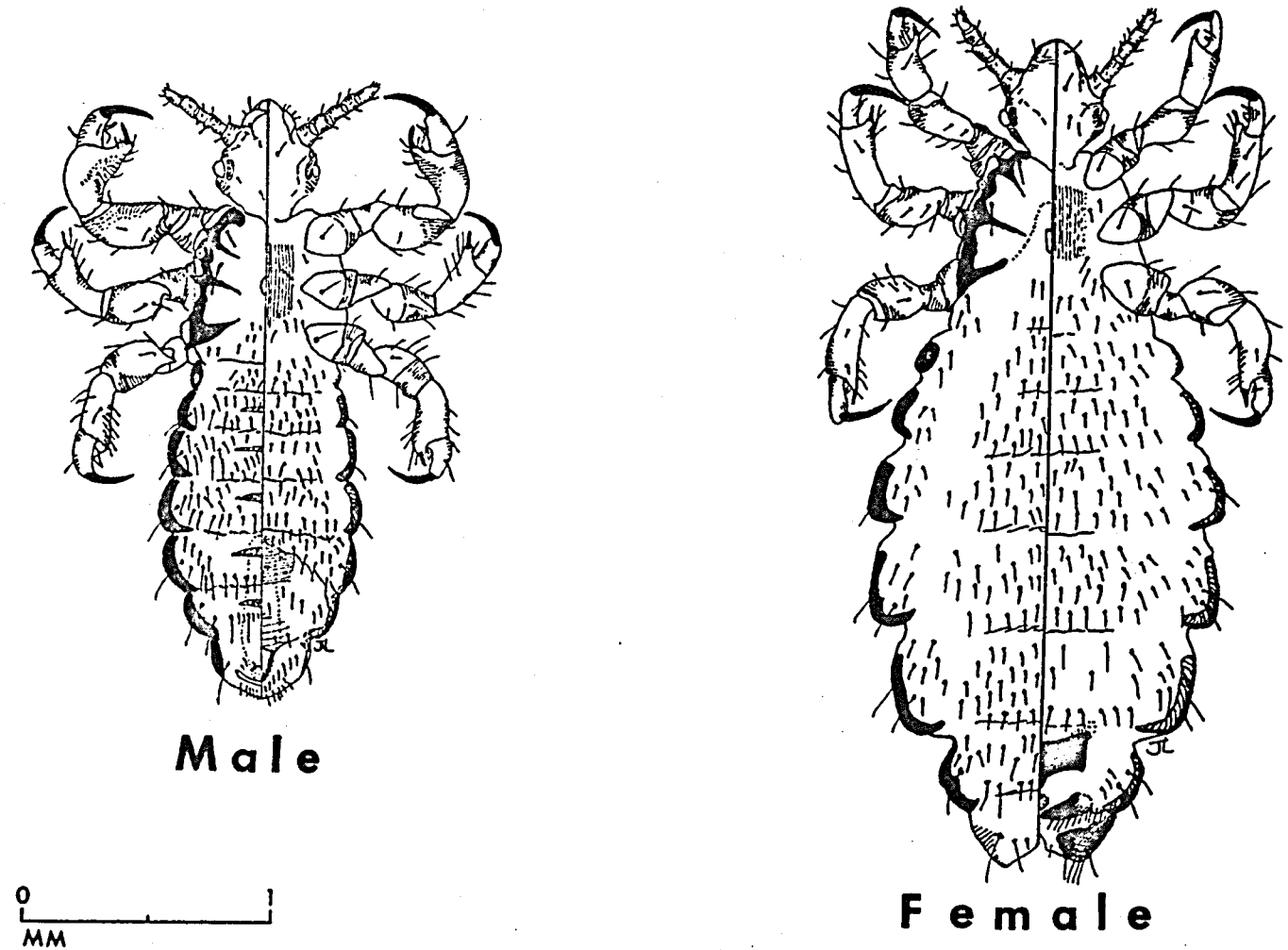

Fig. 2. Dorsal and ventral view of the typical forms of the adult male and female head louse, Pediculus humanus capitis (after Ferris, 1951).

METHODS AND MATERIALS

The principal methods used to examine the biology and control of the head louse, Pediculus humanus capitis deGeer, will be given here. Other procedures used in this study will be discussed under the respective topics.

Study Area

Field data concerning the identification, occurrence, and seasonal abundance of the head louse and in part, studies involving the dispersal and transmission, microhabitat, and sex ratio of this louse, were gathered from a study area (Fig. 3) located in Tucson, Arizona. The study area encompassed 46 elementary schools and nine junior high schools with a total enrollment of ca. 33,000 students. These data were collected from September, 1971, through August, 1973.

Tucson is located in a semi-arid region with average maximum temperatures[1], during the collecting period, of 19 C (January) to 37 C (July). The average precipitation during this time varied from 0.01 inches (April) to 2.6 inches (July), while the average percent relative humidity varied approximately with precipitation (26% for April; 41% for July).

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1. Climatological data obtained from U.S. Weather Bureau Office, International Airport, Tucson, Arizona.

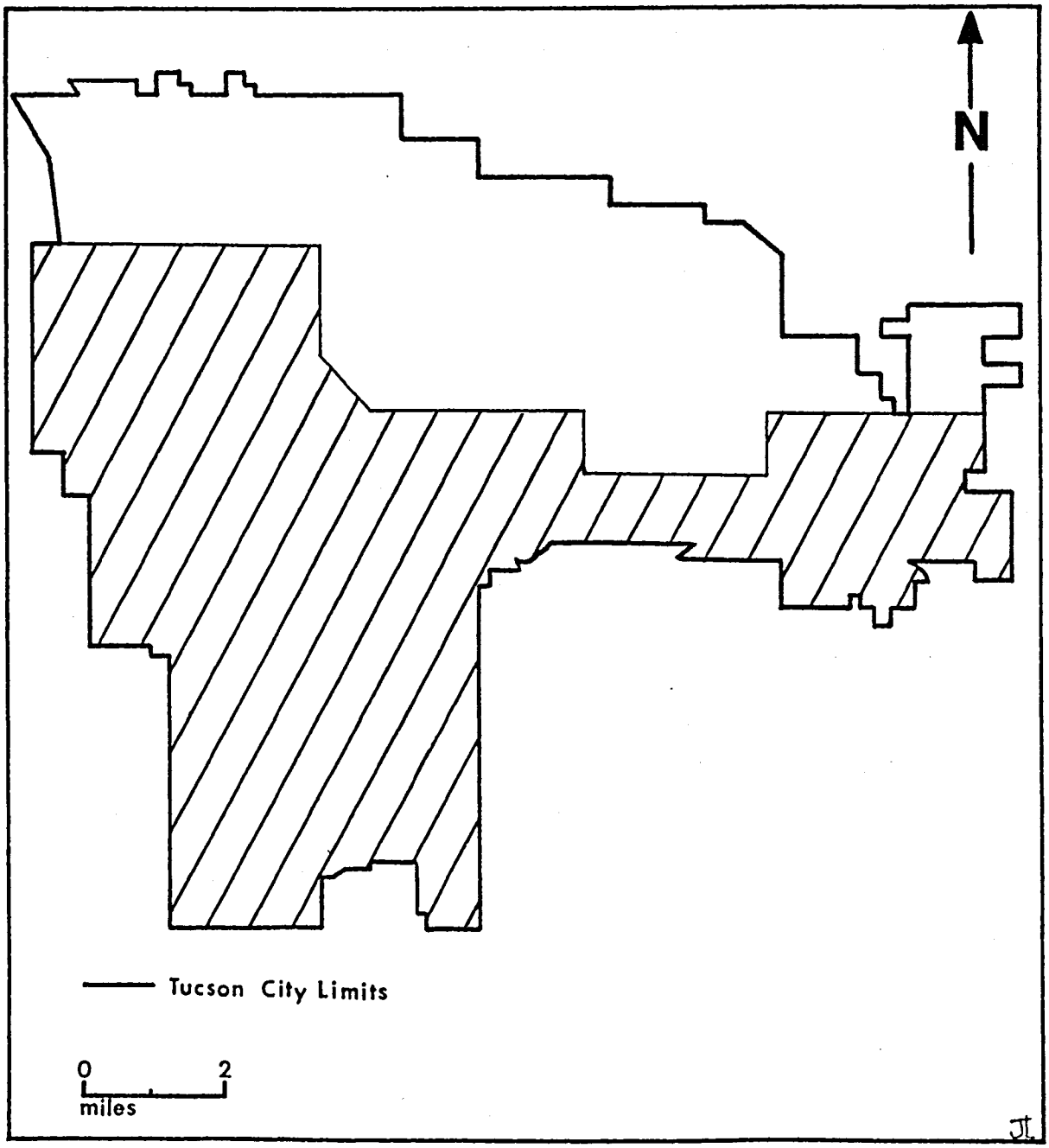

Fig. 3. The study area (hatch marks) in Tucson in which data were collected concerning the head louse, Pediculus humanus capitis.

Sampling Technique

The field data collected from the study area resulted from examining and interviewing over 5,000 students. Head louse data forms (Fig. 4), which were distributed to school nurses in the study area, and to public health nurses, aided the gathering of the field data. Infested individuals were diagnosed by class inspections conducted by the author or by nurses. After examining and treating an individual, completed forms were returned for analysis. Cooperation by nurses in completing the forms was generally good.

Rearing

I noted that if head louse crawling stages were fed 4-5 times daily their ecdysis would be delayed, their pre-mating period would be prolonged, and their egg production markedly reduced. Lice given a constant blood supply, as under natural conditions on the host, were noted to have much shorter developmental, pre-mating, and oviposition periods, while their egg productivity was greatly increased.

The following rearing method, published earlier (Lang and Roan, 1974), which supplied head lice with a constant blood meal, produced eggs and specimens which were utilized in experiments during this study. A portion of a plastic pill bottle was cut off ca. 15 mm from the mouth. The floor of the snap-on lid (Fig. 5A) was replaced with a circular piece of nylon fabric (four strands per mm) which was kept taut when the lid was snapped back onto the mouth. The container was put through a snugly fitting hole made by cutting away part of a second plastic lid and replacing it with nylon chiffon (five strands per mm) which was held

PUBLIC HEALTH ENTOMOLOGY
HEAD LOUSE DATA FORM

Current Date: _____

Age and Sex of Infested Individual: _____

Address or Area of Infested Individuals: _____

Ethnic Code: 1 2 3A 3Y 4 5 6

Length of Hair of Infested Individual:

Less than 2 inches

2-4 inches

4 inches or longer

Approximate Number of Nits Found (estimate):

Less than 50

50 - 100

100 - 200

More than 200

Approximate Number of Adults Found: _____

Pediculicide Used: _____ Date Used: _____

Effectiveness: _____ Retreatment Date: _____

Comments: _____

Fig. 4. Head louse, Pediculus humanus capitis, data form. Legend to ethnic code: 1 = Caucasian; 2 = Mexican-American, 3A = American Indian; 3Y = Yaqui Indian; 4 = Black; 5 = Oriental; 6 = Other.

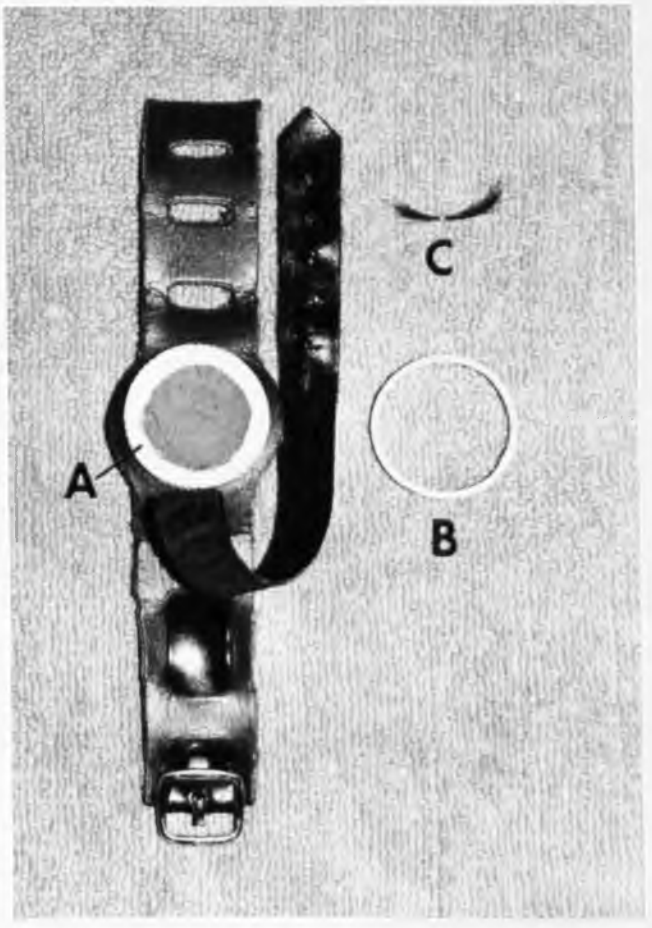

Fig. 5. Leather watch strap with container used for rearing the head louse, Pediculus humanus capitis (after Lang and Roan, 1974). Key to abbreviations: A = lid; B = roof; C = hair sample.

inside the lid with a rubber gasket. The total height of the container was 20 mm. Three to four hair samples, each consisting of ca. 30 strands tied together (Fig. 5C) were kept in the container for egg deposition. The container was held next to the skin by the strap arrangement shown in Figure 5.

Rearing was initiated with six males and 10 females which were collected from Tucson school children. The strap was worn almost 24 hours a day for 14 months, during which time 27 generations of head lice produced over 57,000 eggs. A mean of 400 lice were maintained in the strap container at one time. Removal of eggs, excreta, ecdysial skins, and dead lice from the container was done daily, while new hair samples were added as needed.

Irritation by feeding lice was found to be very annoying, so the watch strap was worn at various locations on the arms or on the lower legs.

Observations concerning individual louse behavior were conducted by using containers, identical to the strap container, but held next to the skin via a belt. These observations included oviposition behavior, ecdysis, mating, insemination, fecundity, and longevity studies.

Previous studies concerning the rearing of Pediculus humanus Linnaeus have principally been with the body louse, P. h. humanus Linnaeus. Maintenance of a large colony of body lice evolved from feeding them, usually twice daily, on man (Moore and Hirschfelder, 1917; Culpepper, 1944) to feeding them once daily on laboratory rabbits (Culpepper, 1948; Smith and Eddy, 1954). These authors found the optimum rearing conditions for lice, kept between feedings, to be

30-32 C/60-80% r.h. Body lice were also successfully reared via an artificial membrane (Fuller, Murray, and Snyder, 1949; Haddon, 1956).

My findings support the majority of previous authors who noted that head lice require a constant blood supply in order to maintain proper growth and reproduction. Murray (1974) had difficulty in maintaining head lice if they were fed 2-3 times daily. Head lice allowed to feed 6-7 times nightly on man had improved development and egg production (Bacot, 1917), while those allowed continuous access to feeding, using a wristlet method, had much improved growth and reproduction (Nuttall, 1917a).

Nuttall's method employed a pasteboard pill box in which portions of the lid and floor were removed and replaced with chiffon (ca. four strands per mm). The chiffon on the floor was held in place by gum arabic and by a silk thread tied around the box. The chiffon was then impregnated with shellac varnish for strength and to insure against smaller lice escaping. A hole was punched in a strap-band for sprained wrists so that the floor rested against the skin. A hair frame was added for egg deposition sites. Nuttall also wore his strap on various locations of his arms and on his knees due to irritation by feeding lice.

Large numbers of head lice have also been produced by feeding them once daily on rabbits (Eddy, 1973). This was accomplished by initially feeding them five times daily on man and then slowly reducing the feedings to once per day. They were then reared on the animals. No other references were found in which head lice were either experimentally or naturally reared on animals.

Rearing head lice using Eddy's (1973) method was not successful, as previously mentioned. An improved version of Nuttall's (1917a) technique for rearing was thus employed. My rearing container proved easier to construct and more durable.

Manipulation of lice during this study was done with a Grumbacher No. 2 camel hair brush.

Head louse eggs and crawling stages which were subjected to various experimental studies throughout this research were kept on 4.25 cm white filter papers in 5.0 x 1.2 cm polystyrene Petri dishes (no. 1006, Falcon Plastics, Oxnard, California) with ventilated lids.

Temperature and Humidity Studies

The methods used to examine the influences of temperature and humidity upon the head louse and its microhabitat will be given here under their respective subtopics.

Microhabitat Measurements

Temperature recordings of the heads of more than 100 elementary school children were carried out from September, 1972, to August, 1973, with a YSI Tele-thermometer (no. 42SC, Yellow Springs Instrument Company, Inc., Yellow Springs, Ohio). During the non-school months of July and August volunteer children were measured. Recordings were made for hair and scalp surface temperatures at the frontal top, crown, mastoidal, and occipital areas of the head. Temperature recording forms (Fig. 6) were completed for each individual. Recordings were generally made at an average room temperature of 25 C and included children who were inside for 2-3 hours and also those just returning from outdoor physical activity.

TEMPERATURE MEASUREMENTS OF HEADS OF DIFFERENT ETHNIC INDIVIDUALS EMPLOYING THE YSI 42SC TELE-THERMOMETER.

Date: _____

Individual's Sex and Age: _____

Hair Length: _____

Room Temperature: _____C Relative Humidity: _____%

Hair Surface Measurements:

Frontal Top Area _____C Mastoid Area _____C

Crown Area _____C Occipital Area _____C

Scalp Surface Measurements:

Frontal Top Area _____C Mastoid Area _____C

Crown Area _____C Occipital Area _____C

Other Pertinent Measurements:

_____C

_____C

_____C

Fig. 6. Form used to record hair and scalp temperatures of individuals.

The Tele-thermometer was also used to record the temperatures in the strap container, the skin surface temperatures for the feeding studies, and the surface temperature of the filter paper for the experiment involving louse survival in direct sunlight.

Water Bath

A water bath (Fig. 7) was used for the experiments involving: oviposition, pigmentation, gregariousness, lice kept in complete darkness, and eggs treated with pediculicides. The temperature of the water bath was regulated by an aquarium water heater (Fig. 7C).

Temperature Cabinets

Temperature regimes required for the experiments concerning the egg stage, ecdysis, and adult longevity and survival were provided by using temperature cabinets, which varied ± 2 C.

Humidity Control

The different relative humidities, used for the experiments involving the water bath and temperature cabinets, were maintained by various saturated salt solutions as summarized by Winston and Bates (1960). Aquasorb^{R} (Mallinckrodt Chemical Works, St. Louis, Missouri) was utilized to maintain 0% r.h. These salt solutions and Aquasorb^{R} were kept in 285 ml glass dishes (10.1 x 5 cm). These dishes were placed in one quart plastic ice cream containers which retained the desired relative humidities. The Falcon Petri dish, containing lice, was separated from the salt solution or Aquasorb^{R} by a wire frame placed on top of the glass dish. Humidities and temperatures of the one-quart

Fig. 7. Water bath used to maintain constant temperatures for experiments involving the head louse, Pediculus humanus capitis.

Key to abbreviations: A = 5 gallon aquarium; B = rearing container; C = 110-120 volt aquarium heater; D = thermometer; E = wires used to hold down container.

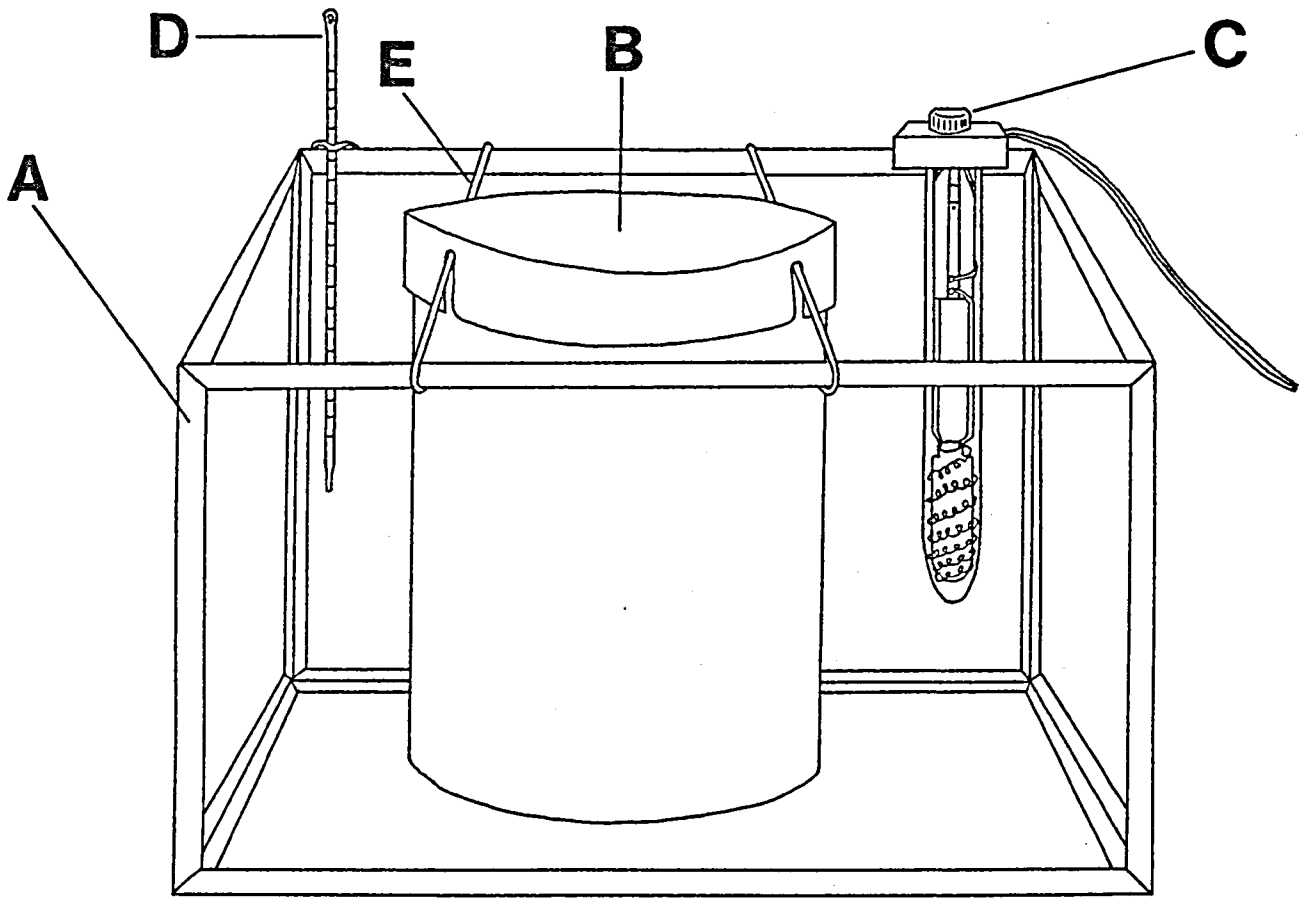

Fig. 7. Water bath used to maintain constant temperatures for experiments involving the head louse, Pediculus humanus capitis.

containers were measured with Ashton Humidiguide^{R} hygrometers (no. 5547, Taylor Instrument, Arden, North Carolina) which were placed on top of the Falcon dishes. These hygrometers were calibrated with a Lufft Durotherm-hygrometer (Lufft Instrument, Inc., Germany).

Control Studies

The following two procedures were used in experiments concerning the control of the head louse.

Effects of Pediculicides Upon the Egg Stage

Eggs produced by head lice in the strap container were immersed in the respective pediculicide for 15, 30, or 60 minutes. Eggs were wetted prior to treatment with 1% malathion (diethyl mercaptosuccinate, S-ester with O,O-dimethyl phosphorodithioate) dust. Viable eggs comprised 97-98% of all the batches, which were 1-2 days old when used. An average of 150 eggs were employed per batch. Three batches were used for each pediculicide exposure time and for each rinse type. Egg batches, following immersion, were rinsed either in mild shampoo and warm water or just in warm water, for ca. one minute. This procedure was followed because the majority of the pediculicides evaluated in this study carry a recommendation of rinsing with shampoo or soap and warm water following treatment. After each type of rinse, a batch was then rinsed twice in dishes of warm water, each for ca. one minute. Eggs were then carefully blotted dry with laboratory paper towel and maintained, together with three control batches, at 32 ± 2 C/82% r.h. until hatching, if any, occurred.

Pediculicide Resistance

The World Health Organization Insecticide Resistance Kit for Body Lice was used to test the susceptibility of Tucson head lice to pediculicides. The Kit furnished three 0.5 gram packages each of various concentrations of DDT (1,1,1-trichloro-2,2-bis=(p-chlorophenol) ethane) and lindane (1,2,3,4,5,6-hexachlorocyclo=hexane, 99% or more γ isomer) powders, and 12.5 cm square cloths. Various concentrations of malathion powder were formulated in the laboratory for use in this experiment. Second generation adult head lice reared in the strap container were used.

The procedure used followed that given by the WHO (1970) for body lice. A package of insecticide was spread uniformly over a cloth which was firmly attached to a board, and worked into the fabric. Ten males and ten females were placed in the center of the treated cloth, covered with a 9 cm Petri dish, and maintained in the dark for two hours. Twenty-four hour exposure times to insecticides, used by the WHO (1970) for body lice, were not used in the present study since 100% mortality was noted for head lice after only eight hours of exposure to all concentrations. The criteria for determining louse mortality following the two-hour exposure period, and recommended by the WHO, was lack of coordinated body movements. Three replicates, each consisting of 20 lice, were used for each concentration of pediculicide.

Statistical Methods

The following statistical methods were used to analyze data during this study. Analysis of variance was used to determine mean

percent mortalities of eggs treated with pediculicides. Duncan's Multiple Range Test determined significant differences of the mean numbers of crawling stages on individuals, the mean feeding times of nymphal instars and adults, the mean longevities of unfed nymphal instars, and the mean percent mortalities of eggs treated with pediculicides for 30 minutes. The Student's "t" test was employed to compare means of scalp and hair surface temperatures of individuals. Probit analysis was used during the resistance experiment, which determined percent mortalities of adults exposed to different pediculicide concentrations.

Duncan's Multiple Range Test was employed as given by Little and Hills (1972), while all other statistical analyses used during this study were as described by Snedecor and Cochran (1967).

RESULTS AND DISCUSSION

Identification on Man

Most authors agree that head louse, Pediculus humanus capitis deGeer, infestations are identified by finding the eggs. The crawling stages are less noticeable unless the person is heavily infested. I found that head lice can also be identified by finding louse fecal material on the shoulders and back of the individual. This material is most evident on heavily infested persons and on those wearing light-colored clothing.

The use of Wood's light, normally used to detect ringworm infections which fluoresce white, proved effective in identifying head louse eggs on individuals on whom eggs were few and therefore difficult to find (Spiller, 1951). This method also aided Spiller in locating eggs of the body louse, P. h. humanus Linnaeus, and crab louse, Pthirus pubis (Linnaeus).

I have occasionally found only hair casts or solidified globules of hair spray on persons purportedly infested with head lice. These and other materials have also been mistaken for head louse eggs by other workers (Kligman, 1957; Keh and Poorbaugh, 1971). Follicle casts, thought to be head louse eggs, caused several thousand children to be sent home from school (Osgood, Jellison, and Kohls, 1961). Only a few of these individuals, however, were actually infested.

Occurrence

The Tucson study area, from which head louse data were partly supplied, contained homes of varied ethnic and socio-economic groups. Analysis of completed louse data forms and individual examinations showed that 1068 students were infested with head lice in the study area from September, 1971, through August, 1973. This figure represented individual cases; reinfestations were not recounted.

The distribution of reported head louse infested students in the study area is depicted in Fig. 8. Eighty-four percent of these individuals (from ca. 120 households) were from the economically poorer areas of Mexican-American and Yaqui Indian communities, where poor housing conditions (Fig. 9) often indicate poor sanitary conditions. These communities serve as reservoirs for louse spread in Tucson, since all of the reinfestations occurred there. Individuals in these communities may remain infested throughout the year unless treated. Even when treated, a child may soon become reinfested from members of his or her family, or from bedding or furniture which was not treated, as well as from infested neighbors or schoolmates. Some of the schools in these highly infested areas had a prevalence rate of 8-10%.

There were ca. 30 households with children infested once during the study period who were not reinfested, usually due to the individual's improved hygienic habits. These households were usually found in Tucson's better socio-economic communities.

If busing becomes mandatory in Tucson, non-infested children from the affluent communities could very well become infested by students from louse-prevalent communities.

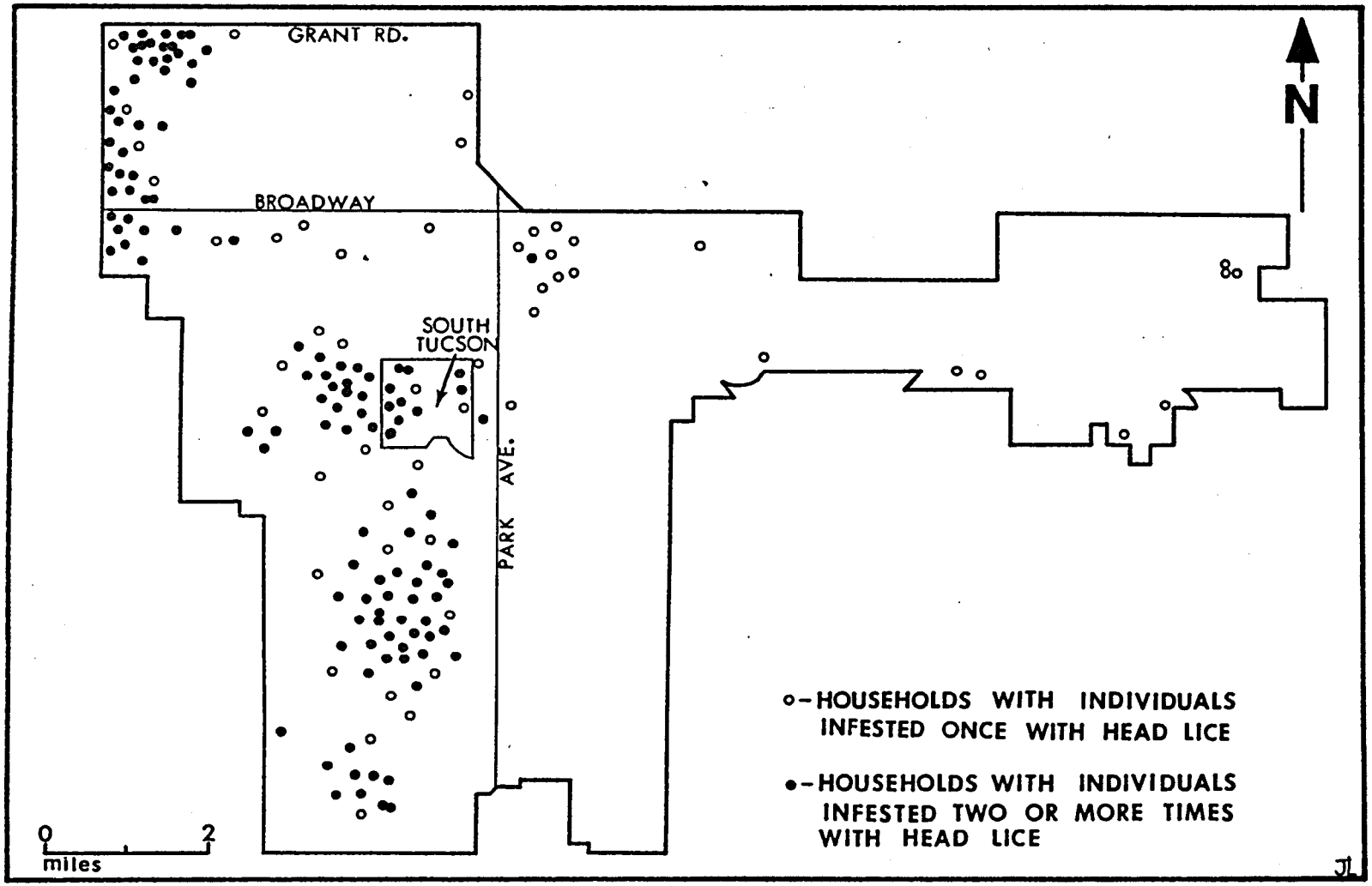

Fig. 8. Distribution of reported head louse, Pediculus humanus capitis, infested students in the Tucson study area from September, 1971, through August, 1973.

Fig. 9. Example of lower socio-economic housing conditions which serve as potential foci for the spread of head lice, Pediculus humanus capitis.

The age, sex, and ethnicity of students who were reported infested in the Tucson study area during the school years 1971-72 and 1972-73 are depicted in Table 3. Ninety-seven percent were between 6 and 11 years of age. Examinations of a few pre-school aged children with lice revealed that they probably became infested from their older brothers or sisters. The marked decline in numbers of infested students beginning at the 12-14 age group was probably due to their better personal grooming habits once they entered junior high school. The use of hair dryers, and hair oils and creams by students in this age group probably acts to kill eggs and adult lice.

Seventy-three percent of the total students infested were females. The percentage of infested males compared to females is somewhat higher than reported in most past studies, no doubt due to the current male long hair styles.

No Black students were reported infested with head lice during this study. Two sisters who were part Yaqui Indian and part Black, however, were reported infested (Table 3). Buxton (1938a) noted that infestations in Africa were partly determined by local customs and preferences in hair style and hairdressing, and that certain races style their hair in an almost permanent manner. These factors may thus allow a greater percentage of individuals to be susceptible to head lice because of their infrequency of hair-combing and washing. Most Tucson Black students examined, on the other hand, had rather short thick hair, which probably inhibits navigation by lice.

Table 3. Students reported from the Tucson study area with infestations of head lice, Pediculus humanus capitis, according to age, sex, and ethnicity for the school years 1971-72 and 1972-73.

Ethnicity	Age of Children								Total
	6-8		9-11		12-14		15-17		
	Males	Females	Males	Females	Males	Females	Males	Females	
American Indian	10	32	8	16	2	3	0	0	71
Caucasian	5	17	7	12	4	10	0	1	56
Mexican-American	99	281	65	186	3	7	0	1	642
Yaqui Indian	52	102	38	102	0	3	0	0	297
Yaqui/Black	0	1	0	1	0	0	0	0	2
Total	166	433	118	317	9	23	0	2	1068

Number per Individual

The number of head louse eggs and crawling stages occurring on individuals was determined by examining 93 students (42 males, 51 females). Some of these students were examined for more than two hours to ensure accurate determinations. The results of these examinations are recorded in Table 4. Female students had significantly higher numbers of adult lice, at the 5% level, no doubt due to their longer hair which provided for a better louse habitat.

Table 4. Mean number of crawling stages of the head louse, Pediculus humanus capitis, collected from 93 infested students.

Sex of Student	Instar Nymphs ($\bar{X}$)	Adults ($\bar{X}$) Male	Female
Male	1.2 cd[a]	0.8 d	1.1 cd
Female	1.5 cd	2.2 b	3.4 a

a. Means followed by the same letters are not significantly different at the 5% level according to Duncan's Multiple Range Test.

The minimum number of head lice collected from a student was one, whereas one female was infested with 530 lice (240 nymphal instars, 100 males, 180 females). This latter figure was not included in the calculations for Table 4 since it would have made the mean number of crawling stages higher than which normally occurred on the students.

The average number of eggs per infested student was ca. 15, owing to their persistence on hair shafts. One recently treated female

yielded very few crawling stages, but averaged ca. 10-15 hatched and mostly non-viable eggs per hair shaft.

Past studies have also reported usually low numbers of head lice on individuals. Buxton (1947) found that the most frequent count per individual was 10 or fewer, with counts of many hundreds or a few thousand being rare. The average number of lice per male and female child was noted to be 13 and 17, respectively (Mellanby, 1942). Mellanby also found that the majority of infestations consisted of less than 10 lice. He attributed these small numbers to hair combing, which removed lice. Favorable conditions may allow large numbers of head lice to persist on an individual. Roy and Ghosh (1944), for example, collected an average of 130 adults and 419 nymphs from infested Burma refugees, one of whom yielded 1,434 adult lice.

Pigmentation

That pigmentation of Pediculus humanus on different races of man varies with that race's color has been well documented by a number of authors. Nuttall (1919a) surveyed thousands of specimens of head lice from various parts of the world and found that darkly pigmented lice were collected from dark-skinned, black-haired races, while Caucasians, whose hair is often light, yielded pale specimens. He also found that body lice reared on white backgrounds produced progeny which were all pale, while the progeny of light lice reared on black backgrounds were all dark. He noted that pigmentation in Pediculus "is a character that may be acquired in a couple of days."

Hindle (1917) observed that the degree of pigmentation by body lice was inherited, but was not sure whether it was sex-linked.

Busvine (1946) was the first to give a detailed study concerning body louse pigmentation. He reared lice on various-colored backgrounds through a number of generations. His results showed that pigmentation does not "depend(s) entirely upon the nature of the background" as stated by Nuttall (1919a), but that it is an inherited characteristic which is apparently not sex-linked. He also found, again contrary to Nuttall (1919a), that darkly pigmented lice can develop in complete darkness.

I noted that the majority of head louse adults collected from black-haired Yaqui Indians and Mexican-Americans in the study area, were darkly pigmented (Fig. 10), while those from Caucasians with brown or blond hair were generally much lighter in color (Fig. 11). Pigmentation experiments involved collecting ca. 20-30 eggs and various nymphal

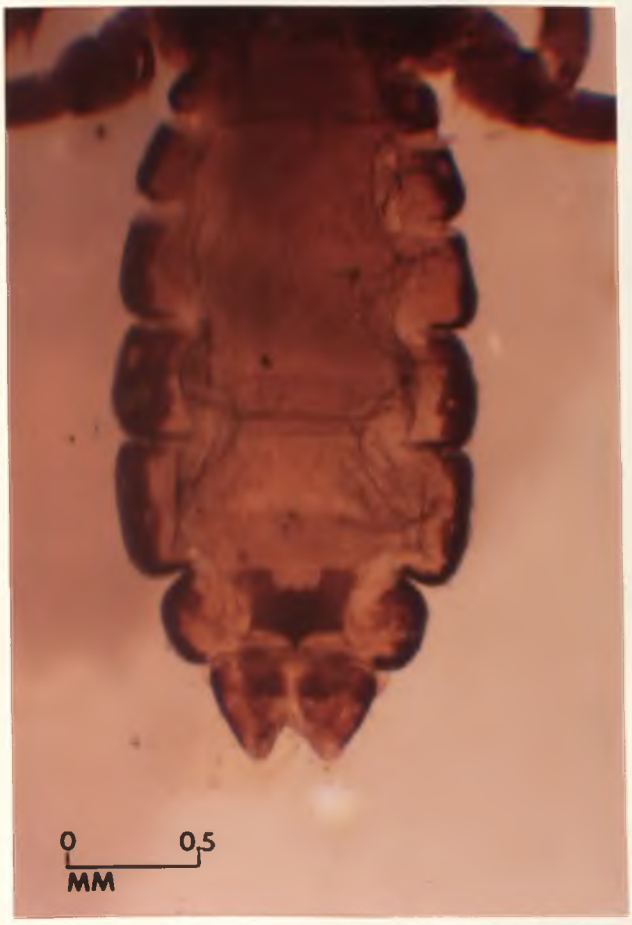

Fig. 10. Dorsal view of the abdomen of a darkly pigmented adult female head louse, Pediculus humanus capitis.

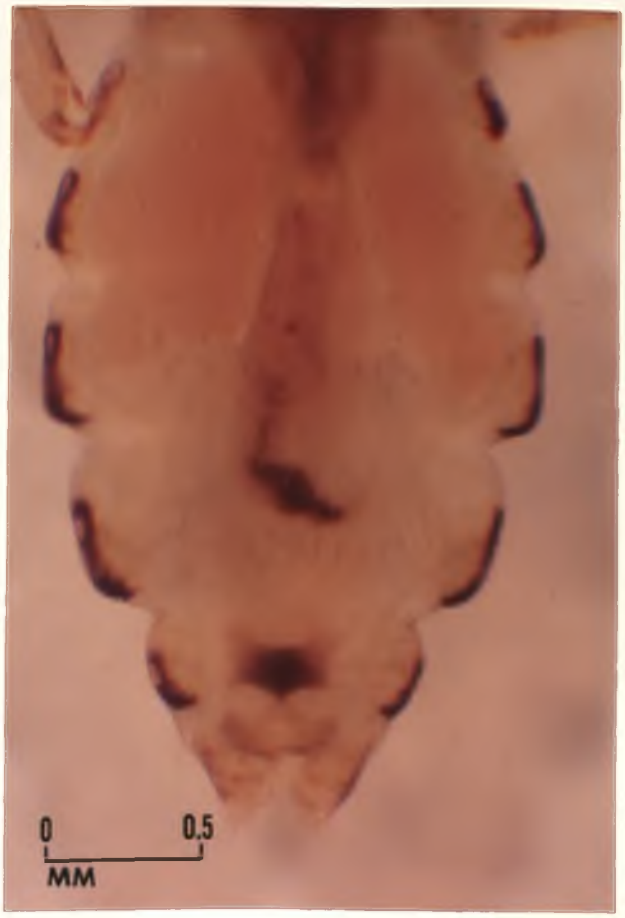

Fig. 11. Dorsal view of the abdomen of a lightly pigmented adult female head louse, Pediculus humanus capitis.

instars from black-haired individuals and rearing them on white filter paper until the adult stage. Some eggs and nymphs were also maintained in complete darkness on black paper in boxes whose insides were blackened. First and second nymphal instars used in this experiment were fed four times daily, while third nymphal instars and adults were fed three times a day.

Results of this experiment showed that the majority of adults (ca. 85%) reared from nymphs on white paper were darkly pigmented, while the rest were moderately pigmented. Lice reared from eggs showed results similar to those reared from nymphs. The adults reared in complete darkness were also mostly dark or moderately pigmented. The strap container, the inside of which was fairly dark, produced mostly moderately pigmented adults (Fig. 12).

Pigmentation experiments involving the progeny of head lice were not performed due to the inability of lice to produce viable eggs when fed 3-4 or even 5-6 times daily (p. 73). These offspring would have been maintained for a number of generations on different colored backgrounds so as to support or refute Busvine's (1946) findings.

My limited experimental results agreed with Busvine's (1946). Pigmentation of head lice, like that of body lice, is not sex-linked, and is a characteristic possessed by some lice and not others.

Dispersal and Transmission

Transmission of head lice can involve direct or indirect means. Direct infestations include physical contact with an infected individual, such as by working, playing or sleeping together, or by lice which

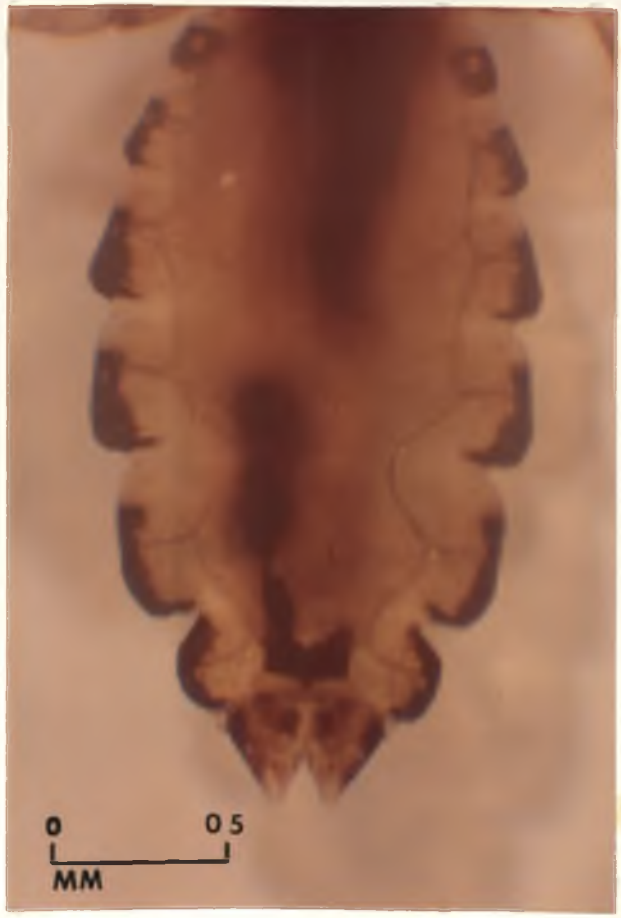

Fig. 12. Dorsal view of the abdomen of a moderately pigmented adult female head louse, Pediculus humanus capitis.

have abandoned infested persons who are feverish, dying or dead. Indirect methods include use of infested combs, brushes, wigs, towels, clothing, bedding, car seats, or furniture.

The most common mode of head louse transmission in Tucson schools was found to be by children playing together. Infestation of school nurses by children being treated for injuries also occurred (Zempel, 1972). Use of infested combs and other indirect means of transmission have also been noted by school nurses. Children who sleep together in the same bed appears to be one of several methods of transmitting head lice among members of a household.

Results of interviews indicated that transmission of head lice among college students and transients occurs principally by sleeping together, while bedding, furniture, and other indirect methods were also common modes of transmission.

Experiments were carried out to test the feasibility of head louse transmission by a few household insects. This experiment involved placing an insect, together with two male and two female adult lice, in a 28 ml plastic container for 30 minutes. A 570 ml glass jar was also used in this experiment. Results showed that faster moving and flying insects, such as cockroaches and flies, were less likely than slower ones to acquire lice. Lice attached to slow-moving insects, such as ground beetles and earwigs, for only 3-4 times over the 30 minute periods in the 28 ml container. Attachments occurred even less in the 570 ml jar. Lice remained attached to insects only a few seconds. These short attachment periods were mainly the result of insects becoming very aggravated once a louse became attached, so that they soon freed

themselves of the louse. The majority of attachments were made on the insect legs. This experiment showed that dispersal of head lice by insects in nature is probably rare. The results of these experiments partly agree with those of past authors. Flies have been supposedly observed transmitting head and body lice from place to place and from person to person (Calandruccio, 1890). Galli-Valerio (1916) placed two flies in a vessel with many head lice (exact number not given) and after 24 hours found a louse attached to a fly's thorax.

Wind has also been implicated in dispersing lice. Schilling (1916) experimentally showed that body lice could be successfully transmitted by wind of medium velocity (exact speed not given).

Seasonal Abundance

Determining whether a seasonal abundance for head lice existed in a semi-arid area such as Tucson was accomplished by examining ca. 20 infested students once monthly from January, 1972, through August, 1973. To avoid biasing the data, these students were not treated with a pediculicide. Results showed that numbers of lice per student remained approximately the same throughout the examining months. Seven students had somewhat higher louse numbers following Christmas and Easter vacations. School nurses also noted that more infestations were reported following holidays. This was no doubt due to an increase in contact with infested relatives and/or neighbors.

Studies regarding the seasonal abundance of head lice in other parts of the world partly agree with my results. Although head lice were found to thrive in a variety of climatic conditions, they were less

abundant in warmer than in colder countries (Zinsser, 1935). No seasonal fluctuation of head lice was noted in areas such as West Africa and Ceylon with equable equatorial climates (Buxton, 1938a). In Kakamega, Kenya, infestations were significantly higher in the wetter months (38% infestations) than in the drier months (below 30%) (Buxton, 1938a). Buxton believed that this fluctuation was probably due to seasonal differences in people's habits, such as staying at home during the wetter, colder months. In southern India, however, infestation rates were the same for the monsoon and dry seasons (Buxton, 1940a).

Man's seasonal and social activities probably thus play a more important role than climate, as Buxton (1938a) also noted, in the seasonal abundance of head lice. The scalp and hair temperatures of Tucson students varied slightly (p. 52), throughout the year, so that these factors probably had no appreciable influence upon seasonal abundance.

Microhabitat

Location of the Eggs, Nymphal Instars, and Adults on Man

Most authors agree that head lice are found primarily on the head but can spread to and establish themselves on other hairy parts of the body, especially the pubic and axillar areas.

I examined over 500 infested school children over a two year period in order to determine the location of head louse eggs and crawling stages. Boys generally had hair 7-10 cm long on top and 5-8 cm long on the sides of the head, while girls had longer hair which was usually worn straight down or tied at the back. The length and thickness of hair,

and the manner in which it was combed, was found to generally determine the location of eggs and crawling stages.

Location of eggs on students occurred principally behind the ears and at the occipital area, with a few being found at the temples. The hair was generally thicker in these areas, providing lice with a more sheltered habitat in which to lay eggs. The humidity of these thicker areas was probably higher than on other areas of the scalp and may have influenced oviposition.

The crawling stages were observed to prefer the temple areas, near the part (if present), and in the other somewhat thinner areas of a child's hair. They were also occasionally found behind the ears. Undisturbed lice were usually found 3-6 mm from the scalp surface, while disturbed lice were observed to crawl rapidly to the thicker areas of the hair.

First instar nymphs were observed to confine themselves to the scalp surface, and were not found on hair shafts. They also remained on the floor of the strap container. They could crawl on a hair shaft, but only with difficulty.

Second and third instar nymphs and adults maintained in the strap container preferred the thicker areas of the hair samples. Physical activity was observed to cause lice in the container to move farther from the floor, no doubt as a result of perspiration. Lice were also found further from scalp surfaces of perspiring children than of those who were not perspiring.

Previous workers have not mentioned where head louse eggs were found on individuals, while they have been generally inconsistent in

determining the location of crawling stages. This may partly be the result of changing hair styles. Cantrell (1889-90, p. 486) noted crawling stages were found on all parts of the scalp, but primarily at the occipital area "which is the better supplied with hair and consequently the warmer." They have also been found mostly at the sides of the head, above and behind the ears (Nuttall, 1917a), and at the temples (Greenough, 1887).

Gregariousness of Nymphal Instars and Adults

Experiments were performed to determine whether gregariousness occurs in head lice. These consisted of placing five instar nymphs and 10 adults (5 males, 5 females) in the center of a filter paper (9 cm in diameter) which was glued to the inside bottom of a glass Petri dish. The location of lice on the paper was then recorded an hour later. This procedure was repeated 38 times, half in light, and half in complete darkness. In the light trials a 60 watt bulb was placed ca. two meters directly above the dish to avoid the negative phototaxis normally exhibited by lice.

Results of this experiment showed that neither instar nymphs nor adults congregate when subjected to light or dark. In a number of trials males were attracted to females for the purpose of mating. The preference of lice for certain areas of the host's head (p. 50) is therefore probably the result of lice avoiding light and/or seeking better conditions of temperature and humidity, rather than to a true gregarious behavior. Previous studies have shown, however, that head lice have a marked tendency to congregate (Nuttall, 1917a), while gregariousness was especially noticeable in nymphs ready to molt (Bacot, 1917).

Temperature of Scalp and Hair

The scalp and hair surface temperatures of more than 100 students were recorded during the school and summer months and compared using the Student's "t" test. Results showed that no significant difference, at the 5% level (P = 95%), occurred for mean temperatures of different scalp surface areas (28.7 ± 0.2 (S.E.)C) compared to hair surface areas (27.9 ± 0.3 C) recorded during the summer months.

Summer temperature recordings showed a significant difference (5% level) for mean scalp (29.4 ± 0.1 C) and hair surface (29.1 ± 0.2 C) recordings at the frontal top area of heads. No other significant differences were noted for the remaining measurements ($\overline{X}$ = 29.3 ± 0.2), for the other areas of the head made during the summer months, nor was significant difference found for the mean (28.3 ± 0.3) of scalp and hair surfaces recorded during the school year as compared to the mean temperatures recorded (29.3 ± 2) during the summer months.

The temperature of the head louse's microhabitat has not been determined previously. My present results quantify Buxton's (1947, p. 69) statement that a head louse "is not exposed to a great range of temperature because man's control of his temperature will prevent the surface of the skin reaching very high or low figures."

Phototactic Response

The negative phototactic response exhibited by P. humanus has been well documented by those working with this species: hungry as well as engorged lice seek shaded areas when experimentally given a choice between light and shade.

Egg Stage

Viability

I have noted that one-day-old non-viable head louse eggs are generally smaller and less full-bodied (Fig. 13) than one-day-old viable eggs (Fig. 14). Usually by day three the author could readily distinguish between a non-viable and a viable egg, from the fullness of the egg.

Ordinarily by day four eye spots appeared in the viable egg. By day eight a non-viable egg was generally shrunken and dark with clear areas present (Fig. 13), while the developing nymphal instar could be distinguished microscopically in an eight-day-old egg (Fig. 14).

The viability of eggs produced by lice maintained in the strap container ranged from 97 to 99%. The percent eclosion was dependent upon conditions to which they were subjected. Occasionally a non-viable egg would be observed among a row of viable eggs attached to a hair in the strap container (Fig. 15). This demonstrated that mated as well as unmated lice could produce non-viable eggs.

My observations concerning the viability of head louse eggs agree with Nuttall's (1917a). His wristlet method produced a mean of 96% viable eggs, of which 94% hatched.

Oviposition Behavior

I also observed that head lice, following feeding on my arm, frequently would lay eggs on hairs which were 0.5-1.0 mm from the skin surface. The opercula of these eggs were facing outwards. Mellanby

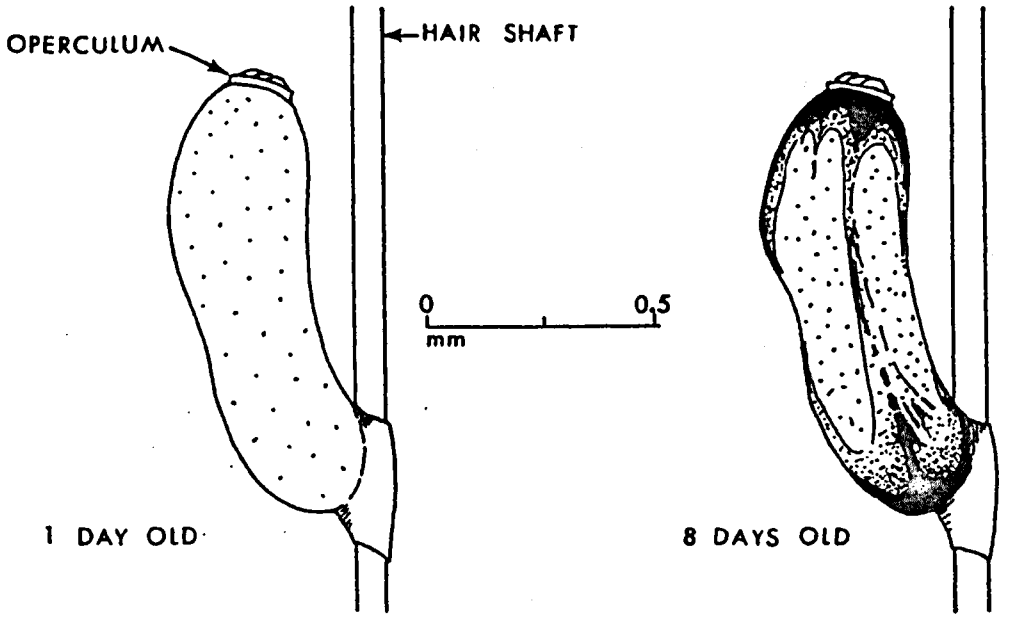

Fig. 13. Non-viable eggs of the head louse, Pediculus humanus capitis, when one and when eight days old.

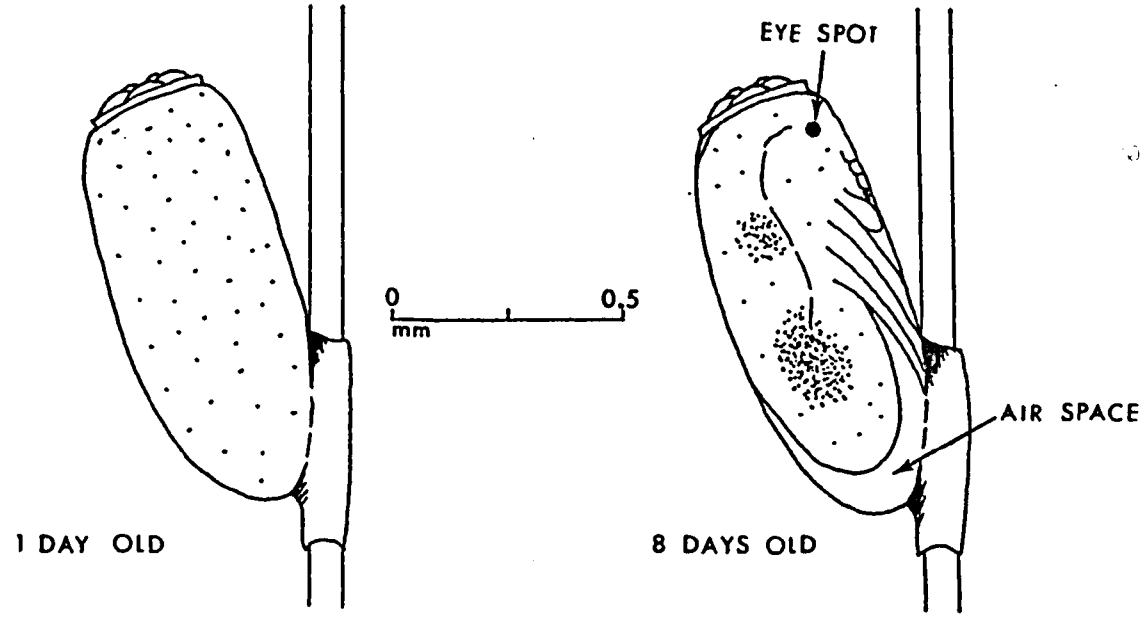

Fig. 14. Viable eggs of the head louse, Pediculus humanus capitis, when one and when eight days old.

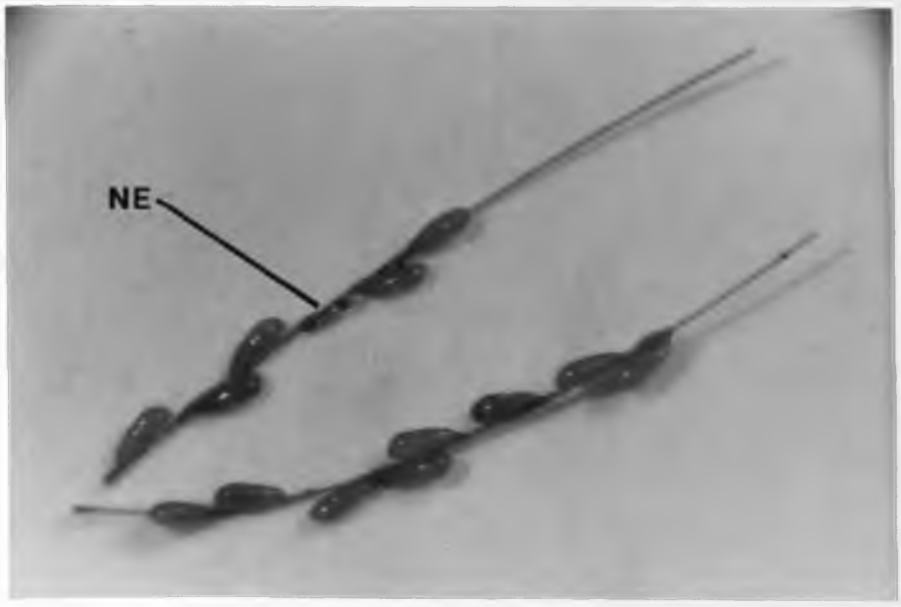

Fig. 15. Egg clustering by the head louse, Pediculus humanus capitis, exhibited in the strap container.

(1942) also noted that newly deposited head louse eggs were laid ca. 1 mm from the scalp surfaces of school children.

Assuming that hair grows at the rate of 0.4 mm per day (Mellanby, 1942), and taking the mean temperature of the hair and scalp as 28.9 C, eggs will hatch in 8-11 days at ca. 3.2-4.4 mm from the scalp surface. Hatched and non-viable eggs will be farther from the scalp unless the person mechanically removes them.

Head lice were usually observed to lay one egg per hair on lightly and moderately infested students. Eggs which were probably newly deposited were found ca. 1 mm from the scalp surface. Many eggs per hair were noted on heavily infested students. Hair samples kept in the strap container bore eggs closely packed together as the result of overcrowding (Fig. 15). Opercula of eggs laid on the frame and those laid on hair samples were oriented away from sheltered and toward less dense areas, as was also noted on students, and on my arm following feeding.

Egg clustering behavior of the head louse was studied using a hair frame and hair samples (Fig. 5C). Individual females, fed four times daily, were put on the frame and on the samples for four-day periods, and maintained at 27 ± 2 C/60% r.h. Lice placed on the hair frame laid eggs which were not clustered, but equally distributed on the frame. Bacot (1917) and Nuttall (1917a) employed a similar hair frame but noted that head lice tended to aggregate their eggs, although less closely than the body louse.

Lice maintained on hair samples were observed to lay eggs in the denser areas, where the samples were tied together. Tying a hair frame

to the floor of the strap container resulted in the majority of eggs being laid on the outer hairs of the frame in more sheltered areas.

During these oviposition experiments lice were always observed to lay just one egg at a time.

The influence of the host's activity upon egg production in the strap container was also examined. Results showed that egg production on inactive days, in which I perspired minimally, averaged 475 ± 15 eggs compared to 230 ± 20 laid on active days, in which perspiration was considerable. Slightly higher egg counts were also noted from noon to midnight ($\overline{X}$ = 54 ± 3%) than from midnight to noon ($\overline{X}$ = 47 ± 4%).

Body movement may have also influenced egg production in the strap container by disturbing oviposition.

Egg production was thus noted to be dependent upon the host's activity, and thus perspiration. The slight temperature variations (p. 52) probably did not influence egg oviposition.

Experiments were also conducted to determine whether the head louse shows a preference in depositing eggs on certain types of hair. Samples of hair were collected from a Caucasian, Mexican-American, Yaqui Indian, two dogs, and a cat. The diameters of twenty hair shafts were measured for each of these hair types using a Zeiss Compound Microscope at a magnification of 125x. Means for each hair type are depicted in Table 5.

Hair frames were constructed using these different hair types. Some frames used slender hairs (e.g., cat) for the outside hairs, and thicker ones (e.g., Caucasian) for the middle hairs. Other frames had thicker hairs on the outside and thinner ones on the inside. Each

Table 5. Mean hair diameters (based on 20 measurements) of hair collected from different ethnicities and animals.

Source	Mean Hair Diameter (μ)
Caucasian	93
Mexican-American	56
Yaqui Indian	64
Dog A	70
Dog B	63
Cat	40

frame was fastened to the floor of the strap container for four days. Results showed that lice laid eggs on outer hairs of the frame, regardless of hair diameter. This experiment demonstrated that head lice do not prefer a particular hair thickness (and perhaps a certain ethnicity) for egg deposition.

Influence of Temperature and Humidity

The incubation periods and percent eclosion for head louse eggs were determined at different temperatures and humidities. Eggs were collected from the strap container once daily so that all were less than 24 hours old. More than 3,200 eggs were used in this experiment. Three batches of eggs were used for each r.h. for each temperature. Eggs were placed in Falcon Petri dishes with the oviposition date written on the lid. Aquasorb^{R} or saturated salt solutions were placed in the bottom of one-quart containers so as to maintain desired humidities (p. 29). An

Ashton hygrometer was then placed in each container to monitor temperature and humidity. Newly emerged nymphs were counted and removed from the dishes every 24 hours. The total numbers of hatched and unhatched eggs were compared in each dish. Nymphs which became caught in eggs when emerging were not counted as having hatched. Non-viable eggs were excluded from the calculations.

The shortest incubation period was found to be 5-6 days at 36 ± 2 C (Table 6), while the maximum percent that emerged (95-99%) occurred at 31 ± 2 C. At 31 ± 2 C and below, incubation periods generally increased (at greater than 90% r.h.) or decreased (at ca. 0% r.h.) by approximately one day. At 36 ± 2 C incubation periods were not affected by different relative humidities.

Table 6. Influence of temperature upon incubation period of eggs of the head louse, Pediculus humanus capitis.

Temperature (± 2 C)	Incubation Period (in days)
39	--
36	5-6
31	6-11
27	9-16
24	--

The means for percent of eggs that hatched at different temperatures and humidities are depicted in Fig. 16. At 31 ± 2 C and 36 ± 2 C, percent eclosion decreased at greater than ca. 83%. At 27 ± 2 C, the maximum percent eclosion was only 16.

Eggs were also kept at 4 ± 2 C for various periods and then placed at 30 ± 2 C/52% r.h. until hatched (Table 7). Results showed that eggs would not hatch if kept at 4 ± 2 C for 6 days or longer.

Head louse eggs were also maintained at 24 ± 2 C for three, six, and nine days, and then kept at 30 ± 2 C/65% r.h. until hatched (Table 8). The 3-day exposure to 24 ± 2 C slightly decreased incubation periods and percent hatched, while 6- and 9-day exposures to 24 ± 2 C adversely influenced percent hatched.

Temperatures and incubation periods were also recorded for head louse eggs maintained in the strap container for the months of March, July, and November, 1973. Temperatures were taken on the floor of the container (Fig. 5B) every three hours for 24 hours during a three-day period for each month (Table 9). The incubation periods for the three months varied slightly and reflect the effects of temperature on the eggs. The actual temperatures of the strap container were probably somewhat higher since they do not wholly concur with incubation periods recorded in Table 7. This may have been caused by the change in air temperature of the container when recording temperatures. The relative humidity of the strap container could not be determined but was probably 60-80%, based upon the percent of eggs that hatched (97-99%).

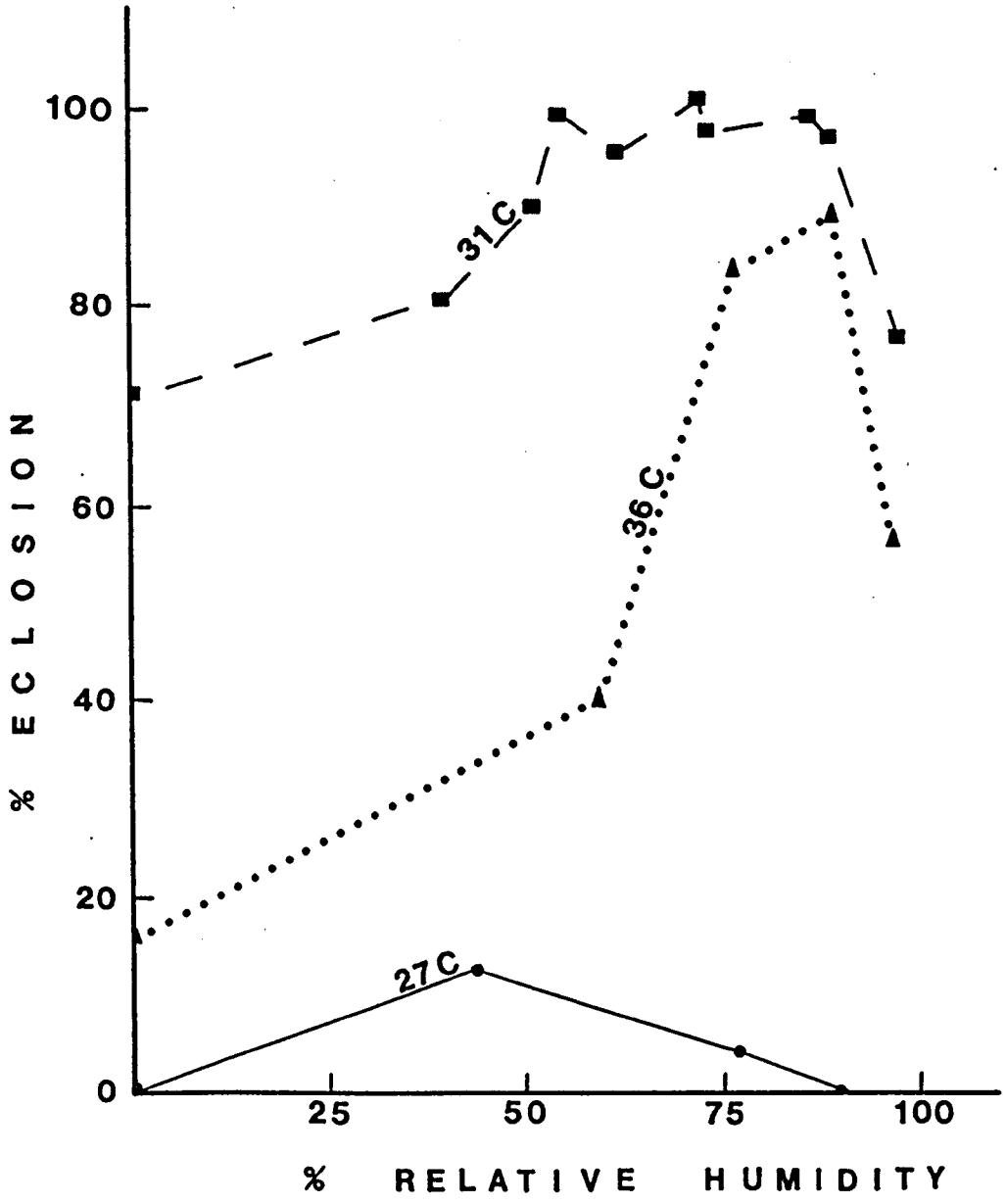

Fig. 16. Mean percent eclosion of eggs of the head louse, Pediculus humanus capitis, exposed to different temperatures (C) and relative humidities.

Table 7. Eggs of the head louse, Pediculus humanus capitis, exposed to 4 ± 2 C for various periods and then maintained at 30 ± 2 C/52% r.h. until hatched.

Number of Eggs Employed	Days at 4 ± 2 C	% Eclosion at 30 ± 2 C on Day 6	7	8	9	10	11
78	2	3.8	3.8	7.6	12.8	12.8	8.9
91	6			0			
140	10			0			

Table 8. Eggs of the head louse, Pediculus humanus capitis, exposed to 24 ± 2 C for various periods and then maintained at 30 ± 2 C/ ca. 65% r.h. until hatched.

Number of Eggs Employed	Days at 24 ± 2 C	Eclosion Period and % Hatched at 30 ± 2 C	
273	3	4(71.4)	5(20.5)
202	6	8(08.9)	9(02.4)
309	9	6(0.3)	

Table 9. Incubation periods and mean temperatures of eggs of the head louse, Pediculus humanus capitis, recorded in the strap container at various periods during 1973.

Month	Incubation Period (in days)	Mean Temperature of Strap Container
March	7-8 (mostly 8)	28.0 ± .45[a]
July	7-8 (mostly 7)	28.5 ± .75
November	7-8 (mostly 8)	27.0 ± .45

a. ± S.D.--Standard Deviation

The majority of previous studies concerning the effects of temperature and humidity upon eggs of Pediculus humanus have involved the body louse. As with my results, Leeson (1941) also noted that percent eclosion for the body louse became reduced at higher and lower humidity ranges. I have noted that a higher percent of head louse eggs hatched at 30 ± 2 C, and above, than those of the body louse as noted by Leeson (1941). At 31 ± 2 C, higher and lower humidities had more effect in increasing and decreasing, respectively, eclosion of head louse eggs than Leeson found for body louse eggs.

Leeson (1941) also subjected body louse eggs to from four to 41-day exposures at 22 C and then at 32 C until hatched. He also kept eggs at 8 C for various periods and then at 32 C until hatched. These results concerning the percent that hatched and the incubation periods were similar to mine obtained with head louse eggs in the present study.

Eclosion

The process by which the head louse emerges from the egg was noted to begin with the nymphal instar pumping in air through the pharynx and expelling it via the anus. An air space (Fig. 14) thus collected behind the nymph which became pressed against the operculum. The operculum was ultimately forced open, freeing the nymph. The nymph appeared pale when it began pumping in air but became pigmented, especially in the head and claw regions, upon emergence. It usually freed itself in 2-5 minutes following the opening of the operculum. The total eclosion process, from initiation of air pumping to emergence, was noted to take 20-24 hours at a mean room temperature of 25 ± 6 C.

A large number of instar nymphs would die during eclosion if the temperature was too high and the humidity too low. This was the result of the nymphs becoming stuck to the hardening egg membrane if they could not quickly free themselves from the egg.

My observations concerning the eclosion of head lice agree with those first made for body lice by Sikora (1915) and later described in detail by Nuttall (1917a). The total eclosion period, however, was not mentioned by these authors.

Nymphal Stage

Feeding Behavior

Head louse crawling stages, when feeding, were usually noted to orient their bodies almost vertically to the skin surface. This is the result of the haustellar teeth penetrating the skin so as to firmly

anchor the louse, thus allowing the head a favorable position for using the piercing mouthparts.

After feeding on my arm, head lice were noted to stay ca. 3-4 mm from the skin surface clinging to hairs where they would remain inactive unless disturbed.

Feeding was noted to depend upon the activity of the host. Lice maintained in the strap container fed more readily when I remained quiet, especially at night and when in bed. It was also noted that lice would feed for a short time when placed on an arm which was slightly damp from perspiration. Feeding by crawling stages on an individual is probably more dependent upon the individual's activity (and thus perspiration) than temperature, since the scalp temperature varies so slightly (p. 52).

First instar nymphs were observed to attempt feeding immediately after hatching, although blood was not seen in their guts until 5-15 minutes following attachment to the skin. The time spent in this initial feeding ranged from 10 to 45 minutes. Nymphs had to feed within 5-6 hours following eclosion. Those not receiving a blood meal within this period died in ca. 15 hours.

Second and third instar nymphs, fed four times daily, were not observed to feed successfully until 30-45 minutes after ecdysis. If they were placed on my arm in less than 30 minutes, following ecdysis, most would attempt to feed but could not, and would die in 1-2 hours without taking a blood meal. Second and third instar nymphs maintained in the strap container, however, would not attempt to feed until ca. 30 minutes following ecdysis.

First instar nymphs collected from students and those reared in the strap container had guts which were almost always fully engorged. The other nymphal and adult stages, from these same sources, had guts that were almost always half engorged. This demonstrates that lice feed quite often when allowed access to a constant blood supply.

Head louse feeding behavior was examined in relation to host skin surface and room temperature. Ten specimens of each crawling stage, which were removed from the strap container, were fed on my wrist once eight times daily over a three-day period. Lice were kept in the water bath rearing container (Fig. 7) between feedings. Specimens were adjusted to this feeding regimen by feeding them once every three hours six hours prior to recording the temperatures. During each feeding period the temperature near the feeding site on the skin was recorded together with the room temperature.

Results for the temperature recordings showed that the skin surface averaged 27.6 ± 0.5 C, with an average high of 28 C from 3 p.m. to 9 p.m. The average room temperature was 21.1 ± 3.5 C, with an average low of 22 C at 3 a.m. and a high of 27 C at 6 p.m.

As shown by Fig. 17, nymphal instar feeding was generally longer from 6 p.m. to 6 a.m. during the hours of approximate darkness. The slight variation of skin surface temperature probably had no influence in prolonging feeding. The room temperature also probably had no effect in determining feeding lengths.

The feeding periods of nymphal instars were determined by removing them from the strap container and placing them on my arm for three two-hour periods. Ten specimens of each instar were used in this

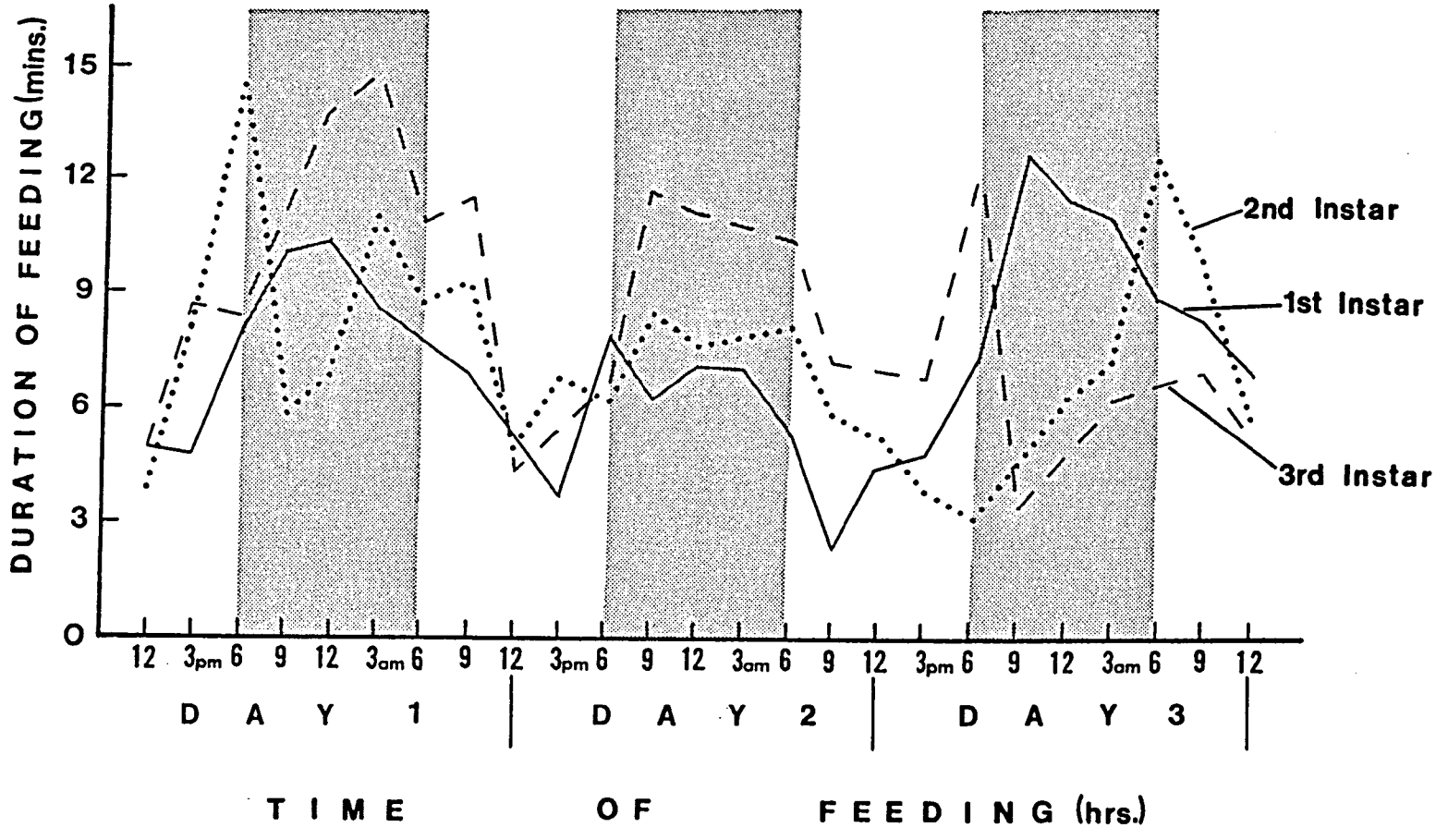

Fig. 17. Mean feeding durations of the nymphal instars of the head louse, Pediculus humanus capitis, fed eight times daily over a three-day period. Shaded areas denote hours of approximate darkness.

experiment. The feeding times for each instar were repeated 8-10 times employing different specimens.

Results from this experiment showed that first, second, and third instars fed a mean of 2.46 ± 1.03, 2.72 ± 1.27, and 4.55 ± 1.44 minutes, respectively. These feeding periods by nymphal instars are probably comparable to the feeding times occurring on the host under natural conditions.

Observations were also made to determine minimal numbers of feeding periods per day necessary for head lice to survive. Seven specimens of each nymphal instar were fed once every six, eight, 12, or 24 hours over a six-day period. Mean feeding durations for instars fed once every six, eight, or 12 hours are recorded in Table 10. These findings showed that feeding periods of instar nymphs fed daily at six- and eight-hour intervals were generally not significantly different at the 5% level. Nymphs fed once every 24 hours survived a mean of 2.5 ± 0.5 days, while those fed every 12 hours survived 4.5 ± 1.5 days.

The minimal feeding times for survival of first and second nymphal instars was four times a day, while third nymphal instars required feeding three times daily. The average developmental times for instar nymphs fed three and four times daily was 9.3 and 8.2 days, respectively.

The majority of previous studies concerning the feeding behavior of nymphal instars of Pediculus humanus involved the body louse. First instar nymphs of the body louse were observed to feed immediately upon emerging from the egg (Warburton, 1910; Fantham, 1912; Nuttall, 1917a), although a later study noted that recently hatched body lice

Table 10. Mean feeding duration of nymphal instars of the head louse, Pediculus humanus capitis, arm-fed at six-, eight-, or 12-hour intervals.

Nymphal Instar	Time Interval (hrs.) and Mean Feeding Duration (mins.) 6	8	12
First	6 cd[a]	7 cd	13 bc
Second	6 cd	8 cd	15 b
Third	7 cd	10 bcd	23 a

a. Means followed by the same letters are not significantly different at the 5% level according to Duncan's Multiple Range Test.

had difficulty in feeding (Buxton, 1940b). My results supported this last author's findings.

Second and third nymphal instars of the body louse were noted to feed very soon following ecdysis (Nuttall, 1917a), but no exact times were given. Sikora (1915) noted that nymphal instars did not feed until 45 minutes after ecdysis. My observations concerning the head louse agree with Sikora's.

My findings concerning the methods of feeding, and the influences of movement and perspiration on feeding by the head louse, support past authors' results concerning these topics.

Ecdysis

Ecdysis by head louse nymphal instars was observed for a number of specimens individually maintained in strap containers. Prior to ecdysis instar nymphs were noted to take in large amounts of blood,

during which time external movements stopped, and gut movements greatly increased. During ecdysis, which took ca. one minute, gut movements decreased or stopped completely. Approximately two minutes were required from cessation of crawling to shedding the ecdysial skin. The newly emerged nymph began crawling again in 2-3 minutes. The entire molting process was thus observed to normally require 4-5 minutes.

Only two authors have mentioned the molting process in P. humanus. Nuttall (1917a), in describing ecdysis by the body louse, did not mention its behavior prior to ecdysis, nor the time molting required. Sikora (1915) noted only that body louse ecdysis took five minutes

Influence of Temperature and Humidity

The influence of temperature and humidity upon rates of development of head louse nymphal instars was examined. Groups of 30-40 instar nymphs, removed from the strap container, were fed four times daily and maintained at various temperatures and relative humidities. Results showed that instar nymphs required a mean of 176.3 ± 23 hours at 27 ± 2 C, a mean of 88.4 ± 10.8 at 34 ± 2 C, and a mean of 70.8 ± 2.1 at 43 ± 2 C. Nymphs could not survive at 47 ± 2 C or higher. Developmental periods did not differ for the three nymphal instars at the specific temperatures.

Humidity did not usually influence instar nymphal development, although high mortalities occurred at lower (< 20%) and at higher humidities (> 85%). These higher humidities caused louse feces to dry slowly, so that nymphs became entrapped and eventually died.

The increased humidity in the strap container as the result of perspiration, especially during the summer months, caused louse feces to remain damp so that lice were adversely affected, especially the smaller nymphs. The problem of feces entrapping lice in natural populations is no doubt very minor, since the feces are probably dispersed from the scalp by movements of the host's head and perhaps by combing.

The detrimental effects of feces in higher humidities was also noted by Culpepper (1944) when rearing body lice.

The developmental times for nymphal instars reared in the strap container were also determined. Temperatures were recorded on the floor of the strap container (Fig. 5B) every three hours daily over a three-day period. The mean temperature for these recordings was 28.5 ± 0.75 C. Each nymphal instar was found to require ca. three days. The total developmental period for the three nymphal instars in natural populations is thus probably ca. nine days.

The developmental time of head louse nymphal instars maintained by Nuttall's (1917a) wristlet method was nine days (1st = 4 days, 2nd = 3 days, 3rd = 2 days). No other developmental periods for head louse instars were found in the literature. My results, unlike Nuttall's, showed that there was no difference in developmental times for the three nymphal instars.

Ten first, second, and third nymphal instars, approximately half engorged, were subjected to various temperatures (each with a r.h. of 75%) in order to determine their longevity. As depicted in Table 11, mean longevity of instars at 36 ± 2 C was significantly shortened at the 5% level.

Table 11. Mean longevity of unfed nymphal instars of the head louse, Pediculus humanus capitis, at different temperatures (r.h. = 75%).

Temperature (± 2 C)	Mean Longevity (hrs.) of Nymphal Instars First	Second	Third
18	36 ab[a]	38 a	39 a
27	21 bcde	30 abcd	33 abc
36	12 e	14 e	15 de

a. Means followed by the same letters are not significantly different at the 5% level according to Duncan's Multiple Range Test.

The survival of head lice (stage not given) separated from the host was found to vary from not more than 25 hours (Roy and Ghosh, 1944), to all stages dying within 30 days regardless of temperature (Keh and Poorbaugh, 1971). The longevity of starved head louse nymphal instars was examined in only one study (Nuttall, 1917a). This involved just the first instar. These instar nymphs, after being moderately fed, had an average survival time of 18 hours (range = 8-24 hours) at 31 C for 10 lice, an average of 38 hours (r. = 21-54 hours) at 17 C for 20 lice, and an average of 83 hours (r. = 48-121 hours) at 12 C for 10 specimens. The humidity was not given for these temperatures. My results for the survival periods of first nymphal instars at different temperatures were generally shorter than Nuttall (1917a) recorded.

Adult Stage

Feeding Behavior

Methods employed for examining the feeding behavior of adult head lice correspond to those used for the nymphal instars. Adults were noted not to feed successfully until 20-30 minutes following ecdysis.

The average feeding times for adults, fed eight times daily for three days, as with nymphal feeding, was generally longer from 6 p.m. to 6 a.m., during the hours of approximate darkness (Fig. 18).

The mean feeding periods of 10 adult males and females, placed on my arm for three two-hour periods, was 5.0 ± 1.4 and 7.4 ± 1.3 minutes, respectively. These feeding periods for adults are probably comparable to the feeding times occurring on the host under natural conditions.

Results for adults fed once every six, eight, or 12 hours over a six-day period are given in Table 12. As shown by this table, there was a significant difference at the 5% level between the six-, and 12-hour feeding regimens.

Minimal feeding required for survival of adults was three times daily. Adults fed once and twice daily survived 2.5 ± 0.5 and 6.5 ± 1.5 days, respectively.

Males and females fed 4-5 times daily, which were fully satiated, were not observed to mate, whereas those fed 4-5 times a day but allowed to feed until they were approximately half engorged were noted to mate. The latter females, however, produced only non-viable eggs.

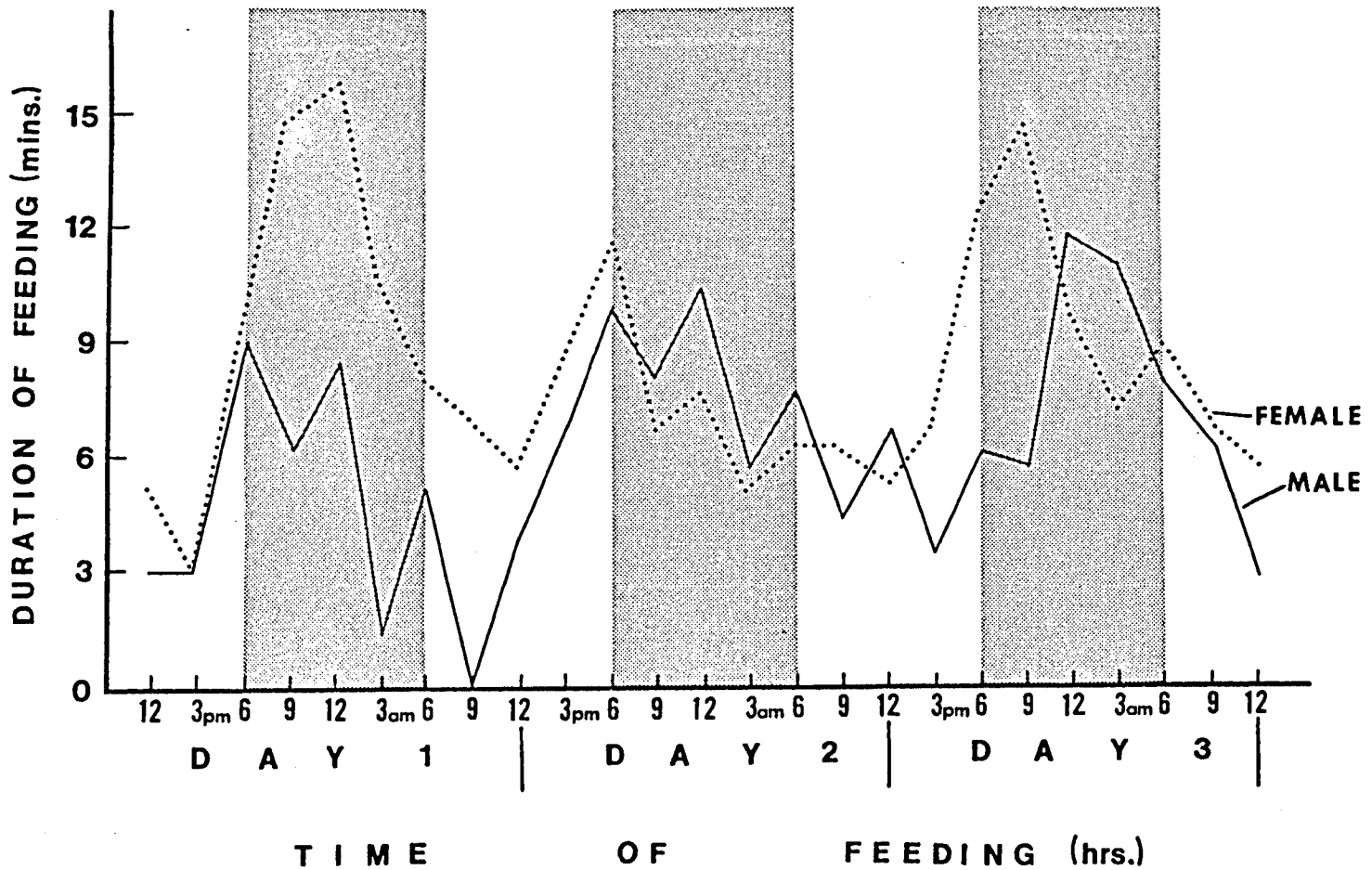

Fig. 18. Mean feeding durations of adult head lice, Pediculus humanus capitis, fed eight times daily over a three-day period. Shaded areas denote hours of approximate darkness.

Table 12. Mean feeding duration of adult head lice, Pediculus humanus capitis, arm-fed at six-, eight-, or 12-hour intervals.

Sex	Time Interval (hrs.) and Mean Feeding Duration (mins.) 6	8	12
Male	11 c[a]	19 bc	38 a
Female	9 c	18 bc	35 ab

a. Means followed by the same letters are not significantly different at the 5% level according to Duncan's Multiple Range Test.

Previous studies involving the feeding behavior of adults of P. humanus, as with those of the nymphal instars, have mainly concerned the body louse. Adult body lice were noted to feed for 20-30 minutes (conditions not given) (Fantham, 1912). They were also observed to feed very soon following ecdysis (times not given) (Nuttall, 1917a).

Only one study was found concerning the influence of temperature on feeding by P. humanus. Of 11 body lice maintained at 39 C, seven fed again after an hour, while two of six adults kept at 7 C fed after nine hours (Hase, 1915). The infrequency of feeding at this lower temperature caused the digestive processes to be suspended (Nuttall, 1917a).

Mating

Mating behavior by head lice was observed for a number of pairs of males and females maintained in individual strap containers. Mating was initiated by the male approaching the female from behind and beneath and seizing her third pair of legs with his first pair. This copulation

position is a modification of the "female above" position given by Chapman (1969). The point of the male's dilator was extruded and oscillated for several minutes until it hooked into the vagina. The mean time spent in copulation was 65 ± 17.7 minutes. In most cases the male would crawl about the female's body for ca. 10 minutes following mating.

Mating by male head lice was noted to first occur ca. 5-7 hours after ecdysis, although insemination could not occur until 14 ± 3.5 hours following ecdysis. Males were observed to mate with the same or a different female (if available) 2-3 times in one day and then to cease mating for ca. 2-3 days.

Lice fed 4-5 times daily were not noted to mate until 2-3 and sometimes 4-5 days after ecdysis. Although these matings produced only non-viable eggs, matings in the strap container predominantly produced viable eggs.

Mating and the copulatory apparatus of the body louse were thoroughly examined by Nuttall (1917c). My observations concerning head louse mating generally agreed with Nuttall for the body louse. He noted only once, however, that the male crawled about the female following mating.

Only one study was found concerning when mating first occurred following ecdysis (Sikora, 1915). He found that mating by body lice, at 35 C, occurred 10 hours following ecdysis. No other information was given.

Mating by a male head louse was found to occur with 10 virgin females; more virgins were not available (Bacot, 1917). The period in

which these matings occurred was not given, nor was it noted whether the females were inseminated.

Insemination

The number of female head lice a male could inseminate was examined using newly emerged pairs of males and females which were isolated in different strap containers. Following mating, the female was replaced with another newly emerged female, and then another. The number of available virgin females limited some of these experiments. One male was observed to inseminate eight virgin females, all of which produced viable eggs in a period of four days. These male insemination frequencies have not previously been determined for the head louse.

Male body lice have been found to require a blood meal prior to inseminating females (Gooding, 1968). All lice had undergone ecdysis within 24 hours of the beginning of Gooding's experiments. He states (p. 266) that "this appears to be the first demonstration of a blood meal needed by a male insect in order to assure insemination." Gooding (1968) found that male body lice could not inseminate femalesuntil 12 hours following feeding. He also noted that timing of insemination is probably more dependent upon time of the male's meal than the female's.

It was not possible in the present study to determine whether male head lice could inseminate females prior to feeding. Isolated pairs of newly emerged unfed male and once-fed female lice, which were then deprived of a blood meal, were not observed to mate.

Fecundity

Fecundity of female head lice was examined by individually isolating them in strap containers following mating. Observations were made every two hours to determine when eggs were produced by mated and unmated females. Eggs were deposited a mean of 14.4 ± 3.7 hours following insemination of virgin females by virgin males. Virgin females inseminated once produced a mean of 56 ± 6.6 viable eggs, while a mean of 7.5 ± 1.4 eggs were laid daily continuously for from seven to ca. eight days (longest being 9.5 days). A mean of 4.5 ± 0.3 non-viable eggs were then produced daily per female.

Head louse eggs and adults were counted for 10 of the 27 generations maintained in the strap container. Results showed that females produced a mean of 6.6 ± 3.9 eggs daily.

Virgin female lice, individually maintained in strap containers, were noted to first produce non-viable eggs a mean of 27.4 ± 1.8 hours following ecdysis. A virgin female was found to lay a mean of 4.6 ± 1.3 non-viable eggs daily for a maximum of 13 continuous days. The maximum number of non-viable eggs laid was 58. Virgin females fed three times daily laid 1-2 non-viable eggs a day for a maximum of 18 continuous days.

Bacot (1917) isolated a female head louse, following contact with a male, and found that it produced 70 viable eggs. He did not state if this female was a virgin prior to insemination, nor did he note how many inseminations occurred. Bacot also found that viable eggs were produced for 7-12 days. Nuttall (1917a) noted that five days was the longest period of continued viability for wristlet-maintained head lice.

Bacot (1917) also observed that the maximum number of eggs (not stated if viable or non-viable) produced by head lice, fed 6-7 hours daily, was 141, with a daily average of four. Nuttall (1917a) recorded that three female head lice, kept with two males, each deposited ca. 82 viable eggs, or almost four per day.

My results generally corresponded with Bacot's (1917) and Nuttall's (1917a) findings, except that the egg viability period agreed more with Bacot than with Nuttall. My findings for the daily mean of viable eggs produced was much higher than these authors noted.

Sex Ratio

The sex ratio was determined for head lice in natural populations and for those reared in the strap container. The percent of females to males collected from 93 infested Tucson students was 76% (Table 4).

Mellanby (1942) found that females comprised 39% of 197 adult lice collected from infested children. A breakdown of sex ratio according to numbers found per child was not done. Buxton (1937) examined 125 infested children, of whom those with 1-10 adult lice yielded 70% females, while females comprised only 40% on those children with over 101 adult lice. Roy and Ghosh (1944) examined 67 infested refugees and noted that those with 1-10 adult lice had 75% females, those with 101-500 adults had 75% females; those with 501-1000 adults had 79% females. One person with 1,434 adults embodied 83% females. These authors thus did not find reduced female ratios on persons heavily infested.

The percent of females to males reared in the strap container was determined for five generations. Lice which were ca. F_3 consisted of 65% females (of a total of 112 adults), ca. F_5 of 60% females (169 adults), ca. F_{15} 61% females (210 adults), ca. F_{20} 62% females (430 adults), and ca. F_{27} 58% females (326 adults). The F_{20} generation was very overcrowded in the strap container, although no decrease in female numbers was noted. The mean percent of females for these generations was 61.2%, compared to 76% observed in natural populations.

The sex ratio of head lice which were reared experimentally was determined only once. Nuttall (1917a) reared four males and six females whose progeny consisted of 100 adults, 57 of which were females.

There was thus a decrease in female percentages for head lice reared under crowded conditions (in the strap container), compared to natural populations in Tucson. These results agreed with Buxton's (1937) and Mellanby's (1942) findings, both of whom noted lower female ratios on those more heavily infested.

Longevity

The longevity of adult head lice was determined by removing third instars from the strap container, placing a single nymph in its own container next to my skin, and observing time of ecdysis and length of adult life. Single pairs of recently emerged males and females were also maintained in individual strap containers. The longevity for virgin adults compared to mated ones was similar: males ($n = 8$) lived a mean of 29 ± 1.4 days, females ($n = 11$) a mean of 31.9 ± 1.5 days. Lice reared from eggs and fed four times daily as nymphs and three times

daily as adults, survived as long as adults maintained in the strap container having a constant blood supply. Third instars, which were collected from school children and from the strap container, fed four times daily, survived only 20-22 days (for males) and 23-26 days (for females).

Waterson (1921) found that adult head lice survived from 21-35 days depending upon feeding, temperature, and other factors. Bacot (1917) noted that adults fed seven hours daily survived a mean of 16 days for males (maximum = 30 days), and 27 days for females (maximum = 38 days).

Nuttall (1917a), in experiments in which adults were fed 6-7 hours daily, noted the same maximum survival periods as Bacot (1917). Nuttall also maintained adults by his wristlet method and found that males lived an average of 23 days and females 22 days. He attributed these shorter longevities to an increased metabolism as the result of more natural conditions.

The longevity of females in the presence of males was also examined by maintaining one or two females with one male. These experiments were repeated ca. 10 times using different lice. Results showed that single females kept with males lived ca. two weeks, while the life expectancies of the two females kept with males were shortened by about 10 days.

Buxton (1947) attributed the significantly lower (using the Chi-square test) number of female head lice on heavily infested children, compared to females on those lightly infested, to more frequent mating

in denser populations. These matings injured females, which shortened their lives and reduced their ratios.

My average longevity periods of lice maintained in the strap container were longer than Nuttall's (1917a) for lice reared by his wristlet method.

My results concerning the difference in female percentages in natural populations (76%) compared to those in the strap container (61.2%), together with my experimental observations, supported Buxton's (1947) findings that male lice increase in denser populations as a result of their adverse effects upon females.

Influence of Temperature and Humidity

Groups of ten male and ten female head lice, which were approximately half engorged, were subjected to various temperatures and relative humidities. Results showed that those maintained at 4 ± 2 C survived a mean of 49.9 ± 4.8 hours; those at 18 ± 2 C, 35 ± 1.7; those at 26 ± 2 C, 24 ± 1.8; and those at 36 ± 2 C lived 8.8 ± 1.8 hours. Adults maintained at 46 ± 2 C lived only 30-35 minutes. Relative humidity did not influence survival time except at low (< 20%) and at high (> 80%) humidities, in which case survival time slightly decreased or increased, respectively.

The survival time of adult head lice exposed to direct sunlight was also examined. Six females and four males, which were half engorged, were placed on a white filter paper, the surface of which was recorded as 36.5 C, while the air temperature was 32 C, and the relative humidity 15-20%. Nine lice survived ca. five minutes, while one female lived six.

Nuttall (1917a) was the only author who gave an accurate account for survival periods of starved adult head lice. These were moderately fed prior to starvation. He found that 10 adults survived a mean of 117 hours (r = 96-143 hrs) at 12 C, 10 survived a mean of 69 hours (r = 48-96 hrs) at 20 C, 10 a mean of 30 hours (r = 23-47 hrs) at 30 C, and five a mean of 25 hours (r = 23-30 hrs) at 33 C.

My adult survival periods were shorter than Nuttall's, especially at 20 C and less.

CONTROL OF THE HEAD LOUSE, PEDICULUS HUMANUS CAPITIS

Introduction

Prevention is the most effective method of controlling the head louse, Pediculus humanus capitis deGeer. This can be accomplished by educating children, parents, teachers, and school nurses as to the louse's identification and biology, particularly its method of transmission (Sobel, 1913; Jalayer, 1967; Lang and Roan, 1972). Good personal hygiene, such as daily combing or brushing of hair and its frequent washing aid in preventing lice from establishing themselves on individuals (Nuttall, 1918; Keh and Poorbaugh, 1971). Prevention can be accomplished only with the wholehearted cooperation of the people involved (Sobel, 1913; Jalayer, 1967). Cooperation is at times difficult since some families have had head lice for generations and see no reason why they should be deloused (Palmer, 1973).

In the present study it was also noted that the attitude of school nurses was most important in preventing head louse infestations among school children. A conscientious school nurse should make weekly class inspections, take the infested child home, and show the parents how to use pediculicides and how to prevent further infestations.

The tradition of certain ethnic groups to wear the hair long, together with the present-day long hair styles, have outdated cutting the hair short in order to discourage head lice as was practiced by European children and men in 1918 (Nuttall, 1918).

Removal of head louse eggs and the crawling stages from lightly infested individuals can be accomplished by hand-picking and employing a fine-toothed comb. Fine-toothed, metal, Derbac combs (Cereal Soaps, Co., Inc., East Northport, Long Island, New York) are specifically made for removing head louse eggs and the crawling stages. A solution of half vinegar (4% acetic acid) and half warm water dissolves the cement of the eggs so that their removal with the Derbac comb is facilitated. Tucson school nurses loan these combs to parents who use them on their infested children. Combs are rarely returned, however, since most are either kept or lost. These combs are also used to remove eggs from the hair following treatment with a pediculicide.

Cutting the hair may be the only resort for those heavily infested, since a Derbac comb is too time-consuming in removing the myriads of eggs present. This was the procedure used for several children during this study.

Prior to the 1940s, most pediculicides used for treatment of head lice possessed some disadvantage, such as being inflammable, or causing irritation. During the 1940s the chlorinated organic insecticide DDT, and other effective insecticides became available for controlling head lice and other arthropods of medical and public health importance. Some of these new chemical compounds proved highly effective and safe, and are still widely used today.

Pediculicides Currently Available in Tucson, Arizona

The principal human louse pediculicides currently available from pharmacies in Tucson are depicted in Table 13. These are also presently

Table 13. Principal pediculicides currently available in Tucson for the treatment of human lice.

Pediculicide	Active Ingredients		Manufacturers' Recommended Lengths of Application
No Prescription Required			
A-200 Pyrinate® (shampoo)	Deodorized kerosene	5.000%	At least 10 min.
	a-{2-(2-butoxyethoxy)=ethoxy}-4,5-methylen-edioxy-2-propyl-toluene	2.000%	
	Pyrethrums	0.165%	
Barc® (lotion)	Propylene glycol	35.000%	Several min.
	Isobornyl thiocyanatoacetate	4.100%	
	Related compounds	0.900%	
Cuprex®	Tetrahydronaphthalene	30.970%	15 min.
	Copper oleate	0.030%	
Prescription Required			
Kwell® Shampoo	Lindane	1.000%	4 min.
Kwell® Lotion	Lindane	1.000%	12-24 hrs.
Kwell® Cream	Lindane	1.000%	12-24 hrs.

available nationally (Miller, 1973). A similar listing was given by Keh and Poorbaugh (1971), in which Bornate^{R} (5% isobornyl thiocyanato-acetate, 0.6% dioctyl sodium sulfosuccinate) replaced Barc^{R}. These authors, who worked in California, also included Topocide^{R} lotion (1% DDT, 12% benzyl benzoate) in their list of pediculicides.

Head louse-infested Tucson school children were treated with Topocide^{R} for 15 years until costs forced school officials to abandon its use in 1970 (Stephens, 1972). In December, 1972, the use of DDT was banned in the United States by the Environmental Protection Agency due to its persistence in the ecosystem.

I replaced Topocide^{R} in the study area with 1% malathion dust, which was distributed in 28 gram containers to school nurses and to Pima County Health Nurses. Distribution of malathion to parents involved a nurse taking the infested child home, showing the parents how to apply the malathion, giving them directions on its use, and supplying them with a Derbac comb. Parents and nurses have commented on malathion's safety and upon its greater efficacy than Topocide^{R} in controlling head lice. The only disadvantages reported with its use were its odor, and its length of application. Both of these factors suggest that a child is infested, thus subjecting him to ridicule by his classmates. For these reasons, a child who is found to be infested is sent home until he is deloused; this procedure also prevents infestation of other children.

The manufacturer's directions for using malathion were re-written because they were too complicated to be followed accurately by parents. The original directions were also not in Spanish, which was a further

difficulty for parents who read little or no English. Directions for the use of malathion were thus simplified for the average individual and also translated into Spanish (Fig. 19).

Effects of Pediculicides upon the Egg Stage

The manufacturers for the pediculicides given in Table 13, as well as for Barc[R] and Topocide[R], state that their compounds kill the egg and the crawling stages of human lice. Although the majority of past and currently used pediculicides kill the crawling stages, a number of reports have been received in the present study concerning the lack of effectiveness by pediculicides in killing head louse eggs. The non-prescription pediculicides and Kwell[R] lotion (Table 13), together with Topocide[R] and 1% malathion dust, were therefore evaluated as to their ovicidal efficacy.

Methods used to evaluate the effects of pediculicides upon head louse eggs are given on pages 31-32. The average of the two mean egg mortalities for the two rinse types following each pediculicide treatment, was determined using analysis of variance (Fig. 20). A mean of 98% of the viable eggs comprising the control batches hatched. Topocide[R] was more effective than the other compounds in killing eggs. Of the currently available pediculicides, A-200 Pyrinate[R] and Cuprex[R] could probably achieve 100% egg mortality if their application times were at least 75 minutes and not 10 and 15 minutes as recommended in Table 16. Kwell[R] lotion and malathion will usually kill all eggs within two hours. As shown by Fig. 20, Barc[R] was the least effective in killing eggs.

USE OF 1% MALATHION DUST FOR THE CONTROL OF HUMAN HEAD, BODY, AND CRAB LICE

Active Ingredients:	
Malathion*.....	1%
Inert Ingredients...	99%
	100%

*diethyl mercaptosuccinate, S-ester with 0,0-dimethyl phosphorodithioate

CAUTION: Avoid prolonged breathing; avoid contamination of feed and foodstuffs; and keep out of reach of children.

CUIDADO: Evitar resollar el polvo por largose ratos; evitar contaminar la comida; poner en un lugar donde no alcanzon los ninos.

DIRECTIONS FOR USE

1. Wet hair so as to better allow dust to cling to hair.
2. Cover eyes, nose, and mouth before applying.
3. Rub from 1/3 to 1/2 of a cup of the dust into hair making sure dust is next to the scalp and that dust is evenly distributed.
4. A shower cap or towel (wrapped turban fashion) can be worn to reduce the smell, but this is not necessary.
5. After 24 hours wash and shampoo hair to remove dust and dead lice.
6. Nits may be removed by washing hair with half warm water and half vinegar, with the fingers, or by a metal comb supplied by the nurses.

COMO SE USA

1. Se moja el cabello par que se pegue el polvo mejor al cabello.
2. Se tapan los ojos, narizes y boca antes de ponerselo.
3. Se hecha 1/3 o 1/2 tasa de polvo en el cabello (que este bein distribuido en la cabeza) y se refriega en el casco.
4. Se puede usar una toalla o una gorra en la cabeza para el olor, pero no es necessario.
5. Despues de 24 horas, se lava bien el cabello para quitarse todo el polvo y los piojos que estaran muertos.
6. Liendres so quitan labandose el cabello con mitad de agua caliente y mitad vinagre, con los dedos o con un peino de metal que les dara la nodriza.

Fig. 19. Revised directions for the use of 1% malathion dust.

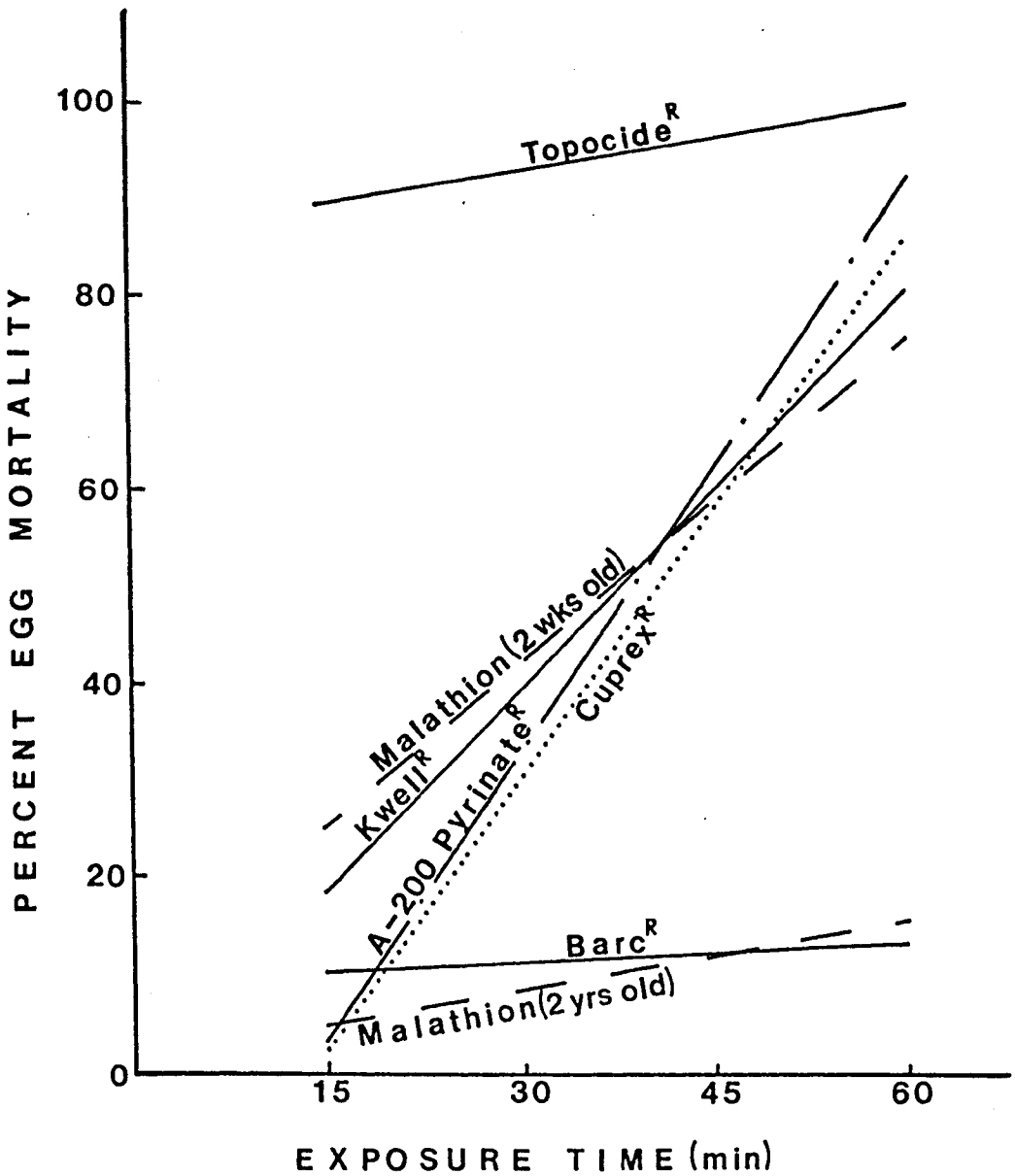

Fig. 20. Mean percent mortality of eggs of the head louse, Pediculus humanus capitis, exposed to pediculicides for various periods.

The mean percent mortalities of eggs, for the two rinse types, exposed to pediculicides for 30 minutes are depicted in Table 14. Egg mortality was significantly different at the 5% level between the two rinse types for Cuprex^{R} and malathion. The residual action of Topocide^{R} is reflected by the somewhat higher mortality of eggs which were rinsed only with warm water.

A number of previous studies have concerned the efficacy of pediculicides upon head louse eggs and the crawling stages. Scobbie (1945) immersed head louse eggs in various compounds for five minutes and noted that 2% DDT emulsion killed 62% of the eggs, while 25% lauryl thiocyanate and paraffin oil produced no egg mortality. She also found that the DDT emulsion gave a 14-18 day residual action. Ten percent DDT dust applied once a week for two weeks killed the crawling stages and also appeared to either kill or retard egg development (Kaiser, 1946). Fifty-five percent wettable DDT powder was shown to kill crawling stages but not eggs so that repetitions once weekly for three weeks were necessary (Morris, 1949).

Ten percent DDT powder was found not to be ovicidal but was residual by killing newly emerged nymphs (Eddy, 1948). Eddy also found that NBIN (6% DDT, 68% benzyl benzoate) was ovicidal and also had a residual effect if the hair was not washed, while MYL (0.2% pyrethrums) was not dependable in giving complete control with one application.

One treatment of 1% lindane shampoo was noted to kill both egg and crawling stages of head lice (Gardner, 1958; Wexler, 1968).

Although these previous treatments killed head louse crawling stages, the egg stage remained less vulnerable depending upon the

Table 14. Mean percent mortality of eggs of the head louse, Pediculus humanus capitis, exposed to pediculicides for 30 minutes.

Pediculicide	Egg Mortality[a] Eggs Rinsed with Shampoo and Water	Eggs Rinsed with Water Only
A-200 Pyrinate[R]	32.2 bcdef[b]	30.0 cdef
Barc[R]	8.5 hij	10.5 gh
Cuprex[R]	34.5 bcd	18.4 g
Kwell[R] Lotion	35.4 bc	34.4 bcde
Malathion	39.5 b	18.4 g
Topocide[R]	89.0 a	93.3 a

a. Mean percent egg mortality for three repetitions per type of rinse.

b. Means followed by the same letters are not significantly different at the 5% level according to Duncan's Multiple Range Test.

pediculicide employed. My results concurred with these past studies in noting that certain pediculicides are more ovicidal than others.

Pediculicide Resistance

Resistance by body lice, P. h. humanus Linnaeus to DDT was first reported in Korea (Hurlbut, Altman, and Nibley, 1952). Natural populations of DDT-resistant body lice have also been found in Tokyo (Barnett and Knoblock, 1952), in Africa (Smith, 1947), and in Egypt (Shawarby, et al., 1963). Global surveys conducted by the World Health Organization from 1953 to 1956 (Wright and Brown, 1957) and from 1958 to 1963 (Wright &

Pal, 1965), concerned the susceptibility of body lice to insecticides. Both these surveys showed body lice to be resistant to DDT in many areas, and that lice were tolerant to lindane in Egypt and several other localities.

Laboratory studies involving the susceptibility of body lice to insecticides have also been reported. Body lice kept on 0.01% DDT for 15 generations were about seven times more resistant than the parent stock (Clark and Cole, 1964). Those subjected to increasing concentrations of lindane for 73 generations developed resistance which was 8,000 times greater than that for susceptible strains. Lice subjected to different concentrations of malathion for 45 generations became twice as tolerant as the parent colony. DDT-resistant body lice from Korea developed more than a five-fold resistance when subjected to 0.01% DDT for 15 generations (Eddy et al., 1955). Lice exposed to lindane and pyrethrins for, respectively, 34 and 17 generations failed to develop more than a two-fold resistance compared to the regular strain.

Three strains of body lice subjected to different concentrations of malathion for from 22 to 40 generations developed no more than a two-fold tolerance when compared to the regular strain (Cole, Clark, and Weidhaas, 1969).

Only two sources have been found concerning insecticide resistance in head lice (Eddy, 1973; Roberts, 1971a). Hybrids produced from several generations of crossing head and body lice were significantly more resistant to certain insecticides than either parent strain (Eddy, 1973); no further data concerning this study was available.

Public health authorities in Flintshire County, England, had used DDT for controlling head lice, but abandoned it in 1967 due to possible harmful long-term effects (Roberts, 1971b). DDT was replaced by Lorexane (lindane), which appeared to be very effective, until one or two areas in Flintshire County yielded head lice resistant to it (Roberts, 1971a). One percent malathion solution was then used just in these areas for effectively controlling head lice (Roberts, 1971a).

The World Health Organization Insecticide Resistance Kit for body lice was used to test the susceptibility of Tucson head lice to pediculicides. Procedures used in this test are given on pages 32-33.

Probit analysis was used to evaluate whether head lice were resistant to the pediculicides tested (Fig. 21). Results showed that adults were probably not resistant to the various concentrations of DDT, lindane, or malathion. The LC_{50} for DDT, lindane, and malathion were 3.35, 0.021, and 0.10%, respectively.

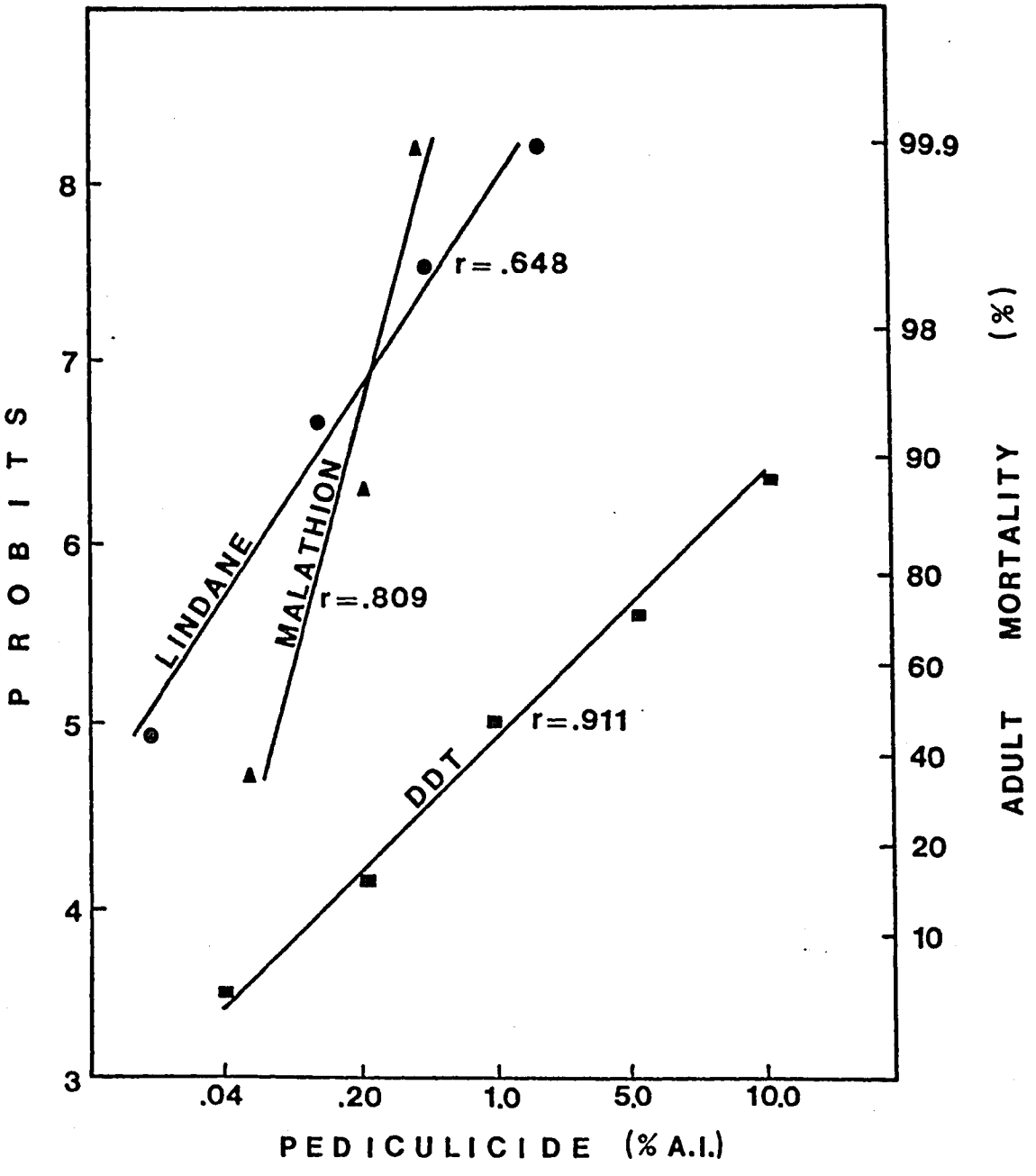

Fig. 21. Mean percent mortality of adult head lice, Pediculus humanus capitis, exposed to various concentrations of pediculicide powder formulations for two-hour periods.

SUMMARY AND CONCLUSIONS

The biology and control of the head louse, Pediculus humanus capitis deGeer, was examined in Tucson, Arizona, which represented a semi-arid urban area. Rearing large numbers of head lice, used for experimental manipulation during this study, was accomplished by improving upon the past rearing method (Nuttall, 1917a). This improved method produced 27 generations of head lice which laid over 57,000 eggs.

Head louse infestations are usually identified when eggs are found. I noted that infestations could also be determined by finding louse fecal material on the shoulders and back of an individual, especially one who was heavily infested.

Ca. 4.3% of the 24,000 elementary school children in the Tucson study area were infested. This percentage is much lower than other studies, no doubt due to the population's overall good hygienic habits. Seventy-three percent of those infested were girls. Eighty-four percent of the total infestations were from the lower socio-economic areas of Tucson, where poor living conditions often reflect poor personal sanitary habits. These areas may serve as reservoirs for louse spread since all reinfestations occurred in these communities. Some of the schools in these areas had infestation rates of 8-10%.

No Black students were reported infested during this study. Head louse scarcity among this ethnic group in Tucson and in other areas of the United States (Sobel, 1913), compared to their relative

frequency among Black Africans (Buxton, 1938a), probably reflects differences in hair styles.

Transmission of head lice by Tucson school children occurred mainly during play activities, but the sharing of infested combs and other indirect means of transmission were also noted by school nurses. A common mode of transmission among siblings was attributed to sleeping together in the same bed, especially in lower socio-economic areas.

In a semi-arid urban area, such as Tucson, no decrease in louse numbers was noted during the warmer summer months. More children were observed to be infested following school holidays, which was probably the result of increased contact with infested relatives and neighbors. The seasonal abundance of head lice in Tucson was probably thus due to seasonal and social habits rather than to climatic differences, as was also reported by Buxton (1938a).

Average head louse infestations in the Tucson study area yielded 1.7 crawling specimens per student, while the maximum number collected from a student was 530. Female students had significantly higher numbers of adults, at the 5% level, probably due to their longer hair, which provided for a better habitat. These findings concur with previous studies.

Location of lice on individuals' heads was determined by conditions of the hair which governed moisture and light to which lice were exposed. Temperature probably had only a slight influence upon louse location since it varied only slightly for scalp (mean = 29.1 ± 0.15 C) and hair (mean = 28.56 ± 0.3 C) surfaces. Temperatures of the head louse microhabitat have not been measured previously.

Developmental time of head lice on the host was ca. 17 days: egg = ca. seven days, nymphal instar = nine days, pre-oviposition = one day. These periods generally coincided with previous findings.

Eggs were usually deposited in the thicker, more sheltered areas of a child's hair, where humidity is probably higher. Newly deposited eggs were usually found attached to the base of a hair ca. 1 mm from the scalp surface with the operculum facing outward. Eggs were noted to be laid one at a time. Lightly infested individuals had certain areas of the head with usually one egg per hair, but 20-30 eggs per hair were not uncommon on those very heavily infested.

The maximum number (95-99%) of eggs hatched at 31 ± 2 C, while the shortest incubation period was 36 ± 2 C in 5-6 days. The maximal and minimal lethal temperatures for eggs was 39 ± 2 and 24 ± 2 C, respectively. At 31 ± 2 and 36 ± 2 C, there was a correlation between humidity and eclosion, with more hatching at 70-80% than at 50%. Humidities greater than ca. 83% decreased eclosion rates at greater than 30 ± 2 C. These findings generally agreed with Leeson's (1941) for eggs of the body louse, P. h. humanus Linn. At 31 ± 2, however, higher and lower humidities resulted, respectively, in higher and lower eclosions for head lice than Leeson found for body lice.

First instar nymphs were noted to confine themselves to the scalp surface, while the other crawling stages were primarily found in thinner areas of the hair where humidity was probably lower. Second and third instar nymphs and adults stayed in the hair near the scalp for access to feeding. An in-depth study of the location of head louse

eggs and crawling stages has not been previously reported in the literature.

Feeding by head lice occurred more readily when the host remained quiet, especially at night during the hours of darkness. Feeding, as with egg production, was more dependent upon perspiration, and thus activity of the individual, than scalp temperature, since the latter varied slightly.

Lice were observed not to feed until 5-10 minutes after eclosion, while second and third nymphal instars could not successfully feed until 30-45 minutes following ecdysis. Adults could not feed until 20-30 minutes after ecdysis.

First, second, and third nymphal instars were found to probably feed on the host for 2.46 ± 1.03, 2.72 ± 1.27, and 4.55 ± 1.44 minutes, respectively. The feeding periods for adults on the host were probably 5.0 ± 1.4 minutes for males, and 7.4 ± 1.3 minutes for females.

Minimal feeding times required for louse survival were four times daily for first and second nymphal instars, and three times daily for the third nymphal instar and adults. The biological processes of lice maintained by feeding 3-4 times daily were markedly hampered: ecdysis was delayed, oviposition and defecation were infrequent, mating (which was rarely observed) produced only non-viable eggs, and longevity was shortened.

My observations concerning feeding by the head louse differed from most past studies involving the body louse. These studies therefore add a great deal of information on the feeding behavior of the head louse.

It was noted that at ca. 27 ± 2 C/75% r.h. first, second, and third nymphal instars, which were half engorged, survived 21, 30, and 33 hours, respectively. Starved adults kept at 4 ± 2 C survived a mean of 49.9 ± 4.8 hours, at 26 ± 2 C a mean of 24 ± 1.8 hours, while at 46 ± 2 C they lived 30-35 minutes. Humidity did not influence length of survival except at low (< 20%) and high (> 80%) humidities, in which case survival periods were slightly decreased or increased, respectively. In direct sunlight (36.5 C) adults survived ca. five minutes. These survival periods for head louse crawling stages were not previously determined accurately.

Head lice were first observed mating 5-7 hours following ecdysis, although insemination was not successful until 14 ± 3.5 hours after ecdysis. A male, during its normal lifespan (ca. 29 days) could conceivably inseminate 21 different females. Males were observed mating with the same or different female 2-3 times daily, then ceasing mating activity for ca. 2-3 days. Past studies concerning mating and insemination by P. humanus Linn. were not thorough, so that my observations enhance these topics considerably.

Females produced a mean of 6.6 ± 3.9 eggs daily, while 183-235 could probably be produced in their lifespans (ca. 31 days). Females produced viable eggs for 7-8 days. Eggs were first produced 14.4 ± 3.7 hours following insemination. Virgin females inseminated once produced 56 ± 6.6 viable eggs. Unmated females first produced non-viable eggs 27.4 ± 1.8 hours following ecdysis, while they laid 4.6 ± 1.3 non-viable eggs daily for a maximum of 13 continuous days. My results regarding head louse fecundity generally agreed with Bacot's (1917) limited observations.

Females comprised ca. 61% of reared adult lice which were counted (n = 1,247), while natural populations on students (n = 230) yielded 76% females. These findings, coupled with my other observations, showed that frequent matings in higher louse populations are detrimental to females, as was also noted by Buxton (1947).

My experiments showed that head lice did not congregate but probably clustered to avoid light and/or to seek better conditions of temperature and humidity. These results disagreed with Bacot (1917) and Nuttall (1917a), both of whom noted that head lice do congregate.

Pigmentation by head lice was noted not to be sex-linked, but a characteristic possessed by some lice and not others.

The most effective method for controlling head lice is by their prevention, which can be accomplished by proper sanitary habits, such as periodic bathing, and washing and combing the hair. Educating people as to their biology, particularly their mode of transmission, is also important. Head lice cannot be prevented without the cooperation of the people involved. The attitude of school nurses was found to be most important in motivating parents to prevent and control head lice.

The tradition of certain ethnic groups to wear long hair, together with current long hair styles, have outdated cutting the hair short to discourage head lice.

The use of specially-made, fine-toothed, metal combs, together with a solution of vinegar (4% acetic acid) and warm water, can facilitate removal of eggs from the hair. This procedure can be used to remove eggs following treatment with a pediculicide, or it can be used by itself, if the individual makes certain all crawling stages are removed.

The manufacturers of the principal pediculicides currently available in Tucson, and nationally, state that their compounds kill head louse eggs and the crawling stages. It was found that some of these were not completely ovicidal if used according to the manufacturers' recommended application times. Barc^{R} was the least ovicidal (killing only 13% in 60 mins.), while A-200 Pyrinate^{R} and Cuprex^{R} could kill all eggs if the application times were increased to 75 minutes. Kwell^{R} lotion and 1% malathion dust were completely ovicidal in two hours, so that the recommended application time for Kwell^{R} lotion (of 12-24 hours) and for malathion (of 24 hours) could be considerably shortened.

The experimental use of 1% malathion dust generally proved effective and safe for controlling head lice. Revising the directions for its use and translating them into Spanish facilitated use by parents.

No resistance to various concentrations of DDT, lindane, and malathion formulated powders was demonstrated in Tucson head lice.

APPENDIX A

OCCURRENCE AND MODE OF TRANSMISSION OF THE CRAB LOUSE, *PTHIRUS PUBIS* (ANOPLURA:PTHIRIDAE), IN TUCSON, ARIZONA

Besides examining the biology and control of the head louse, *Pediculus humanus capitis* deGeer, the other human louse found in Tucson, the crab louse, *Pthirus pubis* (Linnaeus), was also studied as to its occurrence and mode of transmission. In recent years crab louse incidence appears to be on the increase in the United States due to a climate of cultural permissiveness (Keh and Poorbaugh, 1971). A contemporary source for infestation by crab lice is the "hippie live-in" (Ackerman, 1968). Ackerman also noted (p. 950) "crab louse incidence, like that of other venereal diseases (*sic*), has risen significantly as the boundaries of sexual freedom have blurred." Besides communal living and more permissive attitudes toward sex, crab louse incidence is increasing due to poor hygiene and crowded living conditions (Anon., 1974).

The major mode of transmission of the crab louse is by sexual intercourse. Its life history is similar to that of the head louse, but according to most authors it is more often found on the coarser hairs of the human body such as the pubic and perianal areas. It may also occur on other parts of the body, such as on the hairs of the thigh, abdomen, axilla, and head, as well as on the face (Keh and Poorbaugh, 1971).

Crab louse infestation of the scalp has been reported to be extremely rare (Goldman and Friedman, 1941). In a later study the scalp was reported never infested (Alexander, 1968). More recently, six cases of crab louse infestations of the scalp were reported (Elgart and Higdon, 1973; Mueller, 1973). Elgart and Higdon believe that the scalp may be becoming a more common site of infestation by crab lice.

As with other human lice, the crab louse is almost exclusively found on humans. The very few exceptions have been reported on dogs. Crab lice were collected from a dog whose owner shared his bed with it (Frye and Furman, 1968). In the current study a case was reported to me in which a number of individuals shared a house in which their two dogs were highly infested with crab lice.

Crab louse data, in the present study, was supplied from personal interviews with 37 infested individuals in Tucson from September, 1971, through July, 1972. These people were referred to me by friends, referral services, or by relief agencies. Information concerning individual cases was kept on survey forms as depicted in Fig. 22.

Ages of the individuals reported infested with crab lice ranged from 18 to 32. They were mostly students and transients ("street people"). There was therefore some bias in the type of individual who was interviewed. Table 15 depicts their sources of infestation. All of the individuals who became infested directly did so by sexual intercourse, while the majority of those who contracted crab lice from a girl or boy friend, or spouse, knew that their partner was infested but had intercourse regardless. Borrowed sleeping bags were found to

PUBLIC HEALTH ENTOMOLOGY
CRAB LOUSE DATA FORM

Current Date: _____

Age and Sex of Infested Individual: _____

Address or Area of Infested Individual: _____

Ethnic Code: 1 2 3A 3Y 4 5 6

Probable Address or Area Where Infestation Occurred: _____

_____

Probable Date of Infestation: _____

Date Infestation Was First Noted: _____

Was Possible Infestation Made to Other Individuals Following

Initial Infestation? _____

Address or Area of These Other Possible Infested Individuals:

_____

_____

_____

Pediculicide Used: _____

Effectiveness: _____

Fig. 22. Crab louse, Pthirus pubis, data form. Key to ethnic code lettering: 1 = Caucasian; 2 = Mexican-American; 3A = American Indian; 3Y = Yaqui Indian; 4 = Black; 5 = Oriental; 6 = Other.

Table 15. Sources of crab louse, Pthirus pubis, infestations reported in Tucson from September, 1971, through July, 1972.

Ethnicity	Direct Infestation: From Girl/Boy Friend, or Spouse	Direct Infestation: From Prostitutes	Indirect Infestation: From Bedding	Indirect Infestation: From Misc. Objects
American Indian	0	0	1	0
Black	4	1	1	0
Caucasian	8	11	3	1
Mexican-American	4	1	1	1
TOTAL	16	13	6	2

be the main bedding source for indirect infestations, while miscellaneous objects were mostly borrowed towels and blankets. Crab lice were collected from the scalps of three of the 57 infested individuals. These people probably became infested by indirect means.

The majority of people who became infested by prostitutes said they probably did so in Nogales, Sonora, Mexico. One individual became infested in Madrid, Spain, while only one had probably acquired lice from a Tucson prostitute.

About 40% of the infested individuals were transients living in vans, or "crash pads," which served as sleeping quarters. Many of these individuals were also found to be infested with head lice.

Most of the reported crab louse-infested residents of Tucson lived just north and west of The University of Arizona in middle to

lower income-level homes. Two cases reported from a more affluent area on the east side of Tucson. These individuals, both female, reportedly became infested after sharing their apartment with infested male transients. One of these females informed me she became infested in the pubic regions via sexual intercourse, while the other female became infested just on the scalp, from which four crab louse specimens were removed. The latter individual probably became infested from a towel used by the transients, as she reportedly had no sexual contact with them.

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