A Study of the Relationship between the starling <u>Sturnus vulgaris</u> and the Haematophagus mite <u>Ornithonyssus bursa</u>

A thesis presented in partial fulfilment of the requirements
for the degree of Master of Science in Zoology
at Massey University

Ralph Graham Powlesland

1976

Frontispiece: Fifteen day old starling nestling with several individuals of the mite *Ornithonyssus bursa* located around the beak and below the eye.

Table of Contents

List of Tables.

List of Figures.

LIST OF PLATES

ABSTRACT

A description is given of a study of starlings breeding in 160 nest boxes over the two breeding seasons 1974-75 and 1975-76, aimed at determining productivity and some factors which possibly affect it. Changes in productivity through the season and between seasons are discussed, with particular reference to the influence of the mite *Ornithonyssus bursa* on nestling growth rate, weight at 15 days, mortality, blood characteristics, and lipid stores. Also the effect of mite infestations on the mean weight of nestlings from different brood sizes is discussed.

The starling nestling period is described, including changes in feeding activity, growth rates, sanitation measures and behaviour patterns. Factors possibly contributing to the death of late hatching nestlings are discussed.

The life cycle of *O. bursa* is outlined with particular emphasis on feeding methods and their effects on the host. The behaviour of mites in response to some environmental variables is discussed briefly in relation to the effects of mites on nestlings.

The seasonal pattern of *O. bursa* infestation over the starling breeding season is described with particular emphasis on the proportion of nest sites infested and the degree of infestation at each of three periods in the breeding season. Several methods of mite dispersal are considered and their importance in infesting other nest sites are discussed.

Acknowledgements

I wish to thank the many people who have helped in the preparation of this thesis. In particular, I gratefully acknowledge the help from my supervisor Dr.R.A.Fordham, whose constructive criticism and patient assistance were invaluable. I also acknowledge Mr.L. Gurr's help while Dr. Fordham was absent on leave.

My thanks to Ecology Division, D.S.I.R. for their financial assistance for the study and to Dr.H. Wenham, Mr. K. Lowe and Mr.R.F. Webb who allowed me access to their properties for my studies. Also to Mr.H. Robertson who kindly allowed me to use nest boxes he had erected.

I am grateful to my fellow students for their assistance, discussions and suggestions, especially Mr. N. Pomeroy who provided valuable help with photographic techniques.

Finally, many thanks to Mary for her aid throughout this study, especially with correcting and typing the initial manuscript.

1. Introduction

The common starling Sturnus vulgaris, a member of the Family Sturnidae was introduced into New Zealand from Europe in 1862 (Wilson, 1975). Its introduction was encouraged by farmers who believed it to be a valuable consumer of pasture pests. Starlings dispersed rapidly after their introduction and are now distributed widely over the country wherever the habitat is suitable for feeding. They are not found in dense native forests, or often above the snowline, but tend to be restricted to cleared and cultivated land created by farming activities. The starling is essentially an omnivore, its diet consisting largely of soil and sward-inhabiting organisms, with grain and fruit being eaten to a lesser extent (East, 1972).

Although starlings are cosmopolitan their abundance is thought to be controlled to a large extent by the availability of suitable nest sites (von Haartman,1957; Kessel, 1957). Such a situation has occurred in many areas of New Zealand, with a substantial increase in the number of breeding pairs when artifical nest sites have been erected (Bull, 1973). Also in areas where the common myna Acridotheres tristis, is found (north of latitude 40°S) competition for nest sites is evident. The myna is the more aggressive of the two and not only drives starlings from the nest-sites but destroys their eggs and nestlings. To overcome this competition and preferentially increase starling numbers, nest boxes with a 45mm entrance hole have been erected (Wilson, 1975) which allows starlings but not mynas to enter and breed. Thus farmers wishing to build-up local starling populations around their farms in the hope of encouraging consumption of pasture pests have often erected nest boxes in efforts to overcome any lack of natural nest sites.

Several studies have been carried out in New Zealand in recent years to investigate the value of starlings as biological control agents on pasture pests. East (1972) studied starling predation on grass-grub Costelytra zealandica populations while Coleman (1972) examined the feeding ecology and management of starlings; both of these studies being carried out in the

Canterbury Province. Current studies being carried out in Ecology Division, D.S.I.R. are directed towards finding how starling numbers can be increased by the erection of nest boxes; what the best design of nest box is; what eventually checks the population and how the increased population affects grass-grubs and orchards (Bull, 1973).

Some authors writing about the breeding biology of the starling noticed that the nests were often infested with parasitic mites. Royall (1966) in Central Arizona and De Haven and Guarino (1970) at Denver, Colorado found that the nest boxes were heavily infested with the red fowl mite *Dermanyssus gallinae*. Also several workers in New Zealand (e.g. Wilson, 1971; Drs.P.C. Bull, J.E.C. Flux and P. Purchas pers. comm) have commented that starling nestlings and nest boxes are often infested with large populations of parasitic mites. The feeding activities of these mites have been suspected as being partly responsible for the death of heavily infested nestlings. Wilson (1971) studied the ecology of the myna in Hawkes Bay and found that both myna and starling broods were often infested by the mite *Ornithonyssus sylviarum*. He concluded that this mite imposed "a strain on the --myna-- nestlings by sucking lymph, causing irritation and weight loss and in severe cases, causing the female to desert from the nest at night --- with obvious serious consequences".

In the Manawatu district, the bloodsucking mite found in starling nest boxes is *O. bursa* which has sometimes been called the "starling mite" (Dr. G.W. Ramsay, pers. comm.). *Ornithonyssus bursa* was first recorded in New Zealand in January 1950 (Murray, 1950) from specimens found on children; the original source of the infection being a deserted starling nest in the ceiling of a house. Since then it has been found in this country on a variety of avian hosts with the domestic fowl *Gallus gallus*, house sparrow *Passer domesticus* and starling being the most common.

Moss and Camin (1971) investigated the influence of the mite *D. prognephilus* on productivity and clutch size in purple martin *Progne subis* colonies but no similar study has yet been made here or elsewhere on the effects of *O. bursa* on productivity of starlings. Thus the objectives of this study were to examine the relationship between starlings and populations of *O. bursa* and in particular to look closely at the effect of mites on nestling growth and survival.

2. STUDY AREAS

2.1 Description

The study areas chosen (Fig.1) were selected because of ready accessibility from Palmerston North and because starlings were already known to breed there. The chief characteristics of each area are now detailed.

(1) Te Matai Road

This area, about eight kilometres from Palmerston North, is part of the property of DD..H. Wenham and is bordered on the eastern side by the Manawatu River (Fig.2). The study area covered approximately 12 ha. of flood-derived alluvial soils, now guarded by stop-banks. The land is flat with macrocarpas, *Cupressus macrocarpa* willows, *Salix babylonica* blue gums, Eucalyptus globulus and poplars *Populus nigra* being the only barriers to prevailing nor-westerly and easterly winds. The farm carries a flock of Coopworth sheep, but most of the property is maintained in pasture with about three hectares of lucerne for grazing and hay production. Each year three or four crops of hay are taken off the two paddocks of lucerne after which these are available for grazing sheep. In spring about two hectares are sown in potatoes, and after harvesting this crop in late summer the area is sown in pasture once more.

The land within a five kilometre radius of the study area is used mainly for pasture production, and there are small areas of commercial vegetables, grain and fodder crops.

Nest boxes were first introduced into the study area in the winter of 1972 when Dr. Wenham erected 12 boxes on trees and buildings. During winter 1973 a further 40 boxes were erected by Dr.Wenham on four fence-lines, followed by another 17 during the next breeding season. In May and June 1974 I set up 43 boxes so that in the 1974-75 and 1975-76 breeding seasons a total of 100 nest boxes on fence-lines were available to starlings.

The nest boxes were all made to the same pattern from 17cm by 1.3cm timber. Internal measurements were 14cm x 14cm square at the base and c. 30cm deep. The lid sloped down

<u>Figure 1</u>: Map showing the Study Areas and their relation to Palmerston North.

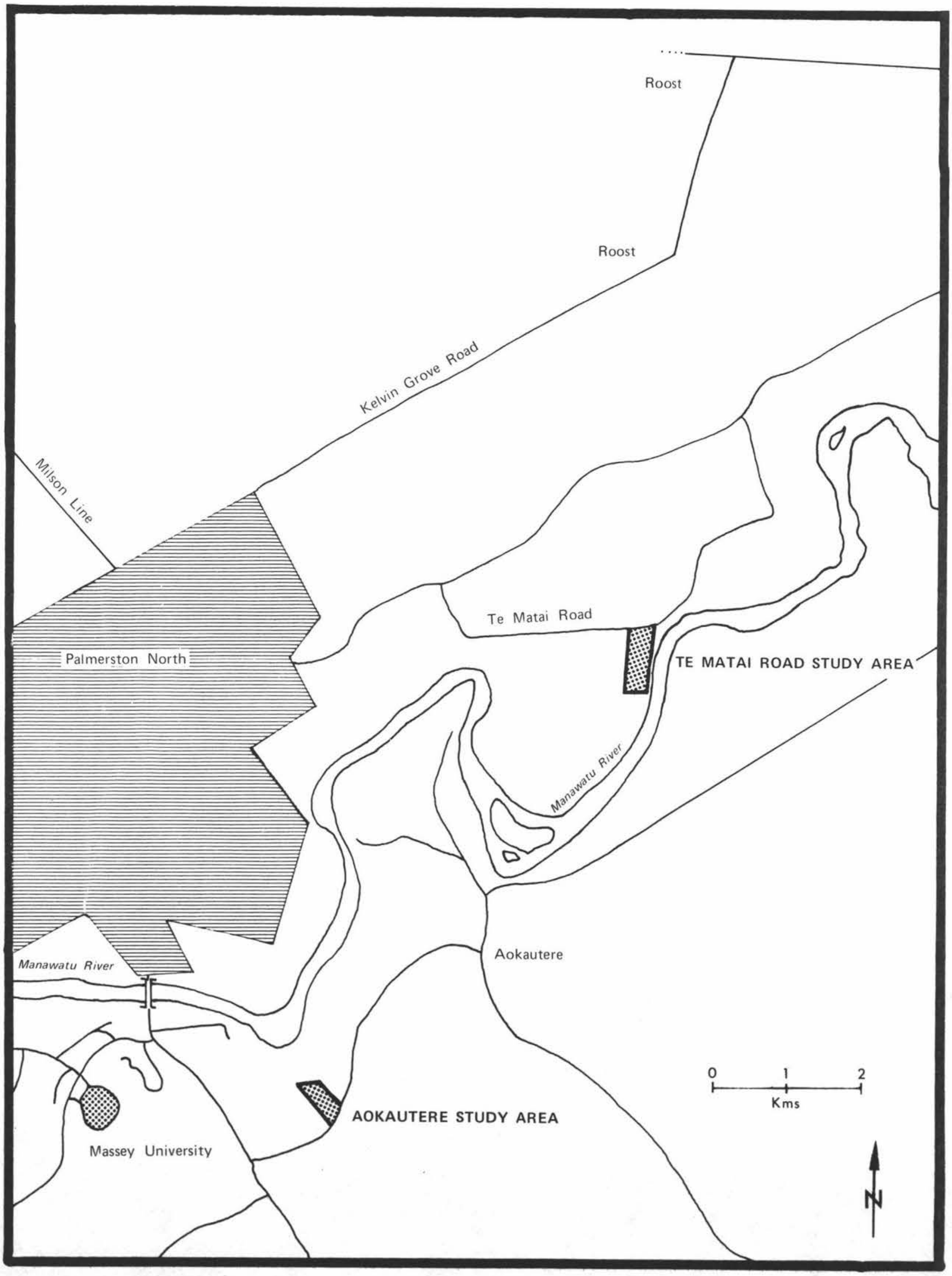
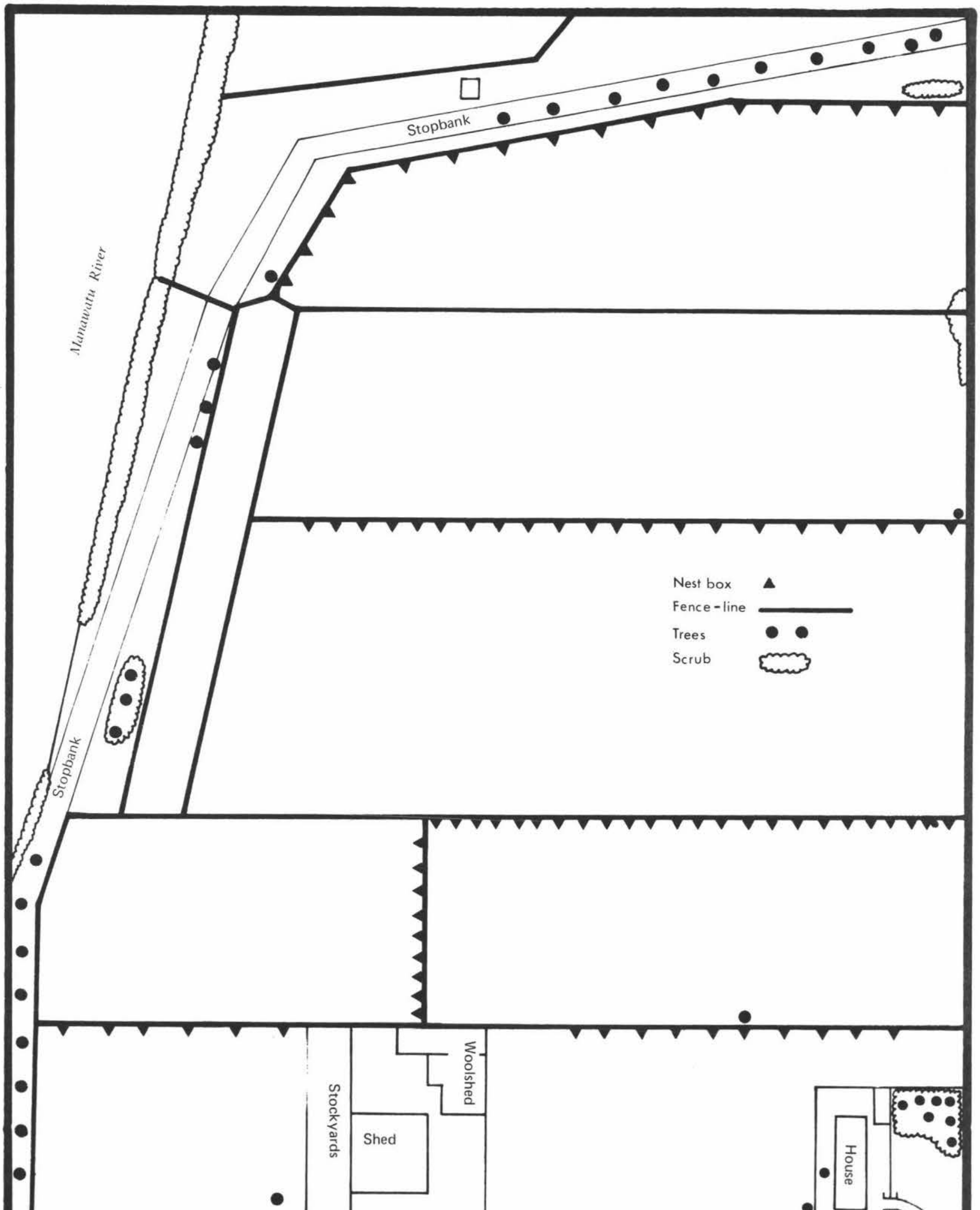

Roost
Roost
Kelvin Grove Road
Milson Line
Te Matai Road
Palmerston North
TE MATAI ROAD STUDY AREA
Manawatu River
Aokautere
Manawatu River
AOKAUTERE STUDY AREA
Massey University
0
1
2
Kms
N

Figure 2: Map of the Te Matai Study Area.


Manawatu River
Stopbank
Stopbank
Nest box ▲
Fence-line
Trees ● ●
Scrub
Woolshed
Stockyards
Shed
House
Te Matai Road

towards the rear with the entrance hole and a perch 10cm from the top. All nest boxes were stapled to the top two wires of the fence so that the entrance holes were approximately 1.25m from the ground. On average the nest boxes were 9.5m apart (maximum 15.0m;minimum 6.8m). Ninety-three nest boxes faced in a NNW direction, while the remaining seven faced NE.

(2) Aokautere

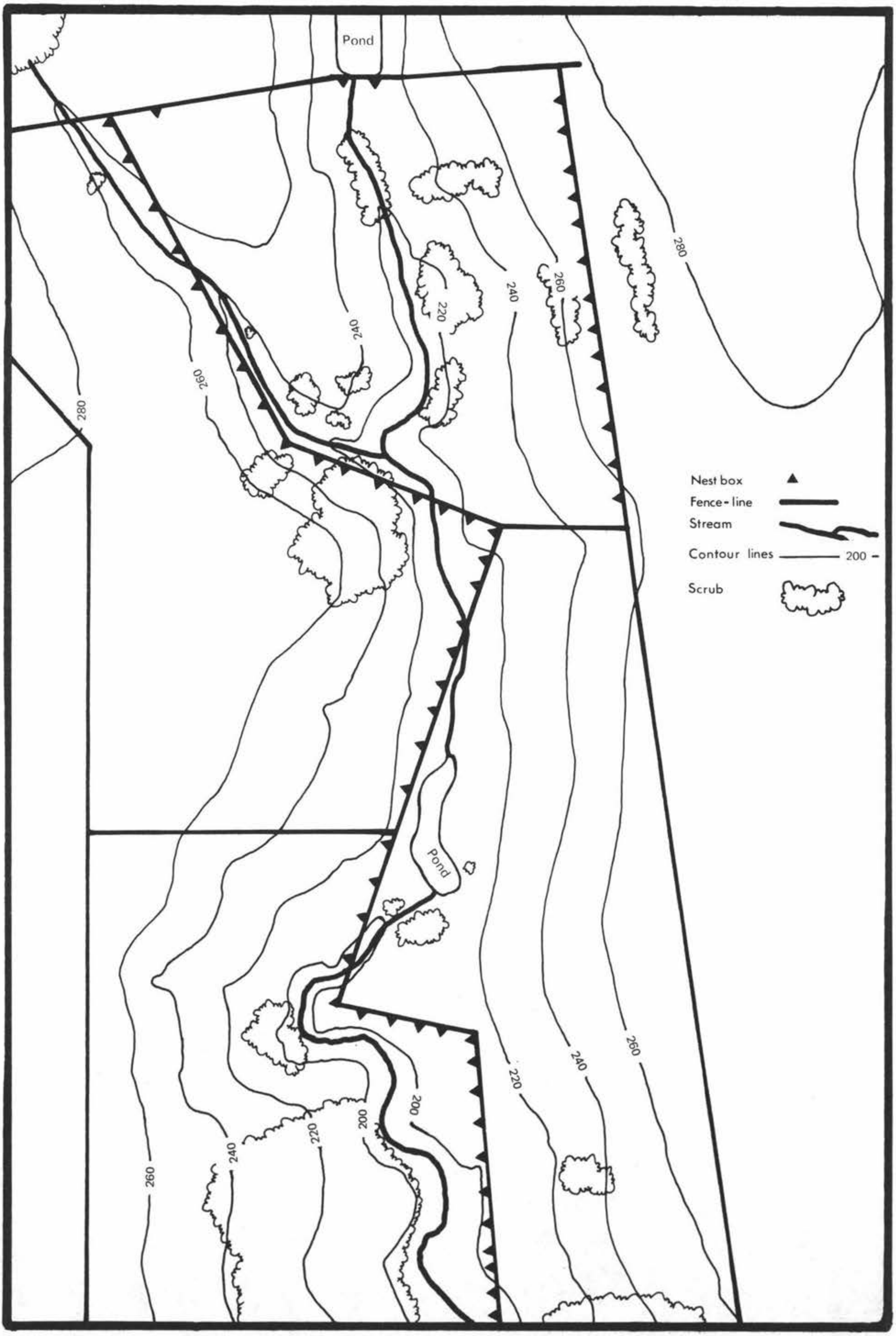
The Aokautere study area, on Mr.K.L. Lowe's property, is four kilometres from Palmerston North, and differed from the Te Matai Road area in topography (Fig.3). It is situated in a valley of about 10 ha with a soil comprising yellow-grey earth and loess.. A stream meanders down the valley and above this the valley sides rise some 120m. to substantial areas of flat land. These areas are utilized equally for pasture production and crops such as barley Hordeum vulgare and maize Zea mays. Willows grow by parts of the stream and considerable areas of the valley sides are covered in gorse Ulex europaeus and hawthorn Crataegus monogyna. A small flock of sheep and a few steers graze in the valley.

Prior to the 1974-75 breeding season, Mr.H. Robertson erected 51 nest boxes on fence-lines in the study area and I put up a further nine bringing the total number of nest boxes in the study area to 60. All the boxes were attached to the tops of fence posts, which made the entrance holes about 1.5m from the ground. On average the nest boxes were 10.8m apart (maximum 17.6; minimum 4.8m), and they faced in a NNE-NE direction.

(3) Massey University

Prior to the 1975-76 breeding season it was decided that destructive analysis of some nest boxes was essential to obtain total numbers of mites present (rather than indices of numbers present) at various times of the breeding season. So as to avoid draining the main study areas of Te Matai Rd and Aokautere, 28 additional boxes were erected on Massey University No. 3 Sheep Farm and on No.2 Dairy Farm. These boxes were identical to those already in use in the other study areas, however to facilitate quick and efficient dismantling they were not nailed together but instead were braced tightly with wire. They were then nailed to the top of suitable wooden fence posts, but were spaced far apart to enduce a high rate of occupancy. Twenty-one

Figure 3: Map of the Aokautere Study Area. Conour-lines are in metres.


Pond
Pond
280
280
260
260
240
240
240
220
220
200
200
260
240
220
260
240
260
Nest box ▲
Fence-line
Stream
Contour lines 200
Scrub

faced in a NE direction while the remaining seven faced W. The land surrounding the nest boxes was mainly flat pasture with a small area cultivated for cropping and trial-pasture plots.

2.2 Meteorology

It has been established elsewhere that climate influences breeding success in starlings. For instance, Dunnet (1955) showed that in Scotland during the breeding season about 95% of the food taken by foraging starlings lived just below the soil surface, in the region most influenced by weather. Drying of the soil surface, due to drought conditions, can result in a decrease in the availability of food to the foraging parent starlings. Studies carried out on irrigated pastures (Lobb and Wood,1971) and non-irrigated pastures (Coleman,1972) on the Canterbury Plains showed that starlings consumed animal material when it was available. However, when drying of the sward occurred they were "forced to consume cereals from stubble fields to supplement their insect diet" (East,1972). Taitt (1973) has shown in feeding studies with starlings that vegetable material has a lower energy value and digestive efficiency when compared to animal material. Therefore nestlings with a high proportion of vegetable material in their diet would be expected to have a reduced growth rate and less chance of survival. Thus weather over the breeding season (September to January in New Zealand) is an important influence on breeding starlings and the climate in the study areas for this period is now considered.

Meteorological records used were those obtained by Grasslands Division, D.S.I.R. at Station 19, which is situated next to Massey University. These measurements were considered reasonable accurate for the two main study areas because both are within 10km of the station. Meteorological records for the five breeding seasons prior to 1974-75 (see Appendix 1) show that as the breeding season progresses there is generally a decrease in monthly total rainfall, and a rise in mean temperature (= half the sum of the maximum and minimum monthly temperatures) but the amount of wind remains fairly constant. Therefore during the breeding season the potential for evaporation of surface water increases, which contributes to a drying of the soil surface and this in turn impedes probing by starlings in the grassy sward. Lobb and Wood (1971) found from faecal analyses that most of the major foods of starlings were insect pests and worms that inhabit the sward and the upper two centimetres of soil. In 1969, between mid-June and late August they found that when the weather was dry with frequent frosts, very few grass-grub (Costelytra zealandica) fragments were recovered but they were found throughout this period in 1970 when rainfall was closer to normal. Therefore because a major portion of starling food is usually obtained from this stratum of the soil it may be inferred that nestlings could suffer when excessive drying occurs.

Weather records are now given for the two breeding seasons studied — 1974-75 and 1975-76.

Table 1.

Some Meteorological Records for the 1974-75 Starling Breeding Season.

	Rainfall (mm) (Total Monthly)	Mean temp. (°C) = (½ max. + min.)	Wind (Total Run.km)	Evaporation (0.1mm)
Sep.	115.9	12.2	6994.0	636.0
Oct.	128.0	13.0	8617.0	788.0
Nov.	50.6	16.0	9663.0	1334.0
Dec.	75.7	18.1	7715.0	1551.0
Jan.	37.9	20.2	7504.0	1919.0

Table 1 shows that the total monthly rainfall decreased from September to January while the mean temperature and potential for evaporation increased. The data suggest that drying of the soil surface would occur during November and December and this was supported by casual observation. In addition, during early summer several districts in the immediate vicinity of Palmerston North were classified by the Ministry of Agriculture and Fisheries as being under drought conditions. Any marked drying of the soil surface would have restricted the foraging activities of the parents and this was reflected in the high mortality and low fledging weights of late nestlings. (see Section 9) In addition hot weather seemed in some cases to influence the nestlings directly by apparently inducing physiological stress. Often young were found 'panting' in the heat of the nest boxes, which suggested that a few nestlings may have suffered from the effects of dessication.

The weather conditions that prevailed for the 1975-76 breeding season were remarkably unlike those of the previous season (Table 2).

Table 2.

Some Meteorological Records for the 1975-76 Starling Breeding Season

	Rainfall (mm) (Total Monthly)	Mean temp. ($^{\circ}$C) = ($\frac{1}{2}$ max. + min.)	Wind (Total Run.km)	Evaporation (0.1mm)
Sep.	54.0	10.7	9686.0	712.0
Oct.	82.7	13.3	10678.0	1160.0
Nov.	53.1	13.3	10398.0	1154.0
Dec.	103.3	15.2	12338.0	1564.0
Jan.	90.1	17.7	9472.0	1837.0

Instead of a dry spell occuring towards the end of the season, heavy rain fell which resulted in moist soils and abundant growth of pasture. Although the wind run was high, and the potential for evaporation about the same as for 1974-75, the soil surface did not become dry because of the low temperatures and high rainfall. The overall result of these conditions was that starlings were able to feed in pasture throughout the season and the ample food available was reflected in the weights and survival of the late nestlings.

3. Methods

3.1 Mite Censusing

From May 1974 nest boxes at Te Matai Road were checked to find out if any mites were present before starlings began to occupy them to breed. These checks were made each week until the end of September; every two days over the fortnight before laying began; and then monthly after breeding finished. During the breeding season visits were made at one or two-day intervals. At first I simply made visual observations, but later experience proved this to be inadequate for the detection of O. bursa and another technique was developed. Each time a box was inspected for mites I placed my hand for five seconds on each of several areas of the nest box surface, and then counted the total number of mites on my skin. This number was used to estimate the total number present in the box, as described in Section 5. The surfaces inspected were:

a. The underside of the lid and perch.
b. The top of the sides where they met the lid.
c. The inside surface of a wall.
d. The nest material.

If any mites were present on my hand, I tried to return them to the nest by brushing my hand against the box. However, this was not easily accomplished so to prevent contamination of other nest boxes I swabbed my hands with alcohol. This did not seem to deter mites from moving onto my hands when further boxes were inspected.

The number of mites on each nestling was estimated by looking closely at several specific areas. This was done as soon as the nestlings were lifted from the nest so that mites had little time to move away from their original position. The areas checked for mites were: around the anus and eyes; under the bill and wings; between the toes; and over the ventral surface of the abdomen.

3.2 Breeding Information

As soon as egg laying began the nest boxes were inspected every second day. This did not involve looking in all boxes, just those that had not been occupied on the previous inspection.

An occupied nest was defined as one in which an egg had been laid. As eggs were mostly laid in the morning, visits were made in the afternoon so as not to disturb those birds that were laying. Once a nest had its first egg it was not inspected for another four or five days because I found that during the laying period females were easily disturbed.

Throughout the incubation period a couple of inspections were made to check for abandonment or any interference to the nest. On such visits I whistled loudly or tapped lightly on the fence wires approaching the nest so as to allow the incubating bird time to escape before the nest box was opened. There was great variation in the starlings' response to my inspections during breeding. Some pairs were never seen at the nest, while others remained on their eggs even when I slid the lid partly open to peer in at them.

Over the hatching period nests were visited on the twelfth day from the laying of the penultimate egg because in general the first nestlings would have hatched the previous night. A second inspection was made two days later to obtain the final number hatched and to note any eggs not hatched. After this, the nest was visited on the fifth, tenth and fifteenth days after hatching to weigh nestlings and estimate the size of the mite population.

3.3 Banding

Metal serial bands (size D, butt-ended) were placed on all nestlings between the ages of five and ten days as part of the banding scheme of the Ornithological Society of New Zealand. These bands allowed nestlings to be identified individually for future weighing and for measuring mite infestations. Also, during the 1974-75 breeding season, nestlings aged 15 days were colour banded and flashed to facilitate their relocation in flocks after fledging. The colour bands were obtained from the O.S.N.Z. and the material for the flashes was obtained from Ecology Division, D.S.I.R. The flashes, c. 5cm X 1cm, were of a durable nylon-coated vinyl called 'Saflags' and the colours available were white, dark blue and blaze orange. The orange was a 'flourescent day-glo' colour but the white and blue colours were not, and so were much harder to see when all three flashes were viewed from a similar distance.

The nestlings were colour banded and flashed at 15 days of age, using colours to represent different weight categories. As I had no data for fledging weights prior to the 1974-75 breeding season three weight categories were selected from a sample of 29 nestlings, weighed previously at 15 days of age by Dr. J.E.C. Flux. I chose categories so that they contained roughly similar proportions of the sample of individuals (Table 3). This ensured that similar numbers of each category were banded and hopefully, therefore, that a reasonable sample of each could be observed later in the field.

Table 3 : Fledging Weight Categories.

Category	Weight range	Proportion of sample (N=29)	Band	Flash
Heavy	greater than 78gm	31%	white	white
Medium	78 - 68gm	38%	red	orange
Light	less than 68gm	31%	yellow	blue

The purpose of the marking programme was to see if the degree of mite infestation and body weight at fledging affected the subsequent survival of young nestlings. It has often been surmised (Lack, 1948; Perrins, 1965) that light fledged young are less able to survive than heavy ones. In small passerine species, such as the starling, nestlings can remain alive and develop their feathers normally although badly underweight. The chief effect of under-nourishment is not death in the nest, but a reduced fledging weight (Lack, 1948). Therefore it is possible that under-nourishment and/or severe mite infestations could increase the mortality of underweight nestlings, not so much while they are in the nest, but when they fledge. Perrins (1965) in his discussion of the survival of great tit, Parus major nestlings after leaving the nest, mentions that "the heavier young may be carrying more fat than the lighter ones and ..... it is largely this food store which enables these young to survive better than the lighter ones ..... It seems likely that a young bird will stand a much better chance of surviving this critical period in its life if it has an internal food reserve on which it can survive for a day or two in an emergency, than if it has no such food reserve, particularly later in the season".

With the above in mind, I hoped to see flashed nestlings during a weekly six km transect along Te Mati Road and then compare between fledgings in different weight categories: rates of feeding, and survival and dispersal.

3.4 Weighing

Nestlings were weighed in a plastic bag by a 100gm Salter spring scale accurate to ± 0.5gm. Even the heaviest nestlings could be weighed by this scale. Plastic bags were used because they were readily available, did not fall apart when they became soiled with faeces, could be tied to prevent mites getting out of them and after a thorough wash in detergant, could be used again. Being transparent, any mites in them were easily noticed. A separate bag was used for each brood of nestlings after which it was washed before being used again.

After experience with early broods in 1974-75, I ceased inspecting or weighing nestlings after 15 days of age as this led to some taking fright and leaving the nest box prematurely. After the nestlings had fledged the nest box was examined for dead nestlings and the presence of mites. When mites were present, a record was kept of their numbers and location on the nest box.

In general, my activities around the nests appeared to cause little disturbance to the breeding starlings although a few broods were abandoned following the weighing and banding carried out at five days.

3.5 Observation Boxes

The two observation boxes were situated in attics in the Interim Biology Building, Massey University. They were 30cm deep by 25cm long, 8cm wide and were made of particle board except for their glass tops. Panes of glass were removed from windows in the building and the nest boxes attached to panels that replaced them. Each attic was securely blacked out so that the only light entering was through the entrance hole of the nest. This allowed me to look into the boxes without being seen by the starlings.

4. Starling Life History

4.1 Introduction

The observations which form the basis for this section were obtained from three broods in glass-topped nest-boxes (Section 3), and from nestlings in nest boxes in the field over two seasons. Production data appear in Section 9.

In the Manawatu, egg laying starts in the first week of October. Incubation lasts about 11 days from the laying of the penultimate egg. However, a few clutches take longer and one full clutch took 18 days to hatch. The nestling period of the common starling is approximately 21 days, during which time the psilopaedic nestling weighing about six grams at hatching grows rapidly to a fledging of about 75g. Within five days of leaving the nest such nestlings forage independently of its parents. Because some pairs raise two broods, nestlings were present in the study areas from late October until late December or early January.

4.2 Brooding

Newly hatched nestlings have only scattered pre-pennae over their bodies and are brooded by the parents, both taking turns during the day, but only the female brooding at night. As the nestlings grow they require less brooding which ceases after seven or eight days. This has also been noted by Wallraff (1953). After the first week the female stays at the nest for several more nights where she sleeps at the edge of the nest, but does not brood.

4.3 Late Hatched Nestlings

The early survival of young nestlings depends to a large extent upon when the adults begin to incubate. Because starlings start incubating before the last egg is laid, the clutch usually hatches over a period of twenty-four hours or more. Since nestlings are fed as soon as they hatch, those that hatch first have an advantage because they have grown considerably by the time their later-hatching nest mates emerge. Thus, they are more advanced and better able to compete for food offered by the adults. Both Dunnet (1955) and Kessel (1957) noted that any nestling hatching a day or more later than its fellows was definitely handicapped. This is because growth is so rapid initially that the early hatched nestlings quadruple their weight during the first four days. Thus the nestlings that hatch late are much smaller in comparison.

If competition for food is very keen the late hatched nestling die of starvation. Dunnet (1955) was able to show at Craibstone, Scotland, that the proportion of deaths in late-hatched nestlings increased with brood size, but that these deaths occurred independently of the amount of food available to the parents. Therefore Dunnet related their death to the parent's feeding response, which in turn is related to a stimulus from the nestlings, and a threshold may be involved such that when demand for food decreases to a certain point, feeding slackens off. Dunnet (1955) found that for about the first five days parents brood the nestlings during the day, feeding them only when the feeding stimulus overcomes the brooding drive. When this occurs, strong nestlings obtain enough food to satisfy their demands so that the feeding stimulus ceases and the brooding drive takes over. If a late hatched nestling does not get sufficient food and is unable to maintain the feeding stimulus above the threshold it dies of starvation.

From my observations I can add the following to Dunnet's findings. First, I noticed that the response of late-hatched nestlings was weaker than that of their stronger nest-mates because they were slower in responding to a returning parent and because they could not maintain the food-begging posture as long. In addition, they were usually at the back of the nest cup and therefore farthest from the nest entrance and the incoming parent.

Observation of a late-hatching nestling in a glass-topped box showed that the bird initially received a small amount of food, but because its stronger siblings received relatively greater amounts they grew and developed much faster. Being unable to compete successfully, the weakling lost weight by the second day, and by the third had been removed (presumably dead) from the nest. When I visited nest boxes in the study areas it was not uncommon to find a late-hatched nestling being trampled by its larger nest mates. Once this situation developed such a nestling was usually dead within twenty-four hours, presumably because it was prevented from protuding its head high enough to get food from the adults.

4.4 Feeding

Feeding of young begins as soon as they hatch. It occurs from sunrise until sunset while the young are small, but as they develop it stops progressively early, often as much as an hour before sunset. Feeding is most active in the early morning and early evening. Kluijver (1933) found that the number of feedings per day increased until about the seventh day, remained at this level until the sevententh day and then declined.

At the observation boxes nestlings were observed for one hour each day until they were 15 days old, to record the feeding visits made by the parents. Generally these observation periods were carried out in the late morning, with a few occurring in the afternoon.

Table 4 : Feeding Visits for the Observation Periods

No. of nestlings in brood	Age (days)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Four	14	15	11	22	14	17	13	15	19	15	21	23	30	23	18
Four	11	9	13	9	10	10	14	15	14	14	17	12	18	18	9
One	4	4	4	2	3	10	10	7	7	12	9	14	4	14	9
Average:	10	9	9	11	9	12	12	12	13	14	16	16	17	18	9

Over the fifteen day period there was an increase in the number of feeding visits for each observation hour although this number varied considerably from day to day. Casual observations suggested that the amount of food brought in at each visit also varied considerably.

As the nestlings developed the size of food items fed to them increased and the manner of feeding changed. During the first few days, the parents brought small items which they gently tucked into the nestlings' gaping throats. Earthworms that were brought to them were broken into about one centimetre lengths.

Allard (1940) reported that tiny caterpillars and other insects were brought one at a time to small nestlings, often in a crushed or macerated condition. As the Palmerston North nestlings increased in size larger items were fed to them and these were gathered by the beak full so that by the time they were five days old they were taking whole earthworms, often several at a time.

Feeding became hurried and less careful by the time the nestlings were seven days old and all food was presented in large mouthfuls which were quickly jabbed into their throats.

4.5 Development

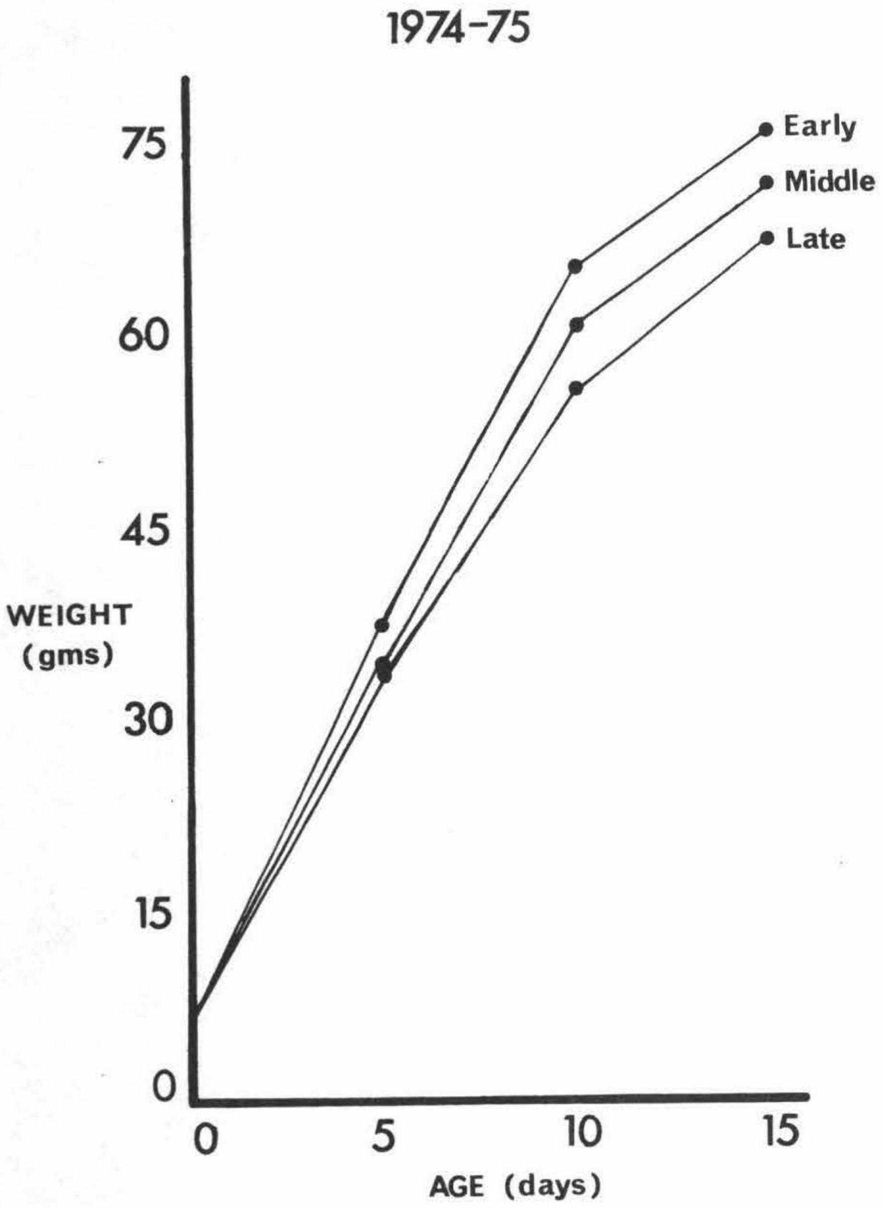
Nestlings hatched with their eyes closed and responded to any movement or noise in the nest by stretching up their necks and opening their large mouths. For the first couple of days they were able to maintain this food-begging posture for only a few seconds before collapsing back into the nest cup. By the fith day, healthy nestlings had quadrupled their hatching weight (Figure 4), and were able to support themselves and move about vigorously using their wings and legs to propel themselves. At this stage contour feathers began to show as black spots under the skin, but it was not until the sixth or seventh day that the feather sheaths began to break through the surface of the skin.

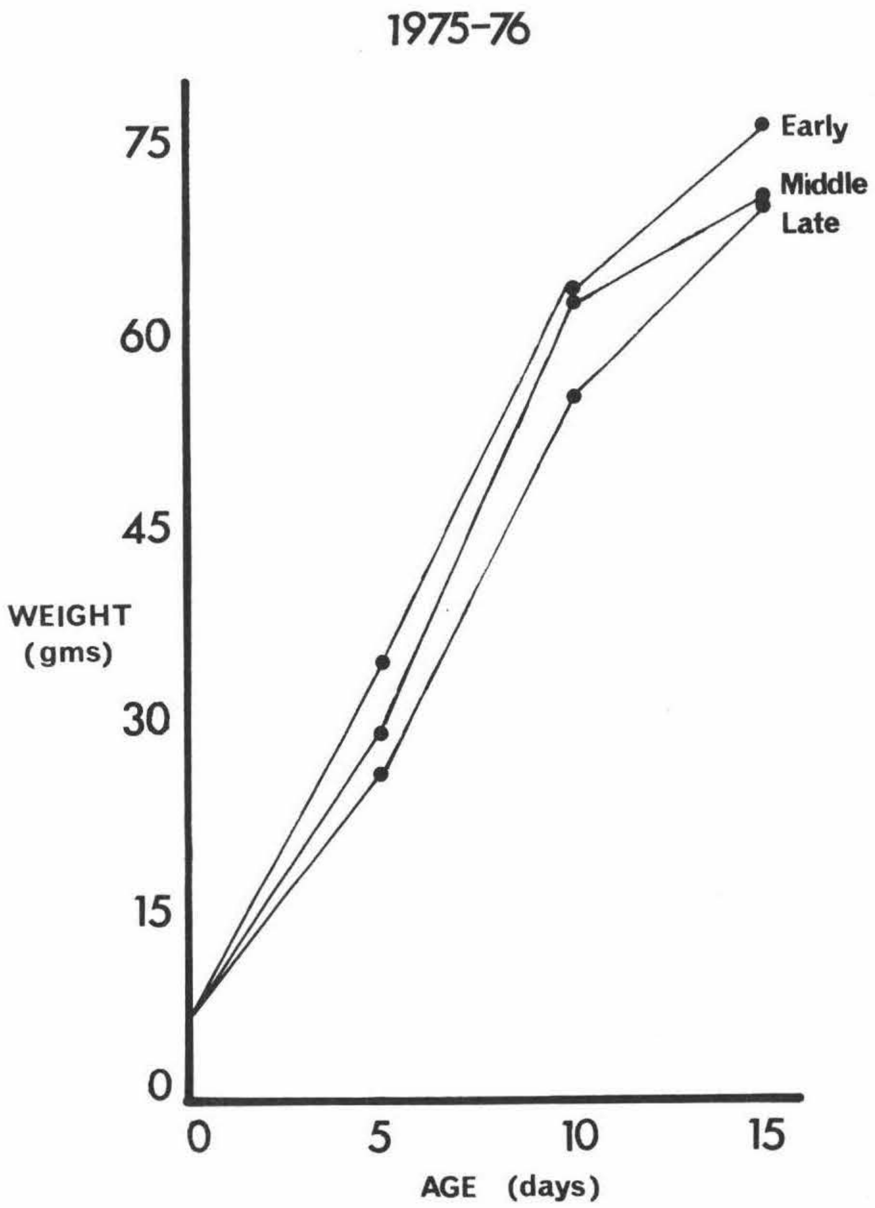
The eyes opened about the sixth day which resulted in a change in the nestlings' behaviour. They no longer responded to inappropriate stimuli but remained huddled in the nest cup. When handled they showed no recognizable fear and did not attempt to escape. However, by the tenth day they clearly showed escape behaviour. By the time the nestlings were fourteen days old they were quite active, stretching and beating their wings. Often they were seen with their heads protruding from the entrance waiting for their parents to return with food. From the fifteenth day until they left the nest box their body, wing and tail feathers continued to develop and at fledging they were fully feathered.

4.6 Weight Increase

The weight gain of early hatched nestlings was rapid and sigmoid in form for the first twelve to fourteen days, by which time the young approached the weight of the adult

<u>Figure 4</u>: Graphs showing Nestling Weight Gain over 15 days.


1974-75
WEIGHT (gms)
75
60
45
30
15
0
AGE (days)
0
5
10
15
Early
Middle
Late


1975-76
WEIGHT (gms)
75
60
45
30
15
0
AGE (days)
0
5
10
15
Early
Middle
Late

birds (Fig. 4). Kessel (1957) states that for the first broods (when conditions are apparently optimum for growth), there is little variation in the weight of nestlings, especially during the first three or four days, but after ten to twelve days the weight curves level off and then fluctuate. This age corresponds to the time when the plumage begins its rapid development. This situation was not observed in the Manawatu. On the first day, the individuals in a brood ranged in weight from about seven grams to fourteen grams, and this variation increased with age, contrary to the findings of Kessel. I found that only when the nestlings reached the top of the sigmoid curve did the variation begin to lessen.

For late broods the hatching weights were similar to those of early broods, but the rate of growth was slower (Appendix 2). This was due to one or more of the following factors (Kessel, 1957):

1. The waning industry of the parents in bringing food to the young.
2. The male being sometimes absent.
3. Increased temperatures drying the soil, which reduced the availability of food.
4. The presence of nest parasites in greater numbers than was normal for early broods.

The weight curves of the second brood nestlings frequently did not begin to level off until the fourteenth day or later. The maximum growth realized by these individuals was rarely as great as that for the first broods, and their mean weight at fledging was lower.

4.7 Sanitation

Sanitation of the nest is very important to the well-being of nestlings. The extent to which it succeeds depends upon many factors such as the industry of the parents, the size of the nest box, the character of the food and ambient temperature. In crowded quarters, such as the nest boxes in the study areas, nest sanitation apparently became much more difficult. The volume of the nest boxes allowed enough room for the nest-cup to be built, but little extra space where nestlings could deposit faeces away from the nest-cup.

Defecation by nestlings began as soon as feeding started.

For the first four days nestlings defecated sporadically into the nest cup; later this became a regular event after feeding. Both parents were very active during the early days, searching diligently among the nestlings for faeces, and interrupted their brooding to do this. Because faeces of young nestlings are relatively solid and enclosed in a gelatinous sac their removal was made comparatively easy for the parents. However the faeces became larger and more viscous as the nestlings aged, which resulted in the parents having to return more than once to remove the faecal sac completely.

About the seventh day, when the nestlings opened their eyes, faeces were deposited outside the nest-cup for the **first** time. To accomplish this the nestling backed out of the cup after each feed. By the time nestlings were twelve days old, nearly all faeces were excreted out of the nest cup and in the direction of the nest entrance. Eventually, if the entrance to the nest cavity is not too far above the nest, excrement is ejected out of the hole itself (Kessel, 1957). The nest boxes provided at the study areas did not allow this to occur until the nestlings were nearly fledged. As the nestlings grew and the tempo of feeding increased, parents often failed to remove faeces as fast as they were deposited, with the result that some of the nests became fouled and damp.

If the nest became excessively dirty the feathers of the nestlings became wet and matted, their feet often caked with faeces and this sometimes preceded death. Kluijver (1933) found that dirty nests sometimes caused the young to leave the nest prematurely at 15-16 days of age. Occasionally I found nestlings (that were healthy at fifteen days of age) dead in a wet, faecal-covered nest, after the rest of the brood had fledged, but other factors, for example starvation, may have been involved.

A sanitation procedure in which the parent starlings engaged fairly regularly was probing in nest material, after which they often left the nest carrying faeces in their beaks. My observations of this behaviour lead me to believe that it is a nest-clearing procedure to find faeces excreted in the nest cup. This behaviour, carried out by either parent, was evident from the first day after hatching until the nestlings were about twelve days old, after which it rarely occurred. The end of this "nest-clearing" procedure therefore coincided with the start of nestling-defecation outside the nest cup. Although it seems clear that at least one probable function of nest-probing is to remove faeces, it is quite likely that rummaging through the nest cup for excrement would also reorganize the nest material slightly, thus aerating it and helping to maintain a clean, dry nest. Allard (1940) described the action as "making --- the nest", and involved the parents "standing astride the nestlings or among them and jabbing its beak everywhere deep down evidently poking holes into the consolidated mat, perhaps to aerate it or to hasten drying". Wilson (1971) observed the same behaviour in the common myna and stated that a parent was seen "pecking and shaking the whole base of the nest and reorganizing the nest structure".

4.8 Preening

The nestlings are not physically able to accomplish bodily-maintenance activities straight after hatching, and often are found with bits of food or faecal material adhering to their pre-pennae. The preening necessary to remove these contaminants was not observed until nestlings were approximately nine days old, by which time quills were just beginning to break through the skin, and sprout feathers. However, from then on increasing amounts of time were spent preening the newly emerging feathers, and removing the dead skin that sloughed from most of the body surface. Occasionally young nestlings were preened by their parents but this was not observed after they were about eight days old.

4.9 Fledging and Dispersal.

Nestlings normally fledge between 21 and 25 days of age. During the 1974-75 breeding season all 98 nestlings that fledged were marked with colour-bands and flashes to facilitate their relocation in flocks after fledging (Section 3). During my movements about the study areas the flashed juveniles were seen for the first few days after they had fledged, perched in trees near their nests, calling continually to their parents.

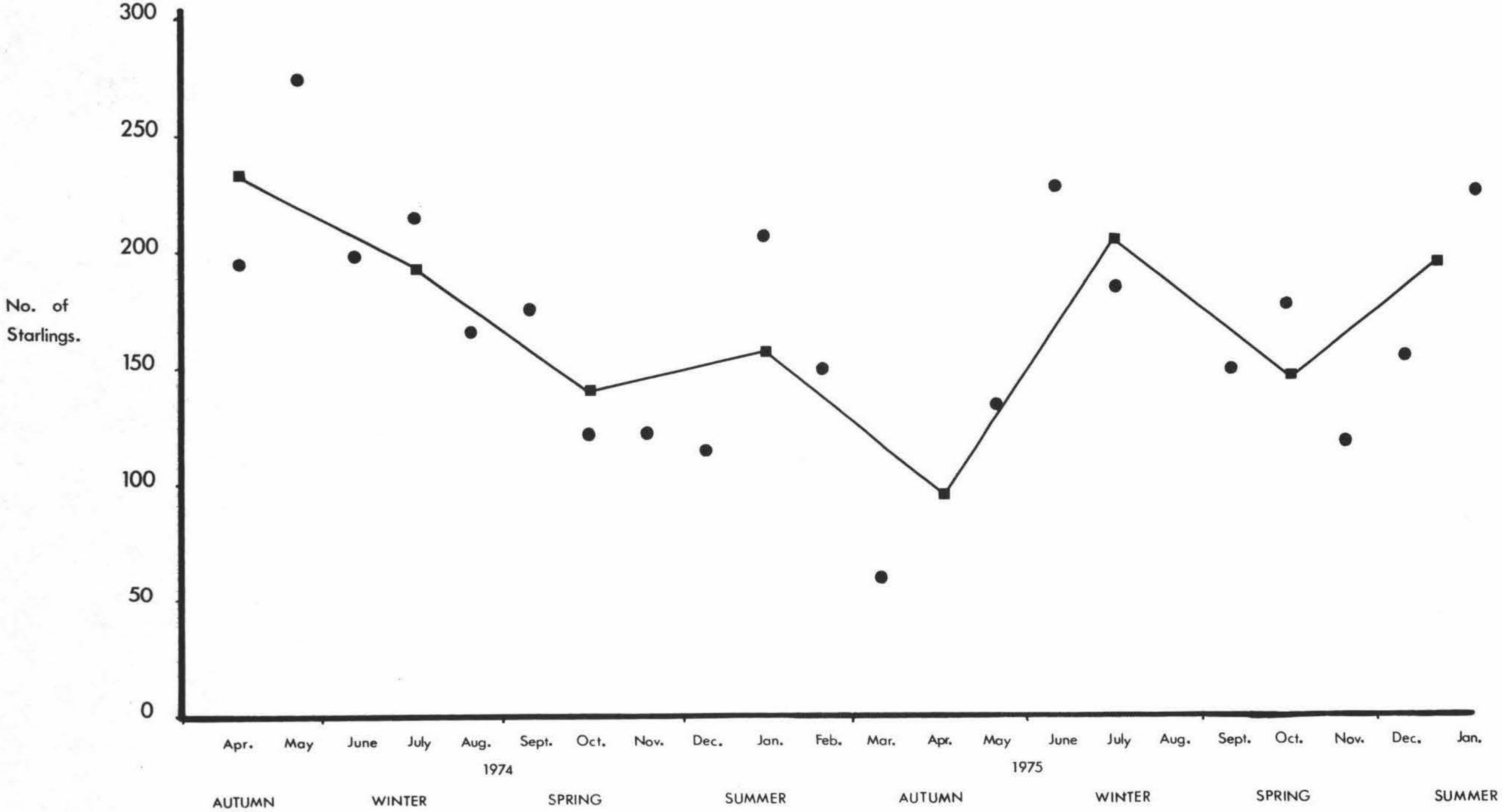
However, within ten days all flashed juveniles had apparently dispersed from the study area, as none were located during the transects although many unflashed ones were seen. It is possible that flashed juveniles were present among flocks in the area, but that the length of the pasture and the large number of unbanded birds contributed to the failure to recognize them. Generally, flocks of juveniles were much less approachable than were flocks of adults. If a flock of juveniles was approached while the birds were feeding or were perched near the road, they invariably flew up. Unless the juveniles were feeding over cultivated soil, their legs (and consequently any attached flashes) were hidden from sight. A white-flashed juvenile(s) was observed five times at dawn as it bathed in a water trough and investigated several nest boxes,but as no conclusions could be drawn from these sightings and as returns fell far short of effort put in, this marking procedure was not continued in the 1975-76 breeding season.

Dispersal of juveniles from the transect area might in part depend on the food supply available to them. The weekly transects, which were maintained over the entire investigation period, showed clearly (Figure 5) that in autumn 1974 there was many birds in the area, while in autumn 1975 there were very few. This was possibly due to drought conditions that prevailed in the area over summer of 1974-75, when breeding output was low in the late period (Section 9, Table 11). Possibly non-breeding starlings left the vicinity of the study area, while established breeders remained.

The only band returned so far is some indication of the extent to which the juveniles may disperse during their first year. This bird was found dead a year after it was banded, 19km south of Pahiatua (c 30km from Te Matai Road in a direct line).

Figure 5: Starling numbers observed during transects of Te Matai Road.

The line joins the means for each season and the unjoined circles are monthly means.


300
250
200
150
100
50
0
No. of Starlings.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
1974
1975
AUTUMN
WINTER
SPRING
SUMMER
AUTUMN
WINTER
SPRING
SUMMER

5. Some Aspects of the Biology of Ornithonyssus bursa

5.1 Identification

To identify parasitic mites, such as O. bursa, the gut contents of blood must be bleached so that important identification features, i.e. setae and sclerites, can be seen clearly. Bleaching was achieved by placing the mites in a 10% solution of KOH and heating them for about eight hours at approximately 50C. The specimens were then transferred to distilled water to remove any remaining KOH which would otherwise react with the mountant (Hoyers solution[1]) to form a cloudy solution. To ensure effective rinsing, the specimens were held in distilled water for about eight hours and the water changed several times. Mites were then mounted and dried at 50°C for a week to ensure thorough drying of the mountant before the edges of the coverslip were sealed.

Comparison of cleared and mounted specimens with diagnostic features given by R.J. Flynn (1973), enabled me to tentatively identify mites found on starling nestlings as Ornithonyssus bursa (Berlese). Dr. G.W. Ramsay, Entomology Division, D.S.I.R., Auckland, confirmed this identification. Popularly referred to as the tropical fowl mite, O. bursa has received over the years several generic name changes, so that in the literature the genus may be referred to as Liponyssis, Bdellonyssus or Ornithonyssus.

O. bursa can be easily confused with O. sylviarum, which is also found on starlings in New Zealand (P.R.Wilson, 1971). One distinguishing feature is the number of pairs of setae on the sternal shield. O. sylviarum typically has two pairs on the sternal shield, with a third pair situated on the unsclerotized integument. O. bursa on the other hand has all three

[1] Hoyer's solution:

	50gm of water
	30gm of clear gum arabic crystals
	200gm of choral-hydrate
	20gm of glycerine

The above ingredients are mixed in the order of listing. It was found that some heat had to be applied to liquefy the gum arabic crystals and the choral-hydrate so that they thoroughly mixed into the solution. This recipe was kindly given to me by Dr. R. Emberson, Lincoln College.

pairs of setae on the sternal shield (Plate 2). However, confusion can occur over this feature since some specimens of O. sylviarum have one or both of the third pair of sternal setae on the sternal shield. An alternative distinguishing character is the number of pairs of setae at the posterior end of the dorsal shield. O. bursa has two pairs of well-developed setae here while O. sylviarum has only one pair (Plate 3). The shape of the dorsal shield also differs between the two species. The shield of O. bursa progressively narrows at the anal end while that of O. sylviarum has a distinct constriction towards the end (Plate 1). Diagnostic features are summarized in Table

Table 24.

Major External Characters Distinguishing
Ornithonyssus bursa and O. sylviarum

Character.	O. bursa.	O. sylviarum.
1. Setae on sternal sheild.	three pairs.	two pairs.
2. Setae on posterior end of the dorsal sheild.	two pairs, long.	one pair, short.
3. Shape of dorsal sheild.	progressively narrows.	distinct constriction.

5.2 Life History

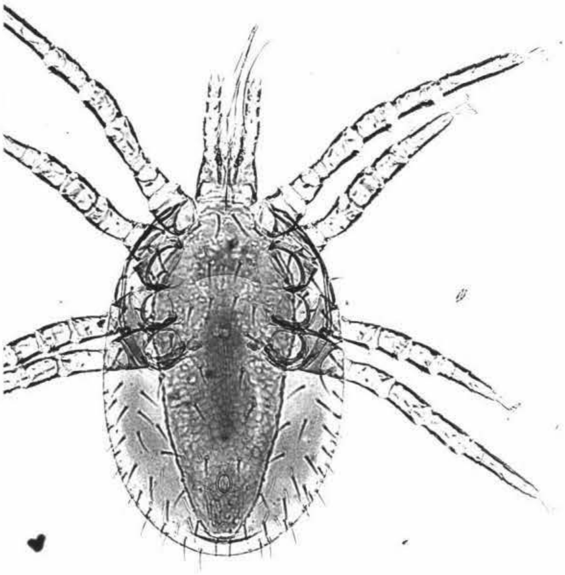
Ornithonyssus bursa is a hematophagus ectoparasite of the starling. It is a mesostigmatic mite of the Family Dermanyssidae and is not host-specific to the starling, but parasitizes several avian species especially the domestic fowl Gallus gallus and the house sparrow Passer domesticus. It has also been reported on a lizard (Cameron, 1938) and frequently on man (Murray, 1950).

The life cycle of O. bursa (Fig. 6) encompasses five stages and is typical of the Dermanyssidae. A mature female, after a substantial blood meal, lays her eggs either directly on the host or within the nest material. It has been found (Sikes and Chamberlain, 1954) that on average a female O. bursa can lay one to five eggs in 48 hours under warm conditions following engorgement. Newly oviposited eggs measure approximately 0.3mm

Plate 1a: *Ornithonyssus bursa*. X 80.
Note the dorsal sheild gradually tapering to a blunt posterior end.

Plate 1b: *Ornithonyssus sylviarum*. X 70.
Note the dorsal sheild suddenly tapering to form a tongue-like continuation about half as wide for the remainder of its length.

1a.



1b.

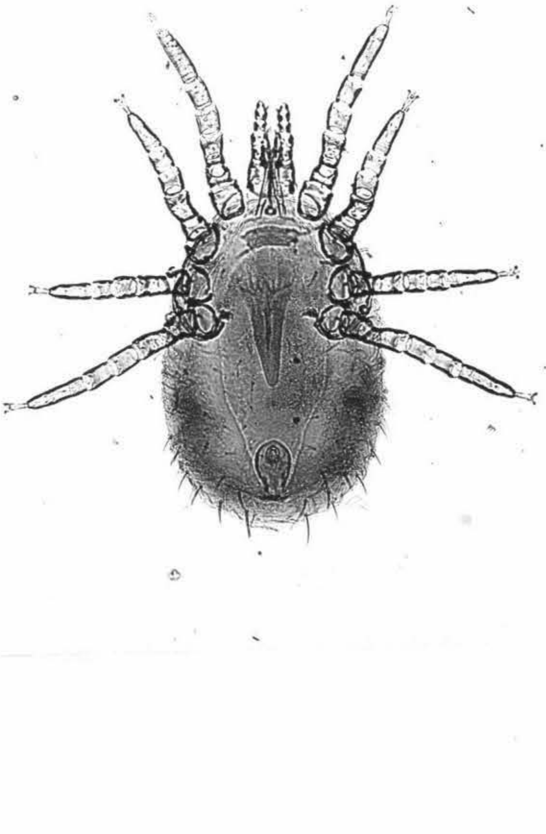
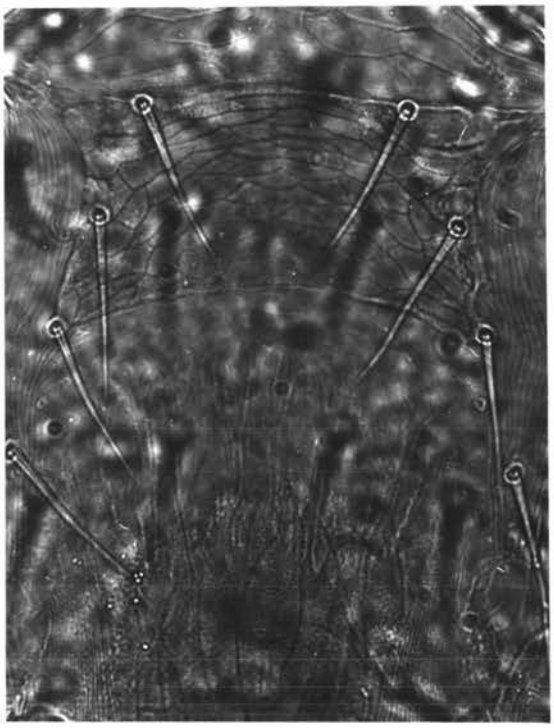


Plate 2a: Sternal sheild of <u>Ornithonyssus</u> <u>bursa</u> bearing three pairs of setae. X 800.

<u>Plate 2b</u>: Sternal sheild of <u>Ornithonyssus</u> <u>sylviarum</u> bearing two pairs of setae. X 700.

2a.



2b.

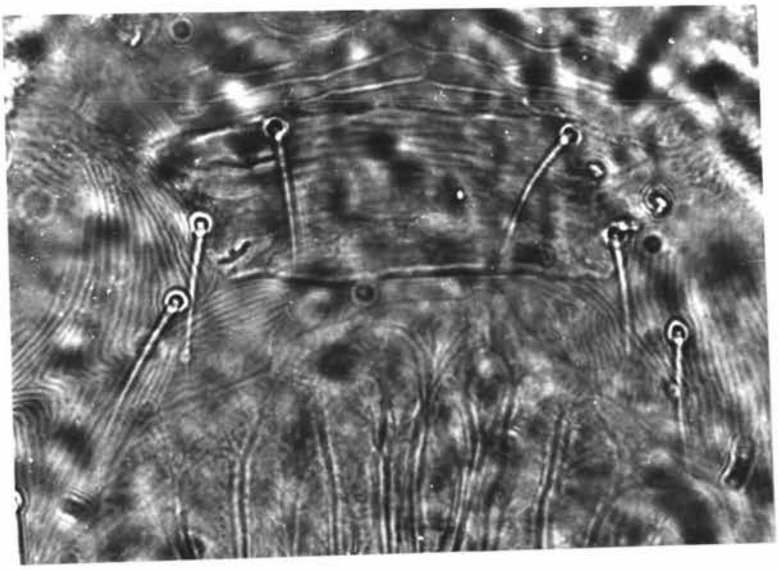
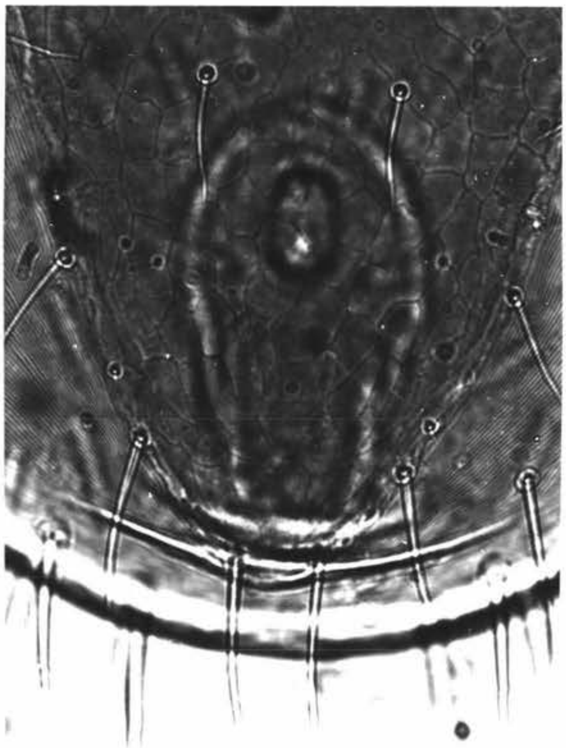


Plate 3a: Posterior portion of the dorsal sheild of *Ornithonyssus bursa* with two pairs of long setae. X 800.

Plate 3b: Posterior portion of the dorsal sheild of *Ornithonyssus sylviarum* with one pair of short setae. X 700.

3a.



3b.

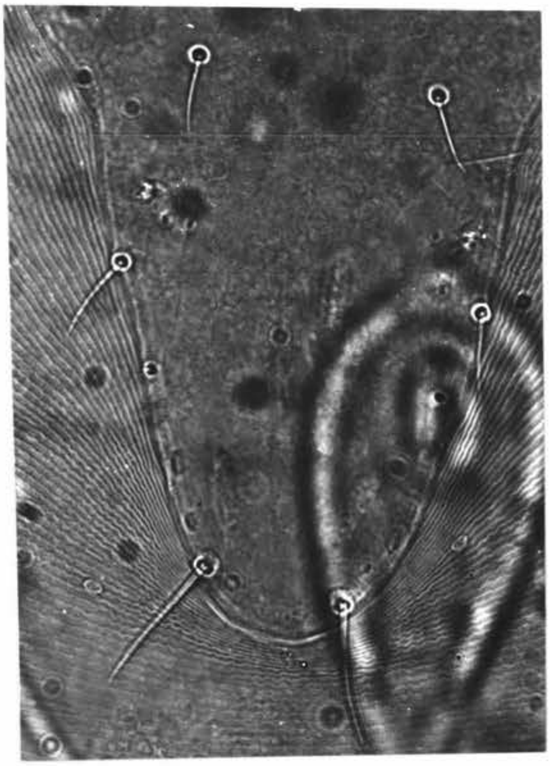
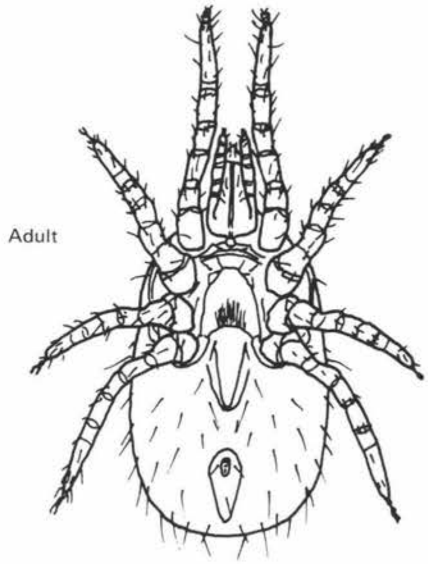
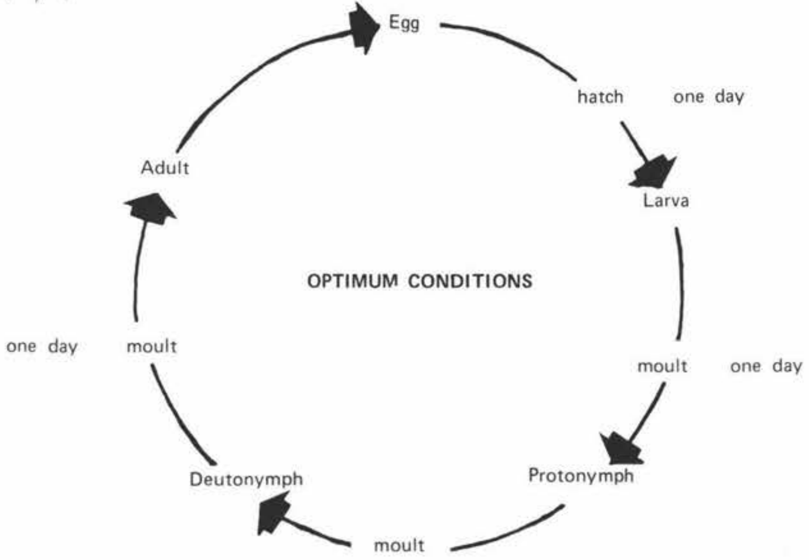
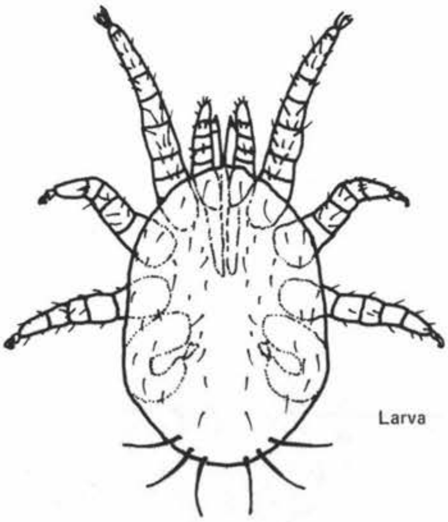


Figure 6: Life cycle of Ornithonyssus bursa.





Life-cycle completed within seven days
under optimum conditions



by 0.2mm and are coated with a sticky substance (Sikes and Chamberlain, 1954) that enables the eggs to stick to the feathers of the avian host. Camin and Erlich (1960) report that when a population of O. bursa is extremely large eggs are laid in hollow straws making up the nest material, which would offer protection to the eggs from preening activities of the host. This habit is in keeping with that of the adult mites because during the starling nestling period they are to be found wandering throughout the nest material and over the inside walls of the nest boxes. Also, initially the nestlings are featherless except for pre-pennae which are of little use for attachment of eggs.

Under optimum conditions, (including fairly high humidity) the eggs hatch in about a day after oviposition (Sikes and Chamberlain, 1954). However, this period can be extended by several days should the conditions be unsuitable for development of the embryo. The larval stage hatches with only three pairs of legs; the hind-most pair being retained within the larval 'skin'. The colourless larva is quiescent and nonfeeding, with nonfunctional chelicerae and no shields on either the ventral or dorsal surfaces.

Sikes and Chamberlain (1954) found that after about a day the larva moults to the eight-legged protonymphal stage. The protonymph of most species of Dermanyssidae requires at least two periods of feeding before engorgement occurs. Approximately 36 hours after engorgement it moults to form the deutonymph. Most species, including O. bursa have a non-feeding deutonymph stage which results in the nymph moulting within a day to give rise to the adult stage. Under optimum conditions the complete life cycle can take place within seven days, however it usually takes about a fortnight (Sikes and Chamberlain,1954).

5.3 Feeding

Adults feed on blood which they obtain by piercing the host with their chelicerae. An engorged female is approximately 1.0mm long by 0.5mm wide. From these measurements and the wieght changes that occurred as a result of feeding, Sikes and Chamberlain (1954) were able to determine that an engorged female contained 0.077mg of blood. This involved the ingestion of 1.8 times their own body weight in blood. The protonymph stage consumes about 0.025mg of blood when it engorges.

Matheson (1923) reported that on poultry most of the mites are found on "fluffy parts of the feathers" especially those around the vent. The mites tend to be present on a few feathers with large numbers of them giving these feathers a dirty appearance. The distribution of the mites on the birds may be patchy; hundreds being found in small areas. I did not find such a distribution on starling nestlings; the mites were all over them. Flynn (1973) states that O. bursa on young domestic chickens showed preference for feeding around the beak and eyes. I found that this preference applied also to mites on starling nestlings.

Among authors who have written on O. bursa there is divergence of opinion as to when feeding occurs. Furman (1963) reports that feeding stages may attack the host at anytime of day or night. However, Lodha (1969) when investigating the occurrence of an infestation of O. bursa was unable to find any mites in the nest during the day, but found numerous specimens at night. My observations which were carried out at three-hourly intervals over three nights revealed that mites were much more numerous and active over the nestlings then than they were in daytime. I did not notice any peak of mite activity during the night. During the day the mites tended to be found only at concealed sites such as the ventral surfaces, under the wings and among feathers. The reason for this may be their negatively phototactic behaviour.

5.4 Effect on the Host

Ornithonyssus bursa, being a blood sucking ectoparasite, can affect its host in several ways. Loss of blood from the host might be expected to bring about exsanguination when thousands of mites are present in the nest-box. However, Loomis et al (1970) has shown from whole blood and serum analyses of domestic fowls that mean protein values of birds heavily infested with O. sylviarum were not statistically different from those of uninfected birds. The packed-cell-volume of heavily infested hens was not lower than that of non-infested hens, suggesting that anaemia is not a symptom of a heavy mite infestation. Similar experiments (see Section 9) carried out on the blood of young nestling starlings revealed that only those nestlings subjected to severe mite infestations and an inadequate food supply showed any abnormal blood characteristics.

It is possible that mites may inject a toxic substance into the host when they break the tissues with their chelicerae. The toxin may be a virus or bacterium but is more likely to be a substance that promotes blood flow to the injured site and prevents it from clotting. Moss and Camin (1970) maintained laboratory colonies of the purple martin mite, *Dermanyssus prognephilus* on the domestic fowl, which is an unnatural host. He found that "two-week-old chickens introduced as hosts generally died within a relatively short time, frequently in as little as three hours." The investigators were unable to determine the cause of death in so short a time, but proposed as a likely cause the toxicity of mite saliva, and not exsanguination.

Mites also irritate the host as they move about and pierce its tissues. Wilson (1971) reported this as a possible reason why parent mynahs failed during the night to brood young nestlings when they were infested with large populations of *O. sylviarum*. He also reported that some nestlings fledged earlier than usual when infestations of mites were high and concluded that these nestlings fledged early to escape irritation by the mites. I noted similar behaviour in starling nestlings heavily infested with *O. bursa* (Section 8). Infested nestlings in a glass-topped nest-box were very active in moving about, consistent with the suggestion that they were irritated by mites.

From laboratory cultures (Chamberlain and Sikes, 1950; and Moss, 1966) it has been found that *O. sylviarum* brings about only minor damage to the host *G. gallus*. I found that *O. bursa* had the same almost negligible effect on domestic chickens. Day-old chickens introduced into a colony of *O. bursa* in a culture cage were not removed until about ten days of age and suffered no obvious harm from mites over this period; possibly because they were able to compensate for loss of lymph and blood taken by the mites. However, it had been shown that a large population of *O. bursa* does influence the growth rate and survival of starling nestlings under some circumstances during the breeding season (Section 9). Moss (1966) reports that domestic chickens kept in a laboratory culture of O. sylviarum withstood extremely high populations over several weeks with deleterious effects chiefly confined to loss of feather condition. Dermanyssus gallinae in comparison, brings about loss of feather condition and reduced egg production when in moderate numbers on domestic fowls. (Evans et al., 1961).

5.5 General Behaviour

Camin (1963) proposed a scheme to classify parasitic mites on behavioural features. A component of behaviour that is very important to a parasite is its ability to maintain close contact with the host, whether that involves constant attachment or movement onto the host only for feeding. Ornithonyssus bursa does not fit closely into Camin's proposed division of parasitic mites into nest-dwelling and host-dwelling kinds, but tends to be intermediate in behaviour between these two groups.

A host-dwelling parasite spends its entire life cycle on the host and frequently goes through many generations without leaving it. This type of parasite is most commonly found on gregarious hosts, with the parasite feeding almost continuously, but taking relatively little food per unit time.

The second group consists of the nidicoles or nest-dwelling parasites. The acarines of this group are hematophagous and are on the host only while acquiring a blood meal. They feed less frequently than the 'continuous' or host-dwelling parasites, but generally ingest much more food at each feeding by engorging to repletion. After feeding, they drop from the host but remain in the nest material in close proximity to the host. The behavioural activities of this group are more varied than those of host-dwelling parasites and therefore they have better developed locomotory and sensory organs. They respond to a great variety of stimuli and their behaviour patterns are more complex in comparison, but nevertheless quite stereotyped (Camin, 1963).

Acari of nidicolous hosts become very active and may leave the nest when they have been starved for several days, (as may happen if the host dies or abandons the nest), or when the population become so large that there are insufficient hosts to support them. Presumably the vast majority of such randon migrants die without ever finding another host simply because they are adapted to stay in the vicinity of their host, and travel back and forth the short distance between it and the nest material. Their stereotyped behaviour patterns do not enable them to find a new host by their own actions. Instead they are transferred passively from host to host through the activities of the host, rather than by their own efforts.

O. bursa tends to show behaviour which is intermediate between host-dwelling and nest-dwelling parasites. On the one hand it spends more of its time on its host than do its nest-dwelling relatives. For example, the purple martin mite, *D. prognephilus* and the red fowl mite *D. gallinae*, overwinter in the nests of their hosts and therefore are associated directly with them only during the breeding season. Also these species spend only enough time on their hosts to obtain their blood meals, after which they retire into the nest material. These two species are able to overwinter or remain for several months without a blood meal. *Ornithonyssus bursa* differs in that during winter adults are present as residual populations on starlings (see Section 10) because they require a blood meal at least every six weeks.

On the other hand, the behaviour of *O. bursa* in nest boxes is akin more to that of nest-dwelling parasites than to host-dwellers, as shown by their distribution in the nest box. In low concentrations, the mites are located on nestlings and in nest material directly beneath. However, once the number of mites reaches several thousands they tend to congregate away from the nestlings while not feeding in the manner of nest-dwelling species. Thus *O. bursa* shows nest-dwelling features during the breeding season and host-dwelling features during the winter.

5.6 Longevity

There is considerable evidence in the literature to support the view that *O. bursa* and *O. sylviarum* do not overwinter in the nest as do nest-dwelling mites such as *D. gallinae* and

D. prognephilus. Moss (1966) reports that *O. sylviarum* was present in great numbers in the purple martins' nests immediately after the young martins had fledged, but showed a sharp decline soon afterwards. In the spring before the martins returned no specimens of *O. sylviarum* were extracted from nest material placed in Berlese funnels, however, the nest-dwelling mite *D. progenphilus* was still present as a nucleus population in the nest material. Further evidence is provided by Kirkwood's (1963) experiment with *O. sylviarum* in which specimens placed individually in cottonwool plugged test-tubes and left without access to blood starved and died within 28 days. The results of these longevity experiments and the fact that the mites were observed on the birds throughout the year confirmed the statement of Cameron (1938) that *O. sylviarum* does not aestivate.

Various authors have obtained different information on the length of time starved *O. bursa* mites can survive. Hirst (1915) stated that *O. bursa* lived for only ten days away from an avian host, while Murray (1950) found that specimens kept in a closed phial on his bench remained alive for up to five weeks. I carried out experiments in a starling nest box to see how long *O. bursa* could survive without a blood meal. Ten 35mm by 10mm test-tubes were placed in a holding-block of polystyrene. A piece of filter paper to absorb any excess moisture, and two mature mites were added to each tube, the tops of which were then plugged with cotton wool to allow cross ventilation with the nest box environment. During the 1975-76 season five racks each with 10 tubes was placed individually into a nest box. The mites in the tubes were inspected every second day and a mite was classed as dead (and not just moribund) when its legs were curled in towards the body and when it could not be stimulated into movement by exposure to light and tapping on the test-tube. No mites involved in these longevity experiments were inspected every four days and the number alive in each test-tube recorded.

I found that 50% (n = 100) were dead within three weeks but that the last to die survived for six weeks, implying that *O. bursa* needs to have a blood meal from a host at least once every four weeks. However, some specimens survived the entire winter in one of the nest boxes at Te Matai Road study area. This could be atypical, but I observed starlings visiting the nest boxes during dawn observations on 16 days spread throughout the non-breeding season (February —— September), so it is possible that the mites obtained a blood meal from these visiting birds.

Acarine parasites are generally unable to detect the presence of a host over large distances, and it appears that the mites ensure regular access to a blood meal by being present on the host continuously, particularly during the non-breeding season. To confirm that mites were present on starlings all year round, adult starlings were captured in trap-boxes, and a miticide "Dri-die", applied to obtain any mites they carried (Section 10). The method used for this procedure is described by Kettle (1975). Only 4% (n=75) of the starlings caught were carrying _O. bursa_, but this low percentage may reflect inadequacies in the techniques used to remove mites from live starlings.

5.7 Environmental Factors

Ornithonyssus bursa is sensitive to relatively few environmental stimuli and its responses are rigidly stereotyped (Camin, 1963), varying only with changes in the nutritional state of the mite. The main environmental factors which influence the mites behaviour are temperature, relative humidity and light.

Temperature is an important factor in locating a host. Where mites are found in houses they are attracted towards warm objects once the host has departed. For example, Murray (1950) found that _O. bursa_ was attracted to the warmth of a linen cupboard after their host starlings had fledged from the nest situated immediately above. Thus it would seem that _O. bursa_ uses temperature cues to locate its host from the nest material and the walls of the nest-box. Cross and Wharton (1964) showed that temperature is also important as a feeding stimulus, when they found that _O. bursa_ required high temperatures to initiate feeding. The number of adult and nymphal mites that fed increased with each increase in temperature from 22-24C to 39-42C. At temperatures higher than 39-42C range, the number of feeding mites decreased. Also, more adults and nymphs fed when the blood temperature and the environmental temperatures were the same than when a gradient existed. Thus it would be expected that during the early period of the breeding season when air temperatures are low the feeding of the mites will be inhibited to some extent and the individual's rate of feeding will be low. But as the temperature rises the feeding rate will increase, leading to a higher rate of egg laying and hence an increase in population size.

Relative humidity has also been found to be of considerable importance to the activities of O. bursa. Cross and Wharton (1964) found that relative humidities of 96% and 83% reduced the feeding of O. bursa, but at 73% R.H. the number of mites that fed was not significantly different from the control at 22%. Therefore, it could be deduced that dry conditions in the nest would be an advantage to the mite. Cross and Wharton (1964) found that mites taken from moist surfaces did not feed so readily as those taken from a dry surface, and (Abasa, 1969) has shown that not only do moist surfaces impede feeding, but are actually detrimental to the mite, as they drown readily. Abasa found that condensation that formed in vials containing specimens of O. sylviarum, resulted in the mites drowning. Camin and Erlich (1960) used this feature as a method of maintaining a culture of O. bursa in a culture cage; a moat of water prevented any escapes.

The third environmental factor to be considered is light. From experiments I conducted which involved exposing mites to light and dark areas in a trough, it is evident that they are negatively phototactic to high light intensities. About 300 mites were placed in a one centimetre deep trough which had a glass lid over it. One half was darkened and the other illuminated by a bench lamp with a 40W bulb. The experiment was repeated five times with different mites each time. When placed in the light, O. bursa moved rapidly until they reached a darkened area where they aggregated in clumps of about 20 and remained motionless until disturbed. This behaviour was modified somewhat when the mites had been starved for two or three weeks. Starved mites moved towards light of low intensities, which is similar to the observations Humphries

(1969) made of starved sand martin fleas, Ceratophyllus styx jordani. In the nest-boxes this response would result in the mites reaching the perch and lid of the nest boxes once the hosts had left.

In terms of the environmental factors discussed, the nest-boxes provide a suitable habitat for O. bursa since:

a) the nest material insulates mites from extreme temperature variations and is usually dry;

b) The incubating parent, and then the nestlings maintain the box at a temperature sufficient for feeding activities; and

c) most nest-boxes are dark inside with a small amount of light entering from the entrance hole.

6. ESTIMATION and CENSUSING of MITE POPULATIONS

6.1 Introduction

As several investigators have found e.g. Moss (1966); Wilson (1971), obtaining meaningful estimates of mite numbers in a bird's nest involves considerable problems. First, there was the difficulty of monitoring the population as it changed its position in the nest box. For instance, a small population of O. bursa remained hidden within the nest material and on the nestlings. However, as the population built up to exceed several thousand individuals, mites tended to move up the internal walls of the nest box. It was engorged adults which took up these more exposed sites while larvae and nymphs remained in the nest material. To be valid the methods used had to take account of these changes in location.

Previous investigators have usually resorted to visual estimates of mite numbers when destructive analysis of the box was not feasible. Wilson (1971), in estimating the number of O. sylviarum in nest boxes of the common myna used a points scale to measure the rate of infestation. This involved a visual check of the nest box and allocation of a number on a scale, depending on how many mites were seen. Wilson's scale was: "0, no mites found; 1, only a few seen; 2, approximately 50-100 seen; 3, thousands seen all over chicks and inside and outside the nest box." Wilson 1971). Moss (1966), in his study of the effect of mites on the breeding success of purple martins also used visual estimates to measure mite population size.

6.2 Methods

It was impracticable to attempt at each visit an accurate count of the total population of O. bursa in a starling nest box, therefore an index of population size was used to monitor the increase in numbers during the breeding season. Three methods of indexing were tried at the same time:

(1) Mite-samplers

Initially, I hoped to introduce into the nest box devices in which mites would, after engorgement, collect following their strong thigmotactic response. These mite-samplers could be removed to count numbers and stages present, and then be replaced so that the population was not changed in any way by sampling. A mite-sampler consisted of a glass microscope slide, 7.5cm by 2.5cm, with a piece of cardboard of the same size glued to it, but separated by toothpicks to create a 2mm gap. Thus mite-samplers were intended to mimic a crevice, with the glass surface allowing observation of the mites inside.

This method of sampling required several mite-samplers per box to avoid gaining a false impression of population density. The reason for this was that if one mite encountered a sampler and entered it there was a high probability that others would stop and cluster there. Conversely, if a mite did not encounter a sampler, an impression of low population density could be obtained.

However, this method proved in the 1974-75 season to be impracticable because adult starlings removed the samplers from the nest during 'nest clearing'. Although the mite-samplers were fastened to the nest box and hidden by nest material the parent starlings soon located and removed them. This prevented proper estimation of mite numbers while there were eggs in the nest and while the nestlings were less than seven days old, because the mite population, which was in the initial stages of establishment, was present only in nest material beneath nestlings, where the samplers had to be placed.

Samplers placed beween the walls and he nest material worked satisfactorily for the first seven days or so after nestlings hatched, but later faeces accumulated around the edges of the nest box, discouraging mites from moving near these damp areas and causing the samplers to disintegrate. Often the faeces formed a thick crust over the nest material which prevented the mites reaching any hiding places within it, and causing the engorged mites to congregate in wall crevices. Mite samplers attached to the walls were damaged by the starlings as they tried to remove them.

(2) Painted squares

Another method tried at the start of the 1974-75 season involved painted white 5cm X 5cm squares on the inside wall of the nest box, about four centimetres above the nest material. A similar area silhouetted in white served as a control on whether the mites avoided or aggregated on the painted squares. I envisaged that these squares would provide an index on numbers of mites present on the walls. However the method was unsatisfactory because mites moved up onto the walls when the population had reached several thousands or the nest had been fouled, and so it was abondoned.

For the remainder of the 1974-75 season, mite numbers were estimated using a third technique described in detail in Section 3. The nest box surface, nest material and nestlings were searched and a single estimate of the number of mites was made. Five categories describing population size (or the extent of infestation) were used: noninfested, NI; few mites,F; tens of mites,T; hundreds of mites,H; and thousands of mites,TH.

6.3 Total Counts of Mite Populations

The indexing method just mentioned was correlated with the actual number of mites present by destructively analysing several nest boxes during the 1975-76 season. Twenty-eight boxes were erected especially for this purpose (Section 2.1) and spaced far apart, which resulted in 75% occupancy, compared with less than 50% occupancy at the other study areas.

It was planned that two or three boxes would be selected at random and analysed at each of eight stages during the breeding season; i.e. during the early period when the nestlings were 5,10 and 15 days of age respectively; when the first egg of the late clutch had been laid; just before the late brood hatched; and again when the late nestlings were, 5, 10 and 15 days old respectively. However, because some of the boxes were unoccupied, and others abandoned, 19 nests were analysed. The results from these form a basis for verifying the indexing method, and provide some information on seasonal build-up of mite populations.

Nests scheduled for destructive analysis were observed in the same way as those at the other study areas. On the day of collection the selected box was dismantled in the field, and each component was placed immediately in a separate plastic bag, the nest material being left on the box floor. The wire that held the box together was easily cut, enabling each wall to be quickly separated from the rest so that mites did not have a chance to wander and were not dislodged during the process (Plates 4a and b). In the laboratory, mites were aspirated from wooden surfaces of the nest box. The nest material was put into a mesh cage in an 11 litre bucket. Here the mites reacted by moving out of the nest material and collecting on the underside of the lid of the bucket where they were aspirated and counted. However, if there were hundreds of mites, the nest material was transferred to another bucket so that the mites that had emerged could be chloroformed without killing those still in the nest material. It took about a week for all of the mature mites to move from the nest material onto the sides and top of the bucket. Examination of the material afterwards revealed less than 0.1% of the mature mites, but a lot of protonymphs, most of which would have hatched from eggs in the nest material after the box was dismantled.

If nestlings were present when the nest was scheduled to be censused any mites on them were collected by dusting with the miticide 'Dri-Die', a product marked by Associated Rural Industries Ltd. The nestlings were left on a mesh screen over a collecting dish for 45 minutes. After this period they were given a thorough brushing with a small paint brush to dislodge any mites entangled in feathers.

Thus a total count of the mites present on the nest box, in the material and on the nestlings was obtained. By comparing this total with the estimated total, it was possible to determine the accuracy of the indexing method.

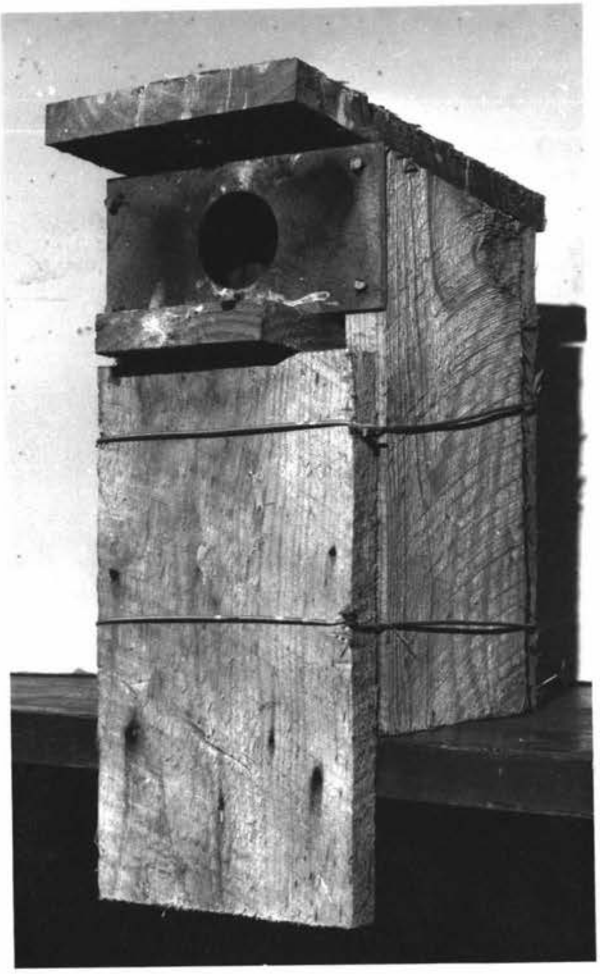
5.4 Results and Discussion

Total counts of mites in some nest boxes are shown in Table 5. In the initial stage of mite infestation, (during laying and incubation of the early clutches), visual methods underestimated the numbers present and in some cases did not detect any mites when in fact a few were present. This was due to their location in the nest material as much as to the small numbers involved. During this period evidence of mite infestation was limited to sighting a few mites, or their

Plate 4a: Nest box constructed for total count of the infesting mite population. The box is held tightly together by wire.

Plate 4b: Nest box dismantled to reveal components.

4a.



4b.

black faeces, on the eggs. Similarly, during the first five days of the early brood few mites were seen on nestlings, but their presence was indicated by blood clots on the toes where they had fed. However, the estimates became more accurate as the nestlings aged, for mites tended to stay on them during the day instead of retiring into the nest material, and also began moving onto the walls. When the nestlings fledged most adult mites moved to exposed surfaces where they were easily counted, and estimates at this period agree with counts obtained from total censuses.

From Table 5 it is noticeable that some of the nests were very heavily infested and reaching as high as 71,000. Of this population only about 4% were not hidden within the nest material during the day. Most of the other examples given where live nestlings are present reveal that the major portion of the population is within the nest material.

In conclusion, the estimation procedure was not reliable during the early stages of infestation and population build-up, when mites remained almost entirely within the nest material. For example, total counts revealed tens or even hundreds of mites undetected within the nest material during the incubation period. Once nestlings hatched the presence of mites was readily detectable although the estimates of numbers were not always accurate. However, when the population became well established and individual mites more obvious, the number estimated was usually in line with the total found by destructive analysis of the boxes.

The inaccuracies in the initial period did not affect the study of the growth rate and survival of nestlings because mite numbers used for these calculations were determined at 15 days, when the estimating procedure was reasonably accurate. Thus there was no need for a correction factor. In any abandoned nest box, the mites produced up to the time of abandonment always moved out of the nest material, so that estimates of their numbers were usually accurate, and no correction factor was needed for these either.

Table 5 Censuses of Mite Populations in Nest Boxes at Different Stages of the Starling Breeding Season 1975-76

Date of Analysis	Stage of Starling Breeding	Visual Estimate of Mite Population	Total Counts of Mite Population				
			Walls	Nest Material	Nestlings	Total	Index
First Clutches:							
Nov.2.	Incubated 15 days	NI	-	-	-	-	NI
No. 2.	Incubated 18 days	NI	-	-	-	-	NI
Nov.2.	Incubated 19 days	NI	-	-	-	-	NI
Nov.2.	Nestlings 3 days Dead	NI	-	3	-	3	F
Nov.3.	Nestlings 5 days Live	NI	-	-	-	-	NI
Nov.4.	Nestlings 5 days Live	NI	-	47	6	53	T
Nov.10.	Nestlings 15 days Live	H	13	261	19	293	H
Nov.11.	Nestlings 8 days Dead	NI	-	-	-	-	NI
Nov.13.	Nestlings 12 days Live	TH	524	47,551	1,491	49,566	TH
Second Clutches:							
Nov.25.	Incubated 10 days	NI	-	73	-	73	T
Nov.26.	Incubated 16 days	NI	-	216	-	216	H
Nov.28.	Nestlings 11 days Dead	H	241	8	34	283	H
Nov.28.	Nestlings 10 days Live	H	11	7,657	110	7,778	TH
Dec. 2.	Nestlings 12 days Live	TH	75	13,306	267	13,648	TH
Dec.12.	Nestlings 4 days Dead	H	446	2,280	-	2,726	TH
Dec.12.	Nestlings 15 days Live	TH	996	68,400	1,810	71,206	TH
Dec.15.	Nestlings 2 days Dead	H	472	547	86	1,105	TH
Dec.24.	Nestlings 10 days Live	TH	3,603	3,428	72	7,103	TH
Dec.27.	Nestlings 10 days Live	H	64	5,190	400	5,654	TH

7. MITE INFESTATIONS

7.1 Infestation of Nests

As described in Section 10 Ornithonyssus bursa is not able to survive for much longer than five weeks when starved, therefore I expected that mites would be unable to hibernate in nest-boxes over winter. Of 36 boxes infested naturally by mites during the 1974-75 season, only one contained mites two weeks before the start of the next breeding season. Four nest boxes that had been infested with mites during summer 1974-75 were removed from the Aokautere study area during winter 1975 and dismantled for very close inspection for live stages of mites, but none were found. This evidence suggested that the nest boxes may be devoid of live mites during the starling non-breeding season, so that initial infestation of early nests may come from some other source.

Supporting evidence for this view came from nest-boxes made from newly-milled timber and erected about a month before the 1974-75 breeding season. These boxes were just as likely to become infected as boxes that had been used previously. At Te Matai Road during 1974-75 76% out of 17 newly erected boxes were occupied by starlings, and of these 12 (92%) were infested with mites. By comparison two fence lines in 1974-75 holding 13 boxes (38% occupied) and 11 boxes (56% occupied) that had been available for use during two previous seasons had only one (20%) and four (66%) respectively infested. Since the source of mite infestation is not always the box itself, it can be assumed that the mites derive from starlings, and this is backed by evidence that over winter O. bursa is a continuous ectoparasite on some adult starlings (Section 10).

By mid-November when the mites are numerous in some nests, agents other than resident breeding starlings result in contamination of non-infested boxes. One of the most probable agents is other starlings, particularly unmated birds. Geer (1929) and Marples (1936b) have reported single males claiming without territorial dispute, nesting sites near those of breeding pairs. However, Kluijver (1933) believes these single males are responsible for many of the broken eggs and those tossed out of the nests. Similarly Wallraff (1953) observed that after the adults began breeding, first year birds, mostly males, appeared in the area and sometimes flew into nests containing young, but left quickly if a parent appeared. During observations of an early brood in a glass-topped nest box I saw strange bird(s) visit the box on seven occasions. Not only did these birds enter the nest but also fed and tried to brood the young that were about 13 days old at this stage. The strange bird was always alert and left the nest before any encounters with the returning parents. Attempts to capture this bird for identification were unsuccessful. However, when a strange bird began visiting the late brood and attacking a nestling, I caught it. The shape and length of hackle feathers, and the black iris identified it as a first year male. Allard (1940) and Kessel (1957) believed that young non-breeding males visit nests out of curiosity over the clamorous noise made by the young.

Further evidence that nest-boxes may become infested in winter by visiting starlings came from observations at the study areas. I saw repeatedly throughout the year starlings moving along a fence-line and investigating each nest.

Because boxes were close together, and prominently placed on fence-lines, and because the resident birds defended what appeared to be only a small area around the nest, unattached birds may have been encouraged to prospect. If a fence-line had a few infested nest boxes this behaviour could rapidly spread mites to other boxes. Therefore, I predicted that the fence-line with the highest percentage of occupied nest sites would also have more of these infested. Table 6 below shows the data for the fence-lines at Te Matai Rd study area for the two breeding seasons. No nests that had been unoccupied during a breeding season were found to contain mites during that time. However, it is likely that some may have had a few mites which were not found during inspections.

Table 6 : Occupation and Infestation of Nest Boxes on Fence-lines at Te Matai Rd Study Area. (1974-75).

Fence-line	No.of boxes	%occupied	%occupied and infested
A	13	38.5	20.0
B	11	54.6	66.0
C	8	37.5	66.0
D	24	20.8	40.0
E	21	14.3	0.0
F	17	76.5	92.0
G	6	14.3	0.0
		(1975-76)	
A	13	46.2	30.0
B	11	27.3	30.0
C	8	37.5	30.0
D	24	45.8	73.0
E	21	30.0	57.0
F	17	82.4	85.0
G	6	50.0	0.0

Results from 1974-75 were consistent with the prediction that fence-lines with a high occupancy would have many nests infested with O. bursa, but results from 1975-76 were variable. The reason for the difference between the two years' data is not clear, but it may have been influenced by the spacing between occupied nests. The wider apart the occupied nests are, the less likely an infested starling is to visit both.

It is apparent therefore that strange starlings frequently enter occupied nest boxes and are likely to be an important source of cross-infestation of mites between boxes. Having visited an infested box a bird is likely to pick up a few mites which are later transferred to other nest-boxes. This is probably the main way that occupied nest-boxes become infested with mites and explains why the proportion of infested nests is much higher in late nests than in early ones (Table 7).

Spread of mites may be influenced by other factors, but these are thought to be of minor importance compared to the dispersal brought about by the starlings themselves. First, there are other species of birds present at the study areas which are known to harbour O. bursa. Miss D.M. Pearce of Wallaceville Animal Research Centre has found specimens on the on the hedge sparrow Prunella modularis occidentalis, the song thrush Turdus philomelos, blackbird T. merula, silvereye Zosterops lateralis, and the house sparrow Passer domesticus. (Pers.comm.). Blackbirds, thrushes, and house sparrows were present in the study areas all year round and often were seen perching in nest boxes. House sparrows occupied four starling boxes at Aokautere during the 1974-75 season though no eggs were hatched. Second, when the hosts leave the nest or when mites are very numerous, the mites move up on to the tops of the nest boxes. At Te Matai Rd some mites were seen actually moving along the fence-wires and tended to accumulate on fence battens, as many as 30 at a time. I doubt whether any such mites would reach a neighbouring nest box, however starlings often perch on the fence battens and become infested by mites. Third, De Haven and Guarino (1970) thought that the presence of mites on feathers collected by starlings might have been a possible source of infestation of nests with D. gallinae at Denver, U.S.A. However this is possibly not an important method of dispersal for O. bursa as this species is so active when exposed to light that it would be unlikely to remain on moulted feathers. Finally, because of the precautionary measures taken (Section 3), I do not think that I would have been responsible for the transfer of many, if any mites from box to box.

7.2 Seasonal Pattern of Infestation

The pattern of infestation of nest boxes by O. bursa over the breeding season is summarized in Table 7. The data show that about 30% of the occupied boxes were infested in the early period. There was a slight (but statistically insignificant by Chi square) increase for the middle period, but by the late period a large percentage were infested.

Table 7 : Percentage of Nest Boxes Infested with O. bursa

Breeding Season	Early Clutches (clutches laid within 8 days of the first peak of laying)	Middle Clutches (Clutches laid between the other two periods.)	Late Clutches (clutches laid 35 or more days after median of early ones.)
1974-75	31.7 (n=41)	42.3 (n=26)	70.0 (n=20)
1975-76	29.5 (n=61)	40.6 (n=32)	95.5 (n=22)

The reason for the low percentage of infestation in the early period was probably that few starlings harbour mites over the winter (see Section 4), but these mites form the nucleus of populations that build-up over the season. Rarely was a small population of mites detected during incubation, but once the nestlings hatched they were more noticable. Destructive analysis of nest boxes during incubation to make total counts of mites revealed that some contained small populations of up to 50 mites, but reached appreciable numbers during the nestling period.

Most of the middle period nests were replacements for earlier failures and therefore possibly contained a few mites derived from early occupants. Apart from these few mites the source of infestation of middle period nests was the same as for the early nests; i.e. from parents, and explains why there was only a slight increase in the percentage infected.

There was a significant increase ($P < 0.05$) of infested nests in the late period owing to mites already present in some boxes and also to the dispersal of mites to previously uninfested nests. Some of the late clutches were laid in the same boxes as the early ones. Between the fledging of the early brood and the start of the late clutch, mites remaining in the nest-boxes migrated to the perch and lid where ultimately they were transmitted to other boxes by intruding birds. The relationship between the time of occupation of late nests and the presence or absence of mites appears in Table 8.

Table 8 : Mite Infestation of Late Nests

Season	% clutches laid in previously unoccupied nests	%clutches in previously occupied but uninfested nests	%clutches in previously occupied and infested nests	%infested when late nestlings fledged
1974-75	25.0 (n=5)	40.0 (n=8)	35.0 (n=7)	70.0 (n=20)
1975-76	9.1 (n=2)	50.0 (n=11)	40.9 (n=9)	95.0 (n=22)

The data show that the percentage of boxes containing mites doubled by the time late nestlings fledged and this was due mainly to the dispersal of mites described above (Section 7.1).

7.3 Degree of Mite Infestation

The number of mites in each nest box was estimated and categorised as described in Section 3. The level of infestation and the way in which it changed over the breeding season is now given for the two seasons studies.

Table 9 : Degree of Infestation of Occupied Nest Boxes

	Non-infested	Few	Tens	Hundreds	Thousands	Total Infested	N=
1974-75							
Early	68.3	12.2	7.3	12.2	0.0	31.7	41
Middle	57.7	11.5	7.7	15.4	7.7	42.3	26
Late	30.0	5.0	30.0	25.0	10.0	70.0	20
TOTAL	56.3	10.0	12.6	16.1	4.6	43.7	87
1975-76							
Early	70.5	11.5	8.2	9.8	0.0	29.5	61
Middle	59.4	0.0	6.3	12.5	21.9	40.6	32
Late	4.6	22.7	13.6	36.4	22.7	95.5	22
TOTAL	54.8	10.4	8.7	15.7	10.4	45.2	115

From the above data and results of destructive analysis of boxes (Section 6) it is possible to represent the seasonal pattern of mite infestation, as shown in Fig.7. It shows the pattern for a single nest box which had two broods raised in it.

During the early period of both seasons the degree of infestation was low, with only a small proportion of boxes containing hundreds of mites, but as the season proceeded more became infested and supported larger populations. Although in the late period of the 1975-76 season almost all occupied nests were infested there was not a significant increase over the same period in the previous season. The percentage infested with high densities of mites (hundreds and thousands) for the late period was also greater in the 1975-76 season but this was statistically insignificant (by Chi square). This outcome was thought to be due to the lower mortality of nestlings in the 1975-76 season so that more nest-boxes contained nestlings for longer periods. High humidity during December 1975 (see Section 2, Table 2) may also have been a factor that favoured mite breeding and survival. Moss and Camin (1971) noted that "a warm, wet nesting season led to extremely large mite populations" in purple martin colonies.

Between fledging of the first brood and laying of the second clutch in the same nestbox (a period averaging nine days), the mite population declined (Fig.7) owing to migration of mites to exposed parts of the nest boxes where they then moved onto visiting starlings (see Section 6.1) or died. Many were seen to be blown off in windy weather. Also most eggs and larvae in the study area boxes were lost when the nest material containing them was thrown out by birds about to raise a second brood. This procedure may have been due to the confined space in such boxes, because at the observation boxes only fouled material was removed. Although many mites were lost over this period sufficient remained to infest the second brood. The initial number infesting the second brood was greater than that for the first brood (Fig.7), so they increased rapidly to large numbers, often tens of thousands. When the population reached this magnitude many mites moved in search of new hosts, possibly because the original hosts were unable to support any more, but more likely as a result of natural dispersal. Camin (1963) states that the 'wanderings' of such excess individuals results mainly in their death as they are unable to locate a host over appreciable distances.

When nestlings fledged the mites climbed to the top of the box and aggregated under the perch and lid in clumps, often numbering several hundred. Any vibration of the box caused them to scurry out from their hiding places in search of a perched host. Over the next two to three months their numbers slowly dwindled, the length of time taken depending on weather and the amount of protection provided by the box.

8. STARLING PRODUCTION and the EFFECTS of MITES

The location of mites in nest boxes and on nestlings changed over the nestling period, due in part to the increasing density of mites present in the nest box, the changing skin texture of the nestlings, their feather development and preening ability, and the accumulation of faeces.

During the first two days of a nestling's life the toes were clenched and not opened for movement about the nest. At this age, the skin was tender and blood vessels close to the surface were visible. This therefore, was an ideal site for mites to feed because they could remain in a dark enclosed area from which they could not be removed by nestling movements. Also, they were close to nest material, allowing them to retire quickly back to it. When nestlings were inspected for mites at this stage often none were seen but their presence was indicated by blood clots on the toes (Plate 5). Within a few days, the legs were used for active movement about the nest (Allard,1940) and were extended to obtain grip and balance to help in maintaining the up-stretched food-begging posture. On being exposed to the nest material, the central area between the toes was subjected to abrasion causing the skin to harden, and mites were no longer found there.

By the fifth day the mites were mostly under the wings and bill and took refuge from the preening activity of nestlings between sprouting feather quills. Beneath the bill was the most favoured site on the head, and mites concealed themselves in folds of skin. Lodha (1969) reported O. bursa present at similar sites when it infested house sparrow nestlings. It is possible that mites congregated at the above mentioned sites because there they could not be removed easily by preening. The tail and wings received most preening from infested nestlings, but when these individuals were scrutinized it was evident that some mites were still present, This suggests that the quills are sufficiently close together to prevent nestlings from readily dislodging mites between them. Mites present under the bill may also be protected to some degree by the unsure balance of nestlings that tried to preen themselves with their feet.

Plate 5: Foot of two-day-old nestling showing blood-clots situated over claws and toes.

5.

As feathers grew and covered the nestlings, the number of mites present on them during the day increased. Feathers shield mites from light and so enable them to remain on the nestlings during the day. Also, while feathers are developing, the skin around the quills is quite tender and makes an ideal site for mites to feed. The mouth parts of mites are able to penetrate this tender skin more easily than the tougher areas between feather tracts.

By the time nestlings were 15 days old, their bodies were almost entirely covered by growing feathers. Mites were then difficult to locate among feathers, especially under the wings where previously they were so numerous. However, when mites were highly concentrated in the nest box they were still found at several sites on the nestlings, the most common being: in folds of skin under the bill; inside the ears; and around the anus where some areas still lacked feathers. Table 10 shows the change in distribution of *O. bursa* mites on starling nestlings as they age.

Table 10 : Average Distribution of Mites on Nestlings of Different Ages. (N=62)

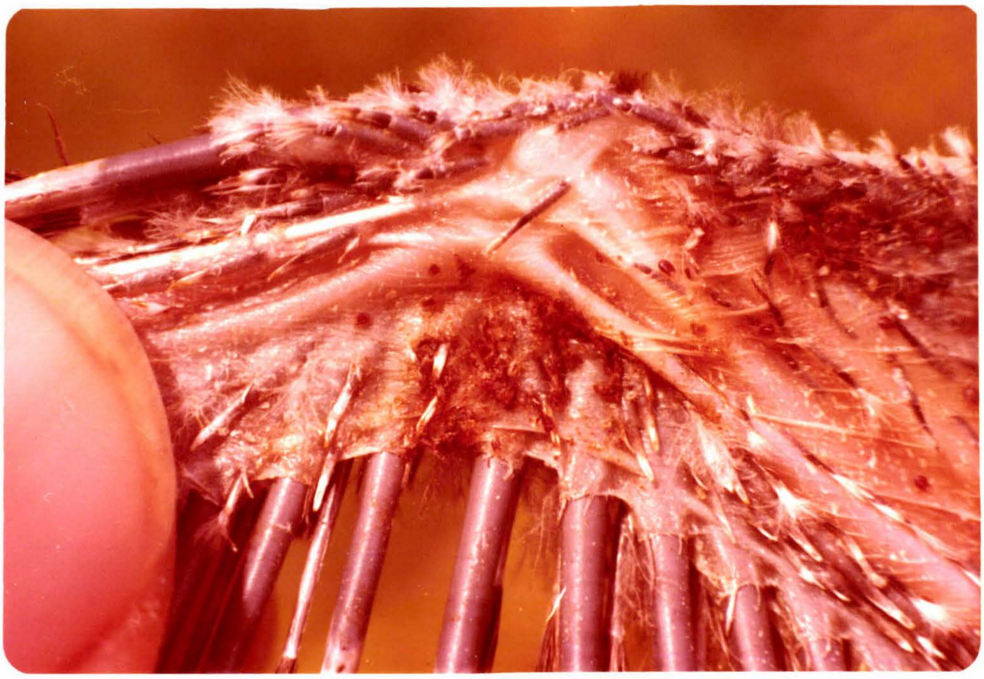
Age	Anus	Bill	Toes blood clots	General body	Ears	Wings
5 days	0	0	2	4	0	1
10 days	2	4	0	7	1	24
15 days	5	21	0	10	3	17

A noticeable behavioural feature of mites was their tendency to clump in clusters of 20 or more at favourable feeding sites under the wings (Plate 6) and bill, and around the anus. Where the mites fed the skin became red and lumpy, and other mites were presumably attracted to these haemorhagic areas by the lymph and blood seeping from punctured skin. Clotted blood was noticed infrequently at these sites, in contrast to the toes of new nestlings where clots were common.

Several investigators have noted that individuals of a brood of nestlings are infested unequally, and even though there is an equal opportunity for the mites to infest all individuals,

Plate 6: Undersurface of a nestling's wing showing aggregated *Ornithonyssus bursa* mites feeding and engorged.

6.



especially in the close confines of a nest box, some birds carry very few mites while others may be covered in hundreds. Wilson (1971) by observations through a glass-topped nest box containing a brood of the common myna, found that nestlings differed in the attention they gave to preening. This resulted in one individual out of four nestlings in the box having "only a few at any one time... in spite of the enormous reservoir of mites swarming on the nest box and lid."

My own observations of infested nestlings revealed that when they were less than seven days old, they seemed unable to rid themselves of mites. At times when mites were observed moving rapidly over their bodies, four heavily infested nestlings in a glass-topped box flailedtheir heads about and moved restlessly in the nest cup. However, when a miticide was applied to the infested nestlings they were almost motionless in the nest within two hours of its application. Thus it appears that the mites do irritate nestlings as they move over them and feed. At this young age, parent starlings often preened nestlings, possibly to help rid them of mites. The vigorous and frequent probing in the nest cup by parents may also disturb and kill a few mites. However, in general the actions of both nestlings and parents do little to curb activity of mites. Mites can move fast and quite a lot of pressure is required to kill them by squeezing.

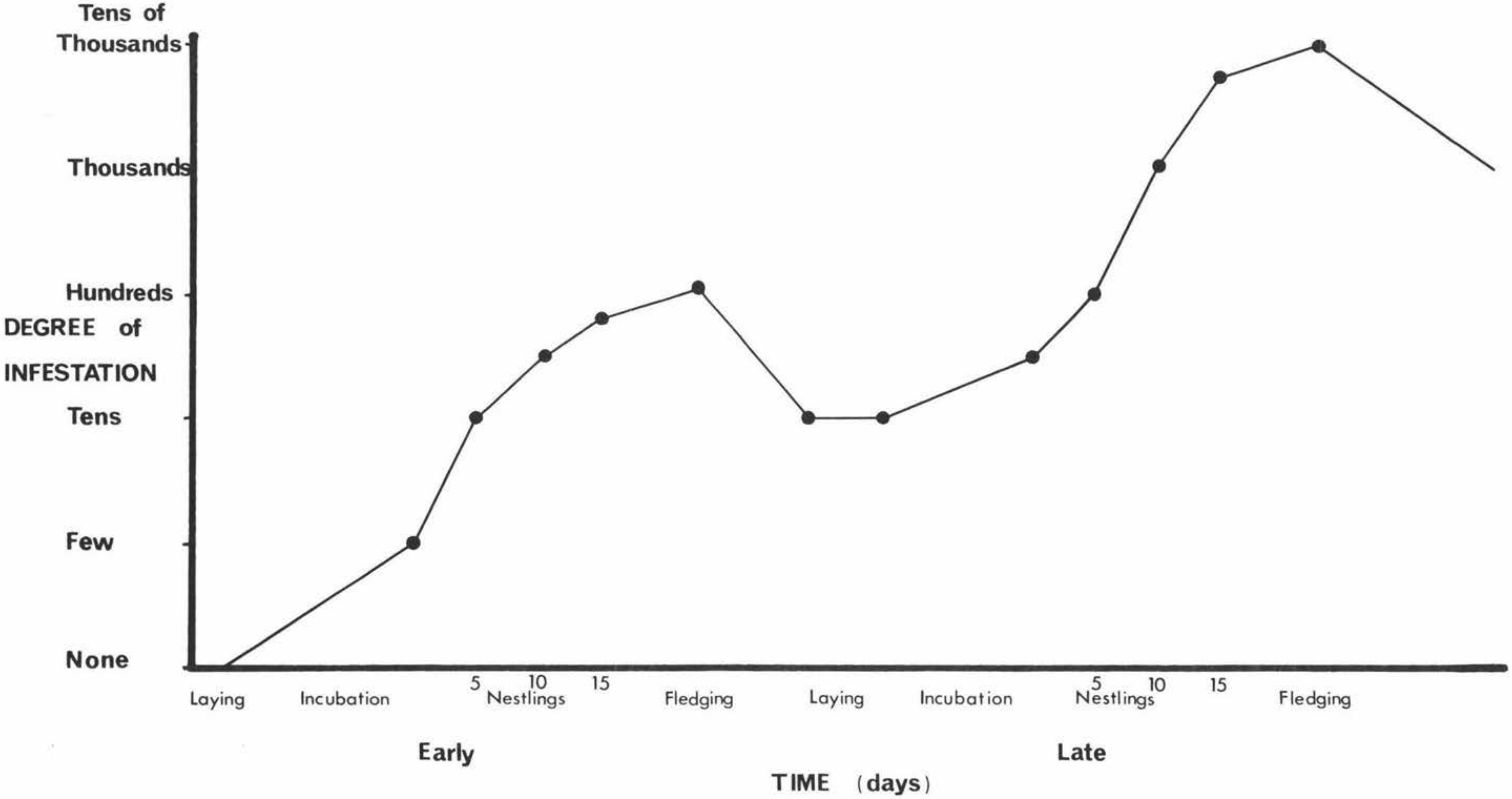
By the time nestlings were 10 days of age their parents were wholly occupied finding food for them and keeping the nest free of faeces. Therefore, the nestlings were left to relieve the irritation of feeding mites by preening themselves. Although they were often observed busily preening themselves, such actions against mites would seem to be ineffective because on inspection of these nestlings mites were just as numerous as on previous censuses. Preening at this time may also have been aimed towards the irritation caused by outer layers of skin being sloughed and feathers sprouting from their quills. Usually the smallest member of a brood was more heavily infested with mites than the rest, perhaps due to slower rate of feather development. This meant that they were an easier source of blood to the mites.

In my experience, mites were only occasionally the cause of death of a nestling. Rarely did parents leave the nest box, apparently prompted by an unusually large population of mites. Such instances occured during incubation of the second clutch in those nest boxes that earlier had held a heavily infested first brood. However, this was abnormal because mites did not usually build up their population numbers sufficiently during the first brood to visibly irritate incubating adults. Also, during the interval between the fledging of the first brood and the laying of the second clutch the number of mites present in the nest material decreased. Abandonment also occured during brooding, apparently because the brooding adult was irritated by mites. Wilson (1975) found that in severe infestations of O. sylviarum when nestlings were young, the irritation of mites at night caused the female to desert the nest, and he considered that this could result in the young dying of exposure.

Sometimes when there was a large number of mites present the parents did not completely abandon the nest, but no longer entered the box. Instead they fed young from the entrance hole and stopped removing faecal material, so that the nest became fouled. This situation generally occured when nestlings were at least 12 days old and sometimes resulted in one or more nestlings dying in damp conditions. However, nestlings usually abandoned the nest box themselves when it became excessively soiled and the mite population was high and presumably a source of irritation. One such instance was recorded when a pair of late nestlings left their nest box at only 17 days of age (instead of the usual 21-25 days), and were found sheltering in long grass nearby. These nestlings were unable to fly strongly at that stage and would have been easy prey to any predator.

Figure 7: Graph showing the Degree of O. bursa Infestation during the Breeding Season.

The example is of a typical nest which contained two broods and was initially infested during laying of the first clutch. A middle period is not represented as a replacement clutch is not involved.


Tens of Thousands
Thousands
Hundreds
DEGREE of INFESTATION
Tens
Few
None
Laying
Incubation
5
10
15
Nestlings
Fledging
Laying
Incubation
5
10
15
Nestlings
Fledging
Early
Late
TIME (days)

9. Performance of Starling Nestlings in Relation to Mite Infestation

9.1 Measures of Breeding Success

The terminology and methods of analysing the breeding data are those used by Ecology Division, D.S.I.R. in its studies on starlings. This allows for standardization and direct comparison of data.

For the purpose of analysis it was convenient to divide the breeding season into early, middle and late periods, based on the peak of laying of first clutches, to broadly separate the laying of the first, replacement and second clutches. Early clutches were those started within eight days either side of the median of the first peak of laying. The first peak was usually followed by a well-marked period when few, if any new clutches were started (Fig.8). Early clutches consist mainly of first clutches though some replacement clutches may have appeared towards the end of the period. Late clutches were those laid 35 days or more after the median of the early ones. They were mainly second clutches, but some replacement clutches. Middle clutches were those begun between the end of the early clutches and the beginning of the late clutches. They consisted mainly of replacement clutches, but there may have been some first clutches at the beginning of the period and a few second clutches at the end of it.

The breeding data are now given for starlings at Te Matai Road and Aokautere study areas (Tables 11 and 12). They are treated together because the distribution of laying of first clutches for the two study areas was unimodal, indicating homogeneity (Fig.8), and because the larger pooled sample was preferable for statistical analysis.

The principal measures of breeding output are now defined:

Occupation rate:	the number of occupied boxes as a percentage of the total number of boxes available to the starlings.
Egg success:	the percentage of all eggs that gave rise to young leaving the nest.
Productivity of occupied boxes:	the mean number of young fledged per occupied box per year. An 'occupied' box is one with a nest containing one or more eggs.

Egg success of full clutches :	the percentage of all eggs from full clutches that gave rise to young leaving the nest. A 'full' clutch is one in which the egg(s) has/have been incubated as judged by their warmth, presence of a bird at the nest or development of the embryo.
Egg success from successful clutches :	the percentage of all eggs from successful clutches that gave rise to young fledging from the nest. A 'successful' clutch is one that produces one or more fledged young.
Fledging success :	the percentage of nestlings that hatched and subsequently fledged.
Fledging success from successful broods :	the percentage of nestlings that hatched in successful broods and subsequently fledged.
Mean number of nestlings fledged per clutch :	the total number of clutches whether they were successful or not.
Mean number of nestlings fledged per full clutch :	the total number of fledged nestlings divided by the number of full clutches.
Mean number of nestlings fledged per successful clutch :	the total number of fledged nestlings divided by the number of clutches that produced them; the successful clutches.
Productivity of all boxes :	the total number of young fledged divided by the total number boxes available, whether they were occupied or not.
Productivity of successful boxes :	the total number of young fledged divided by the number of boxes that produced them.
Percentage success of occupied boxes :	the percentage of occupied boxes that produced one or more nestlings.

<u>Figure 8</u>: Histograms of Laying Dates of the first eggs of all clutches at Te Matai Road and Aokautere Study Areas.

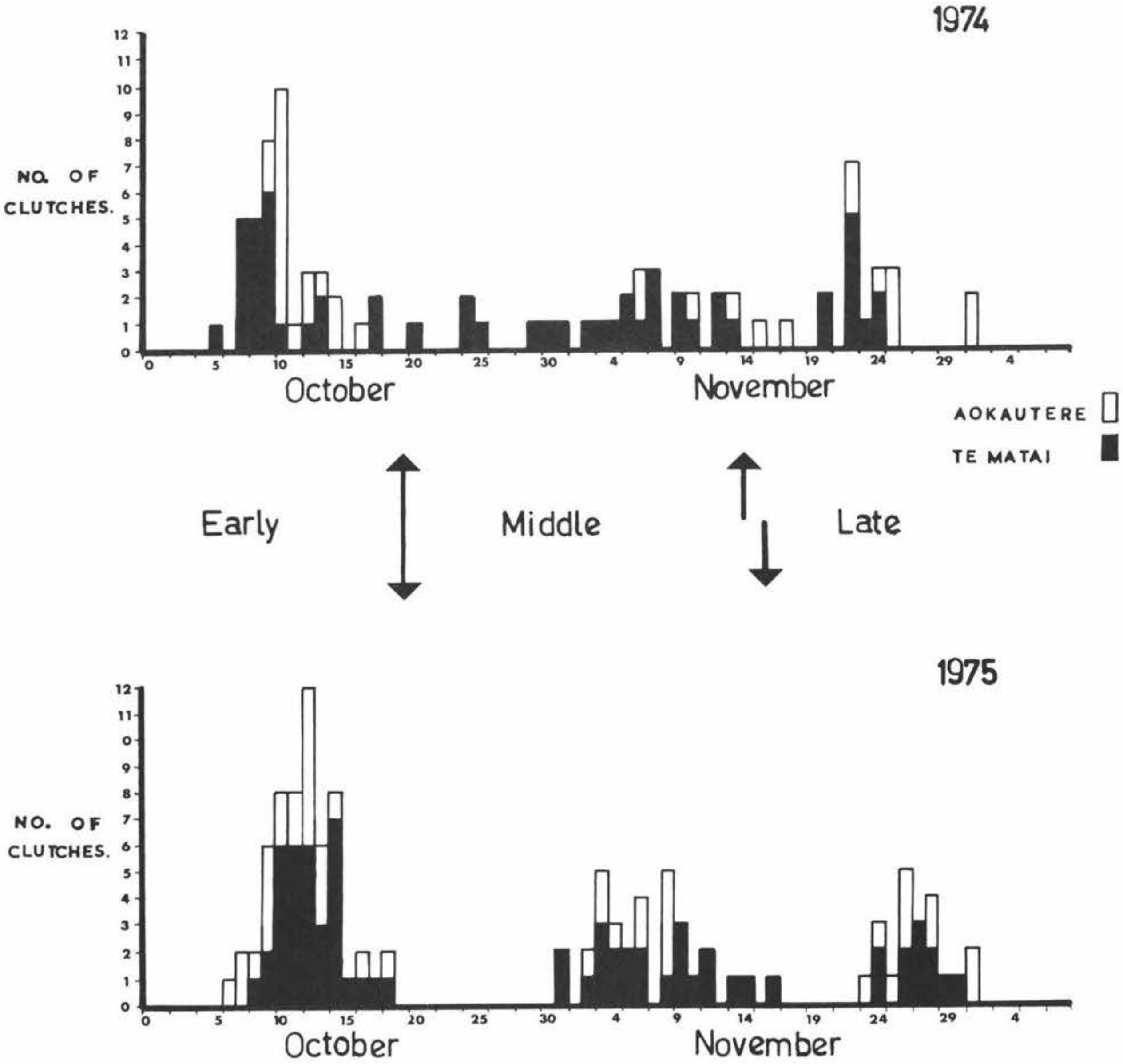

1974
NO. OF CLUTCHES.
0
1
2
3
4
5
6
7
8
9
10
11
12
0
5
10
15
20
25
30
4
9
14
19
24
29
4
October
November
AOKAUTERE ☐
TE MATAI ■
Early
Middle
Late
1975
NO. OF CLUTCHES.
0
1
2
3
4
5
6
7
8
9
o
11
12
0
5
10
15
20
25
30
4
9
14
19
24
29
4
October
November

Table 11 : Breeding data for 1974-75

	Early	Middle	Late	Total
Occupation rate	25.00% n=160	16.25% n=160	12.50% n=160	36.25% n=160
Av. clutch size	4.02 n=41	3.89 n=26	3.80 n=20	3.93 n=87
Egg success	34.38% n=160	36.63% n=101	7.89% n=76	29.08% n=337
Productivity of occupied boxes	1.34 n=41	1.42 n=26	0.30 n=20	1.69 n=58
Egg success of full clutches	39.29% n=140	39.78% n=93	8.11% n=74	31.92% n=307
Egg success from successful clutches	69.62% n=79	67.27% n=55	54.55% n=11	67.58% n=145
No. fledged	55	37	6	98
Fledging success	57.89% n=95	52.86% n=70	15.00% n=40	47.80% n=205
Fledging success from successful broods	84.62% n=65	71.15% n=52	60.00% n=10	77.17% n=127
Mean no. of nestlings fledged per clutch	1.34 n=41	1.42 n=26	0.30 n=20	1.13 n=87
Mean no. of nestlings fledged per full clutch	1.67 n=33	1.68 n=22	0.32 n=19	1.32 n=74
Mean no. of nestlings fledged per successful clutch	3.24 n=17	2.85 n=13	2.00 n=3	2.97 n=33
Productivity of all boxes	0.34 n=160	0.23 n=160	0.04 n=160	0.61 n=160
Productivity of successful boxes	3.24 n=17	2.85 n=13	2.00 n=3	3.06 n=32
Percentage success of occupied boxes	42.50% n=40	50.00% n=26	15.00% n=20	55.17% n=32

Table 12 : Breeding data for 1975-76

	Early	Middle	Late	Total
Occupation rate	36.88% n=160	20.00% n=160	13.13% n=160	48.13% n=160
Av. clutch size	3.75 n=59	3.94 n=32	3.95 n=21	3.84 n=112
Egg success	33.03% n=221	16.67% n=126	24.10% n=83	26.51% n=430
Productivity of occupied boxes	1.24 n=59	0.66 n=32	0.95 n=21	1.48 n=77
Egg success of full clutches	34.27% n=213	16.94% n=214	25.97% n=77	27.53% n=414
Egg success from successful clutches	76.04% n=96	63.63% n=33	64.52% n=31	71.25% n=160
No. fledged	73	21	20	114
Fledging success	59.35% n=123	77.78% n=27	36.36% n=55	55.61% n=205
Fledging success from successful broods	84.88% n=86	77.78% n=27	71.43% n=28	80.85% n=141
Mean no. of nestlings fledged per clutch	1.24 n=59	0.66 n=32	0.95 n=21	1.02 n=112
Mean no. of nestlings fledged per full clutch	1.40 n=52	0.70 n=30	1.11 n=18	1.14 n=100
Mean no. of nestlings fledged per successful clutch	3.17 n=23	2.63 n=8	2.86 n=7	3.00 n=38
Productivity of all boxes	0.46 n=160	0.13 n=160	0.13 n=160	0.71 n=160
Productivity of successful boxes	3.17 n=23	2.63 n=8	2.86 n=7	3.46 n=33
Percentage success of occupied boxes	38.98% n=59	25.00% n=32	33.33% n=21	42.86% n=77

In the 1974-75 season, clutch size decreased significantly between early and late periods ($P < 0.05$). This trend was not apparent in the 1975-76 season owing to a large number of one-egg clutches during the early period. At Te Matai Road seven such clutches were laid (compared to one in 1974-75) and were abandoned because of disturbance from nearby potato-planting operations. If these clutches are deleted from the data, the mean clutch size for the early period is 4.2 which is significantly greater ($P < 0.05$) than the late period.

The outcome of comparing breeding success in the two seasons depends upon what measures are chosen. In the 1975-76 season, more nests were occupied, more eggs laid and more nestlings fledged. However, the number of nestlings fledged per occupied box was lower than the previous season because a large number of nests were lost to predators and vandals. At Te Matai Road nine boxes were abandoned during one night and no trace of eggs or nestlings were left. These nests contained middle-period broods and late-period clutches. No nestlings were fledged in the late period at Te Matai Road, apparently because of predation. Evidence for this comprised small pieces of nestlings and blood on the nest material. Access to the nest boxes would probably have been easy for such competent climbers as mustelids, because the boxes were only 1.25m from the ground.

In terms of the number of nestlings fledged per successful clutch the 1975-76 season was the more successful, possibly owing to the more favourable weather which occurred during the season. Rainfall influences particularly the late period of the season and the drought during the 1974-75 season resulted in high losses of late nestlings so that only 15% of the clutches laid were successful. However, in 1975-76 when ample rain fell 33% of the clutches laid were successful even though, as already stated the Te Matai Road area did not contribute.

Since the pattern of rainfall over the breeding season apparently influenced breeding success, I measured and compared rainfall in each of the three periods for the 25 days that nestlings were present. This interval was calculated from the median day of laying in the early, middle and late periods with five days being allowed for laying and 11 for incubation.

The next 25 days when nestlings were in the nest were the days on which total rainfall was measured. The results are now shown in Table 13.

Table 13 : Rainfall During Nestling Periods

1974-75	Early broods	Middle broods	Late broods
Brood period:	22ndOct.-16thNov.	19thNov.-14thDec.	5thDec.-30thDec.
Rainfall(mm)	95.0	37.6	38.0
No.ofwet days*	13	4	6
1975-76			
Brood period:			
Rainfall(mm)	51.7	47.7	112.3
No.of wet days*	12	10	14

* A wet day is one on which 0.1mm or more of rain fell.

There was considerably more rainfall during the middle and late broods of the 1975-76 season than for similar periods in the previous season. I believe that this contributed to the greater success of the nestlings in the 1975-76 season by affecting the availability of food, and observations of the feeding behaviour of parent starlings at the glass-topped boxes supports this view. (Section 3, Table 4). During the early period, both pairs visited their young with food at least 10 times during the hour's observation. The bulk of the food was earthworms, which were often fed several at a time. However, for the late brood of the same parents, the number of feeding visits was initially only about four. This low food input was reflected in the nestlings' growth rates: two nestlings gained weight slowly but the other two died after three days. Only 12.2mm of rain fell in the 14 days prior to hatching so the soil especially at the surface was relatively dry. This may have been the reason for the low frequency of feeding visits and the small amount of food carried on each visit. Often so little was brought that it was unobservable inside the parent's beak. On the fifth day after hatching heavy rain fell and the rate of feeding increased. Now large amounts of food were brought, which often included beaks full of earthworms. Therefore, it seemed that the greater success of breeding starlings in 1975-76 was due to greater rainfall, especially during the late period.

To summarise the breeding data, it is apparent that success in the early period was similar in both seasons. The higher number of nestlings fledged in 1975-76 reflected the greater proportion of nest boxes that were occupied. However, productivity in the middle period of that season was low because many nests at Te Matai Road suffered vandalism or predation. The number of nestlings fledged in the late period was much higher in 1975-76 because the weather was more favourable; rainfall in December 1975 was sufficient to allow parent birds to obtain food from the soil by probing, which was not possible in 1974 when drought conditions prevailed.

9.2 Nestling Performance

The results now given for nestlings "performance" (weight at 15 days of age, growth rate and mortality) form the background to the influence of O. bursa on nestlings. First, the weights of fledged nestlings at 15 days of age are considered (Table 14).

Table 14 : Mean Live Weight (gm.) of Fledged Nestlings at 15 days

1974-75	Early	Middle	Late	Total
N	55	37	6	98
Mean wt.±SEM	75.5±0.67	71.1±1.31	72.2±3.30	73.6±0.70
1975-76				
N	73	21	20	114
Mean wt.±SEM	77.1±0.71	70.5±1.42	71.5±1.70	74.9±0.67

In both seasons the early nestlings were heavier than the middle and late ones but there was no significant difference between the two early periods ($P<0.2$). In 1974-75 early nestlings were significantly heavier than those in the middle period, but not those in the late; in 1975-76 early nestlings were significantly heavier than both the middle and late individuals.

Nestling weights were categorized into weight classes (Section 3.3) to obtain a better indication of likely survival of nestlings after fledging (Table 15).

Table 15 : Distribution of the Weights of Nestlings Aged 15 days.

	Early	Middle	Late	Total
1974-75[x]				
Light	5.4%	29.7%	33.3%	16.3%
Medium	70.9%	54.0%	50.0%	63.3%
Heavy	23.6%	16.3%	16.7%	20.4%
N	55	37	6	98
1975-76				
Light	5.5%	28.6%	25.0%	13.2%
Medium	49.3%	71.4%	65.0%	56.1%
Heavy	45.2%	0.0%	10.0%	30.7%
N	73	20	21	114

[x] Weight categories:

Light	68gms
Medium	78-68gms
Heavy	78gms

The table shows that the relative proportions of light, medium and heavy nestlings changed over the season so that in general the proportion of heavy nestlings in early broods was high, but decreased later, while the proportion of medium weight and light nestlings was low but increased later. Overall there was a greater proportion of heavy nestlings raised in 1975-76. This can most likely be attributed to the early period and not the late, even though favourable conditions prevailed then. In 1974-75 there was an unexpectedly large proportion of heavy and medium-weight nestlings (considering the drought conditions that prevailed), but this may have been due to the small number of nestlings present in that period. Early period nestlings aged five, ten and fifteen days were significantly heavier (P 0.05) than nestlings of the same ages in the middle and late periods (Fig.4; Appendix 2). (See over page before table).

Figures for nestling mortality (Table 16) show several features which reinforce earlier statements.

Table 16 : Mortality of Nestlings at Different Ages.

	Early	Middle	Late	Total
1974-75				
No. eggs laid	160	101	76	337
% failed to hatch	45.6	26.7	51.3	41.2
% died before 5 days	16.9	21.8	13.2	17.5
% died after 5 days	7.5	14.9	27.6	14.2
% fledged	34.4	36.6	7.9	29.0
1975-76				
No. eggs laid	221	126	83	430
% failed to hatch	43.9	52.4	33.7	44.4
% died before 5 days	16.3	14.3	19.3	16.3
% died after 5 days	6.8	16.7	22.9	12.8
% fledged	33.0	16.7	24.1	26.5

First, in 1974-75 there were high losses of eggs in the late period and most nestlings that hatched died before fledging. As explained earlier, this was a result of the drought at that time. By comparison, in 1975-76 egg losses in the late period were not nearly so high, probably because favourable conditions prevailed then. However in the middle of this period of this season there were high losses of clutches and only a small proportion of nestlings fledged; a reflection of the vandalism and predation that occurred at this time at Te Matai Road.

The proportion of nestlings that hatched but died before five days of age was fairly constant throughout each season and between each season. I think it is possible that these losses were of young that hatched last in their respective broods and so were weak from the start, compared to their earlier hatched nest-mates. Because the proportion was constant I suggest that the death of these young nestlings is influenced largely by the time they hatch in relation to their nest-mates. As discussed earlier in Section 4.3, Dunnet (1955) showed that the death of late hatching nestlings occurred independently of the amount of food available to the parents. Thus it is only those nestlings that survive beyond five days of age that are likely to be exposed to stress-causing factors as undernourishment and mites.

Fifteen day weights of those nestlings that fledged were analysed by comparing the mean weights from different brood sizes (Table 17). In both seasons the 15 day weights of middle and late period nestlings were not significantly different (by $\underline{t}$ test) between brood sizes 2 and 3 so that the data from these broods was pooled to provide bigger samples. For both seasons **comparison** of the weights of broods of two and three nestlings combined, and broods of four revealed no significant differences (by $\underline{t}$ test).

In conclusion, it is clear that during the early period of the season relatively more nestlings were raised than in the rest of the season and these nestlings generally were significantly heavier than later nestlings. Thus it would appear that middle and late periods were suboptimal for starling breeding possibly owing to: weather and its influence on food resources, the waning industry of the parents and/or the increase in <u>O. bursa</u> populations. This conclusion is supported by data showing that mortality was greater during middle period in 1975-76 and late period in 1975-76. Finally, it was found that the weight of nestlings did not decrease significantly in larger broods, but as there were insufficient broods of five or six nestlings for analysis this result may not hold for these larger brood sizes.

Table 17 : Mean Life Weight of Nestlings aged 15 days for the Various Brood Sizes

1974-75

Brood size:	1	2	3	4	5	6
Early N	0	6	7	37	0	6
Mean wt±SEM	-	78.0±2.78	76.9±2.00	73.1±2.12	-	73.7±0.93
Middle N	0	3	14	20	0	0
Mean wt±SEM	-	67.3±8.71	69.8±1.63	72.7±1.54	-	-
Late N	0	2	1	3	0	0
Mean wt±SEM	-	69.5±4.51	64.0	76.7±4.65		

1975-76

Brood size:	1	2	3	4	5	6
Early N	2	4	17	36	8	6
Mean wt±SEM	83.5±3.51	82.0±1.69	77.5±1.31	75.5±1.22	77.1±1.44	79.8±2.21
Middle N	1	2	8	10	0	0
Mean wt±SEM	77.0	72.5±4.51	68.0±3.25	71.4±1.40	-	-
Late N	0	2	3	15	0	0
Mean wt±SEM	-	72.0±1.00	73.0±2.31	71.1±2.32		

9.3 Influence of Ornithonyssus bursa Infestations on the Productivity of Starling Nestlings

During the early period of the breeding season 30% of the occupied nests were infested with small numbers of mites (see details in Section 7.2). By the middle period about 40% of the broods were infested, some with thousands of mites. However, during the late period, about 80% of the nests contained eggs or nestlings infested with mites, and at least half of these contained heavy infestations. The relation between these infestations and the weights of nestlings at 15 days of age is summarized in Table 18.

Table 18 : Mean Live Weights of Nestlings Aged 15 days in relation to the Level of O. bursa Infestation

	Non-infested	Few	Tens	Hundreds	Thousands	Total Infested
1974-75						
Early N	17	12	8	18	0	38
Mean wt±SEM	78.8±4.72	76.8±1.51	71.5±1.96	75.1±1.16	-	74.9±0.82
Middle N	12	6	7	8	4	25
Mean wt±SEM	70.1±2.87	72.0±1.97	74.9±1.62	69.5±3.08	69.8±1.50	71.6±1.37
Late N	0	0	3	2	1	6
Mean wt±SEM	-	-	76.7±4.65	69.5±4.51	64	72.2±3.15
1975-76						
Early N	27	13	13	20	0	46
Mean wt±SEM	78.6±0.49	78.5±1.61	78.1±1.25	73.6±1.78	-	76.2±1.10
Middle N	0	0	3	6	12	21
Mean wt±SEM	-	-	74.0±3.01	72.0±1.51	68.8±2.42	70.5±1.42
Late N	0	0	0	4	12	20
Mean wt±SEM	-	-	-	74.3±1.33	70.8±2.08	71.5±1.70

First, in the early period the level of mite infestation was correlated with the weight of the nestlings only when infestations were heavy. For instance, although the noninfested nestlings of the early period in 1974-75 were significantly heavier (by t test) than infested nestlings, it was individuals with relatively heavy infestations (hundreds) of mites that were significantly lighter than noninfested young. Noninfested and lightly infested (few of tens of mites) young did not differ significantly in weight. In the 1975-76 season early nestlings of heavily infested broods were significantly lighter than noninfested broods, as occurred for the previous season.

Data for the middle and late periods were amalgamated to increase sample sizes. For 1974-75 infested nestlings were significantly heavier than noninfested young! However, in keeping with earlier results, the heavily infested nestlings were significantly lighter than those that were only lightly infested. Unfortunately there were no noninfested broods in these periods to compare with infested ones. In the 1975-76 season, there was no significant difference between lightly and heavily infested nestlings for middle and late periods combined.

The relationship between the weights of nestlings in small and large broods and the level of mite infestation is presented in Table 19. The difference between the weights of nestlings of noninfested broods and nestlings of infested broods of the same size was not significant ($P < 0.2$) for broods containing only four nestlings. However for the amalgamated data of brood sizes two and three there was a significant difference between infested and noninfested nestlings. The reason for the significant difference between noninfested and infested in smaller broods is not readily explainable. Possibly lower brood sizes resulted in individual nestlings harbouring relatively higher densities of mites than young in larger broods.

Moss and Camin (1971) found that the weights of parasitized nestlings of the purple martin were "roughly seven percent lower than that of parasite-free nestlings of the same brood size. Further, maximum weights attained by parasitized young reared in broods of four and three did not differ

Table 19 : Mean Life Weight of Nestlings Aged 15 days from Infested and Non-infested Broods.

	Broodsize					
	1	2	3	4	5	6
1974-75						
Non-infested:						
N	-	-	5	24	-	-
Mean wt±SEM	-	-	67.2±4.08	75.5±1.22	-	-
Infested:						
N	-	11	17	35	-	6
Mean wt±SEM	-	73.6±2.85	73.1±1.49	73.6±0.85	-	73.7±0.93
1975-76						
Non-infested:						
N	1	2	6	4	8	6
Mean wt±SEM	80.0	80.0 ±0	79.8±1.82	76.5±1.71	77.1±1.44	79.8±2.21
Infested:						
N	2	6	22	57	-	-
Mean wt±SEM	82.0±5.02	76.2±2.67	72.8±1.66	73.6±3.92	-	-
Combined seasons						
Non-infested:						
N			11	28		
Mean wt±SEM			74.1±2.73	75.6±1.18		
Infested:						
N			39	92		
Mean wt±SEM			73.0±0.99	73.6±2.44		

statistically from maximum weights of unparasitized nestlings in broods of five and four respectively; that is, there was a tendency for parent birds in the mite-free colony to rear one more offspring than parents in the parasitized colony with no sacrifice in the weight of the young". When I carried out the same analysis on starlings broods containing three and four nestlings, (Table 19) I found that the unparasitized nestlings were 1.5% and 2.5% heavier respectively. Also when the weights of mite-infested nestlings in broods of three were compared with weights of noninfested nestlings in broods of four, there was no significant difference inweight ($P<0.2$). This would seem to agree with Moss and Camins' findings for the influence of mites on the productivity of its avian host. But I also compared the mean weight of infested nestlings from broods of three and four and found no significant difference between the two brood sizes. Therefore, a pair of starlings are able to raise three or four nestlings whether they are parasitized or not, with no significant difference in their weight at 15 days. From this comparison, it would appear that D. prognephilus has a far greater effect on the productivity of the purple martin than does O. bursa on the productivity of starlings.

Because mite populations were small during the incubation period it is not thought that they caused any abandonment. Table 20 shows the percentage of nestlings that died under varying degrees of mite infestations. Whether the deaths of such nestlings can be directly attributed to the presence of the mites is of course not known. Nestlings less than five days old were not included in the table as quite a large proportion were late-hatched and died in similar proportions in all three periods of the season. The death of nestlings older than five days that may be more directly related to the effects of mites concern birds which were the smallest of their broods. They were invariably slower to grow feathers and harboured many more mites than their nest mates.

Most of the mortality that can be correlated to the level of mite infestation occurred during the late period of each season when infestations of O. bursa were heavy. Overall the infested nestlings in 1975-76 suffered a higher mortality than those of 1974-75. This result was not expected or evident from casual observations since conditions for nestling growth and survival seemed more favourable (in terms of weather) in 1975-76. Also the high mortality during the 1975-76 season was due to predation at Te Matai Road. Apart from sheer survival other measures of nestling welfare that can be associated with the level of mite infestation are characters of the blood and amounts of bodily fats. These parameters are now discussed.

Table 20 : Percentage Mortality caused by the Mites

1974-75	EALRY	MIDDLE	LATE	TOTAL
Noninfested	3.27	9.00	0.00	4.25
N	5	9	0	14
Few-tens	3.92	0.00	6.58	3.34
N	6	0	5	11
Hundreds-thousands	0.65	6.00	21.05	6.99
N	1	6	16	23
Total infested	4.57	6.00	27.63	10.33
N	7	6	21	34
1975-76				
Noninfested	2.72	0.00	0.00	1.40
N	6	0	0	6
Few-tens	1.36	0.00	10.84	2.79
N	3	0	9	12
Hundreds-thousands	2.72	16.67	12.05	8.61
N	6	21	10	37
Total infested	4.08	16.67	22.89	11.40
N	9	21	19	49

9.4 The Influence between Infestations of *Ornithonyssus bursa* and Lipid Stores of Starling Nestlings.

Brett (1958) stated that "stress is a state produced by any environmental or other factor which extends the adaptive responses of an animal beyond the normal range or which disturbs the normal functioning process to such an extent that in either case, the chances for survival are significantly reduced". (in Esch et al,1975). By this definition stress could be brought to bear on a host population from the population of a parasite dependent on it. There is some evidence that when a host is stressed, its ability to resist parasites is often influenced. For instance, Seyle (1950), Christian (1950) and Christian and Davis (1964) have all provided evidence which indicates that stress in an animal will in part reduce resistance, both natural and acquired; the mechanism suggested was an increase in corticosteriod output from hyperactive adrenal glands. Thus stress is undoubtedly a factor in parasitism because anything that lowers host resistance is apt to favour the establishment of parasites in the short term. In an experiment on sheep keds (Nelson, 1962) lambs were injected daily with adrenocorticotrophic hormone which broke down the hosts' resistance and allowed the ked population to increase. Nelson concluded that physiologic or environmental stress such as under-nourishment could affect the basic annual ked population cycle on its host, the sheep.

Because starling nestlings depend totally upon their parents for all requirements, they are very vulnerable to situations that create stress. Temperature, crowding and fighting are known to bring about stress reactions in organisms, but perhaps the most likely factors to create stress for starling nestlings are lack of sufficient food and/or the mechanical irritation of feeding mites as well as the blood loss and infection that may be associated with mites feeding.

One way of determining an organisms 'well-being' is to measure the amount of stored energy reserves it has. Under normal circumstances animals store energy in the form of fat, which is then available for use during 'hard times' or stress situations. Therefore, by measuring the amount of fat nestlings contained, I hoped to obtain information on whether or not the nestlings were being placed under stress by the presence of mites.

Following destructive analysis of several nest boxes in the 1975-76 breeding season to census mite populations, 31 nestlings became available for fat analysis. Prior to the nestlings being chloroformed and placed in a freezer, a blood sample was taken for analysis (Section 9.5). Extraction procedure used to obtain the lipid content of each nestling involved a Soxhlet apparatus with 40-60C b.p. petroleum-ether as the solvent. Preparation of nestlings for extraction required maceration and drying to a coarse powder of constant weight. The full procedure outlined below was similar to that used by Baker (1975) for his lipid level analysis of the South Island pied oystercatcher Haematopus ostralegus finscki. Initially frozen nestlings were cut into small pieces and placed in an oven at 70C to dry. After about two days they were ground to a powder using a pestle and mortar and then returned to the oven for a further day. Then each nestling was placed in a 25 X 80 mm fat-free extraction thimble previously dried at 95C to a constant weight. Full thimbles were placed in an oven at 80C until three weighings on a Mettler balance showed that they had attained a constant weight ± 0.005 gm; such a procedure normally took c. four days. The nestlings were then placed in the Soxhlet apparatus with petroleum ether as the solvent and extracted for five hours. From pilot experiments, it was found that a five hour period was sufficient to extract all ether-solvent fats present. Following extraction, the thimble containing the nestling was returned to the 80C oven to dry to a constant weight.

Fifty thimbles were used during the extraction process with an average weight of 1.918gm ± 0.05. Five thimbles were run through the extraction procedure minus nestlings to measure weight loss during extraction. These thimbles lost less than 0.002gm which is slightly less than 0.1% of 1.918gm. This loss in weight did not warrant a correction factor as it represents less than 0.013% of the average dry weight of a nestling.

The above procedure resulted in the following statistics being available for each nestling: live weight, total dry weight, lean dry weight and the weight of ether-extractable lipids from the difference in total dry weight and lean dry weight. In order to obtain a measure of the proportion of fat in a nestling that was contained in its food seven nestlings were dissected and entire contents of their alimentary tracts dried and extracted separately from the rest of the body. The seven nestlings averaged 0.026gm of fat in their food which was 2.11% of their total dry weight of fat.

Table 21 : Lipid extraction results

No.	Live wt.	Total dry wt.	Fat as % of total dry wt.	Degree of infestation
269	73	14.034	7.20	Noninfested
270	64	11.532	8.72	"
271	72	13.675	7.53	"
272	59	10.386	7.21	"
298	65	13.040	5.02	"
299	62	12.553	6.35	"
501	52	9.735	6.39	"
532	69	12.816	13.33	"
533	68	13.292	11.51	"
534	65	11.728	8.42	"
535	70	14.286	13.03	"
Average ± SEM:	65.4±1.72	12.462±1.27	8.61±1.18	
		Infested		
253	84	17.214	7.38	H
254	82	18.084	11.59	"
255	79	18.229	8.72	"
256	52	9.129	6.95	TH
263	67	14.816	8.90	"
264	71	16.700	12.78	"
276	57	11.065	8.63	"
288	62	13.126	15.80	"
289	66	14.710	15.95	"
296	62	13.200	7.15	"
297	61	13.200	5.13	"
300	56	10.757	5.92	"
521	69	14.278	15.01	"
522	59	13.627	18.04	"
523	61	12.994	13.55	"
526	19	3.341	3.86	"
527	24	4.012	5.41	"
528	69	15.202	8.45	"
529	71	14.954	4.92	"
530	61	11.464	4.42	"
Average± SEM	61.6±3.61	13.005±0.89	9.43±0.98	

Using Student's t test, the noninfested nestlings were compared to the infested, to determine whether or not there was a significant difference in the percentage of body dry weight that was lipid. The average difference between the two groups was not significant, ($P < 0.8$). This may mean that heavy mite infestations do not greatly affect the nestlings or that lipid analysis is not a true reflection of a nestling's well-being. On the basis of nestlings 526 and 527, perhaps the later opinion is closer to the real situation. Both these nestlings were grossly underweight and showed no obvious feather development even when 10 days of age. However, nestlings 527 has a higher proportion of lipid material to its total dry weight when compared to nestlings 297, 298, 529 and 530 all of which were healthy feathered nestlings. Thus, I conclude that it is unlikely that figures for bodily fat content adequately represent the well-being of starling nestlings.

9.5 Relationship between infestations of Ornithonyssus bursa and some characters of the blood of starling nestlings

Most references to veterinary parasitology and poultry parasites state that mite infested poultry characteristically show irritability, anaemia, loss of weight and egg production (Cameron, 1951; Benbrook, 1965). However experiments carried out by Loomis et al (1970) on the effects of O. sylviarum revealed that high concentrations of there mites did not significantly influence egg production of blood composition of mite-infested hens. But because O. bursa is present at such high densities (Section 6 Table 5) in starling nests and nestlings are so vulnerable to their feeding activities, I compared some blood characters of infested and on-infested nestlings. Twenty nine nestlings aged 10-12 days were available for analysis.

A sample of blood was removed from the inside of the joint between humerus and radio-ulna and collected into a test-tube containing an anticoagulant. Analysis of the blood was carried out in a clinical pathology laboratory under the supervision of Dr. R.H. Sutton, Department of Veterinary Pathology and Public Health, Massey University.

I thought it possible that large populations of O. bursa feeding on nestlings could cause anaemia and/or a rise in the white cell count following infection. Accordingly the following tests were carried out on the blood samples: haemoglobin assay, percentage packed cell volume, total serum protein and a stained blood smear for a white blood cell differential count. Initially a white blood cell count was made for each sample but owing to the confusing presence of large numbers of immature red blood corpuscles it was not continued. From the ratio (Hb x 100)/ PCV, the mean corpuscular haemoglobin concentration (M.C.H.C.) was obtained, which gave a measure of the mean concentration of haemoglobin in red blood corpuscles.

To overcome variation inherent in the population "Lucas and Denington (1957) found that if the coefficient of variability for the 95% fiducial interval were to be held to some fixed value, for example ± 10% of the group mean, then the following numbers of birds would be needed for a study on each of the components of the blood" (from Lucas and Jamroz, 1961):

Haemoglobin	12 birds
Packed cell volume	8 birds
White cell types	200 birds at least

The 29 nestlings sampled were divided into two groups: noninfested (10) and infested (19) (Table 22). All the infested nestlings came from nests with heavy concentrations of mites. Using the modified Students t test for samples of less than thirty, it was found that there was no significant difference between the two groups for haeoglobin, packed cell volume or total protein ($P < 0.5$) and therefore it appears that O. bursa did not modify the blood characters of nestlings. However nestling 527 which was heavily infested had the lowest PCV and Hb values which indicated that it was anaemic. But mites could not be identified as the sole or even major cause of this, because other nestlings (521,522,523) which carried ten times as many mites had normal blood characters. This suggests that when nestlings are unhealthy because of undernourishment, damp or fouled conditions, the feeding activities of mites becomes a serious burden. The live weight of nestling 527 was only about one third of the mean for infested nestlings and it was undernourished, thus it probably was especially vulnerable to mites.

Nestling were often found with inflamed areas of skin where mites were present in clumps. The reaction of the skin to the feeding of mites is thought to be the result of anticoagulants and bacteria introduced by the mites. Such foreign proteins could be expected to result in the production and liberation of larger than normal numbers of white blood corpuscles. Although not tested statistically (because of the large number of birds required to overcome normal variability present in a population) there was no obvious difference in the white cell differentials between the two groups (Table 23). This conclusion is supported by the evidence that nestling 527 had nearly the same differential as nestling 269 which was non-infested; both nestlings had extreme differential values.

In conclusion the results suggest that so long as nestlings are reasonably healthy they can withstand the drain

Table 22 : Some Characters of the Blood of Starling Nestlings

Non-infested Nestlings.	Live weight (gms)	Haemoglobin assay	Packed cell volume (%)	Total protein	M.C.H.C.
269	73	10.4	32	6.2	32.5
270	64	6.0	23	4.1	32.5
271	72	9.5	26	7.7	36.5
272	59	7.4	29	3.4	25.5
298	65	11.8	39	4.8	30.3
299	62	9.8	32	5.4	30.6
501	52	8.6	31	3.8	27.7
532	69	10.0	27	5.4	37.0
533	68	10.3	34	4.8	30.0
534	65	9.9	28	5.2	35.4
Average	64.9	9.4	30.1	5.08	31.8
S.E.M.	1.98	0.52	1.43	0.39	1.19
Infested Nestlings.					
253	84	10.7	35	5.1	30.6
254	82	10.8	36	4.4	30.0
255	79	11.4	36	6.3	31.7
256	52	8.5	28	6.0	30.4
263	67	8.6	25	6.6	33.7
264	71	9.0	29	5.4	31.0
276	57	8.3	33	4.1	25.2
288	62	8.3	32	3.8	25.9
289	66	9.0	32	4.8	28.1
296	62	9.0	36	4.6	25.0
297	61	8.8	31	4.4	28.4
300	56	7.8	34	4.4	22.9
521	69	7.7	28	4.0	27.5
522	59	7.8	27	4.9	28.9
523	61	8.4	31	4.0	27.1
527	24	5.6	16	7.6	35.0
528	69	11.6	35	4.4	33.0
529	71	11.0	48	3.6	22.9
530	61	13.9	52	4.8	26.7
Average:	63.8	9.3	32.8	4.9	28.6
S.E.M.	2.97	0.66	1.78	0.36	1.74

Table 23 : White Blood Corpuscle Percentage Differential.

Non-infested Nestling	Meterophils	Eosinophils	Basophils	Lymphocytes
269	24	1	2	73
270	54	3	2	41
271	40	0	0	58
272	50	20	2	26
298	33	9	2	56
299	43	12	1	45
501	35	11	1	53

Infested Nestling				
253	46	2	1	49
254	61	3	1	35
255	51	4	1	43
256	37	3	2	58
263	33	2	0	65
264	52	3	0	45
276	60	3	0	37
288	46	8	0	44
289	48	12	2	39
296	61	4	0	35
297	47	2	1	50
300	56	18	1	25
521	49	10	0	40
522	47	15	0	37
523	36	30	1	33
527	16	6	2	76

of lymph and blood of even tens of thousands of mites. Calculation of approximately how much blood a population of mites may consume each day suggests the following: Assuming -

1. a population of 50,000 mites with a 1:1 sex ratio.
2. that mites engorge once every five days and do not feed in between times.
3. that females consume 0.077mg; males consume 0.025mg.
4. that four nestlings are present.

This would represent a drain from each nestling each day of 0.255gm of blood. Such a calculation does not take into account the feeding of the protonymphs. Archer (1965) states that the total blood volume of a 'chicken' is about 60ml/kg of live weight. If these data are valid for starlings, then a nestling weighing 60gm should contain 3.6gm of blood. Thus the 0.255gm of blood consumed by feeding mites in the calculation above would represent about 7% of the total volume in a nestling.

10 MITES DURING THE STARLING NON-BREEDING SEASON.

10.1 Mites in Nests

When late nestings fledged in early January they left behind thousands of mites because only a very small proportion (less than 5.0%) were on the nestlings during the day (Table 5). Once the hosts left, the mites, prompted by this change in nutritional state, appeared over the top and perch of the box. Most of the mites (75%) usually left the nest material within two days, and after a week nearly all mature individuals were at the top of the box. Nymphs normally remained in the material and were often seen clustered in large numbers on feathers.

In the 1974-75 season all second brood nestlings had either fledged or died by 1 January 1975. Of the 36 nest boxes infested during the breeding season, 28 had mites present on them at this time and of these 10 had populations numbering in the hundreds and thousands. At the start of February 17 boxes still harboured O. bursa populations, but these had reduced to six by March, and the populations had dwindled to a 'few' individuals, only detectable by applying one's hand to the surface. By the start of July only one nest box had mites detectable on it.

Migratory behaviour similar to that shown by O. bursa has been noticed for other ectoparasites when their hosts have finished breeding and left the nest site. Humphries (1969) found that the sand martin flea, in its efforts to contact the martins, moved by a positive phototactic response out of the burrow in which the birds nested. However on arrival at the entrance they congregated, with further movements inhibited by the high light intensity. During the period when birds were present fleas remained in the nest because their fully-fed state promoted a negative phototactic reaction.

Like the sand martin flea O. bursa is also an ectoparasite of a hole nesting bird and so may have similar habits. When young starlings fledged O. bursa moved in a positively phototactic manner to the top of the nest box. Once there they retired back to nearby areas which provided protection from strong direct light.

Camin (1963) states for ectoparasites, particularly host-dwellers, that the majority of random movements occurring after the host has deserted the nest result in the migrants dying without encountering a new host. However, for O. bursa these movements would seem to be crucial for their continued survival, for the following reasons. First, nest material is removed during autumn by the starlings so it would be an advantage for the mites to leave it. During March sizeable populations of mites were still found in and on the nest boxes, but there were no adults in the nest material. Second, the daily visits of starlings to their nest boxes enables some mites to contact a host and their migration to exposed areas facilitates this. Mites respond to vibrations,such as those caused by an alighting bird, by swarming on to the upper surfaces where they are most likely to contact the host. If no contact is made the majority of mites return to their hiding places.

The chances of stranded mites contacting a host may be slim, but the territorial behaviour of starlings does provide opportunities. Coleman (1972) states: "Males which have previously bred remain attached to their nesting site throughout autumn and winter, with females showing similar behaviour but to a lesser extent". This attachment to the nest hole and its immediate vicinity, which may have evolved due to the scarcity of 'natural holes' suitable as nest sites, is considered important to the survival and dispersal of O. bursa.

I carried out dawn observations of 24 nest boxes at Te Matai Road twice a month from January to September 1975 to see if nest boxes were visited regularly. I found that starlings regularly visited the nests each morning, just after sunrise, and paid most attention to established nests which were visited first. Nest boxes which had not been occupied during the previous breeding season were not scrutinized so closely by the birds but most (90%) were entered at least once within the first hour after sunrise. Starlings remained on the boxes or fed in pasture nearby for the first couple of hours each day, after which they tended to form flocks and move away from the study area. Kessel (1957) noted that these visits also occurred in the late afternoon and evening but with somewhat less regularity and 'ferver' than the dawn visits. She also noted that "the birds may spend long periods just outside the holes frequently passing in and out" and my observations confirmed this. Such behaviour would aid the dispersal of the mites.

A feature of starling behaviour which may allow O. bursa to overwinter in the nest boxes is the habit of some birds roosting in the nest boxes. Normally during the non-breeding season all birds gather at a communal roosting site, rather that roosting individually or in pairs at their nest sites. I made several night visits to the Aokautere study area during June and July but no roosting starlings were found and this was confirmed by dawn observations; no starlings were seen to emerge from nest boxes before others arrived from the communal roost. Kessel (1957) noted that often 20% of the nest boxes (recorded maximum of 37.1%) were roosted in by starlings at Ithaca, New York. I assume that the winters at Ithaca are much more severe than those of the Manawatu and that New York starlings roost in the boxes as they provide more protection from the weather than do the roosts located in trees and on buildings. It is possible that similar behaviour occurs among starlings in New Zealand [illegible] Central Otago where winter weather conditions are severe with frequent snowfalls. Notwithstanding the evidence above that O. bursa could onverwinter in nest boxes, other evidence that this did not happen was provided when four boxes were dismantled in the laboratory for a close inspection. The boxes selected for analysis were those that had been heavily infested during the previous breeding season and therefore perhaps were most likely to have living mites in them. A thorough search using a stereomicroscope failed to locate any live mites over the surfaces or concealed in crevices, but many dead and dehydrated specimens of O. bursa were found between close-fitting surfaces. Specimens were mounted and searched for evidence of aparity (retention of eggs, larvae or nymphal stages within the female's body but none was found. The ability of adult female mites to retain eggs instead of laying them is well known as an overwintering process in the Orbitadae (Jacot, 1933; Lipa and Chmielewski, 1966).

In conclusion it appears that although starlings visit their nests regularly throughout the non-breeding season, in the majority of cases O. bursa does not remain as a residual population in the nest box during this period. The mite population which reaches peak size when the nestlings fledge, rapidly declines thereafter. The migration of mites to exposed surfaces of the nest box seems aimed at dispersal rather than merely random movement. A few mites do reach a new host in this way, but many die.

10.2 Mites on Starlings

From Section 10.1 it is apparent that few, if any mites overwinter in starling nests. Because O. bursa requires a blood meal about once a month it was expected therefore that mites would be found on starlings during winter. To verify this, I captured starlings throughout the non-breeding season to see what proportion carried mites. Ten trap boxes were erected at Rongotea 15 km from Palmerston North on Mr. R.F. Webb's property and I was able to capture, band and examine at least 10 birds each month. Ectoparasites were removed by dusting with 'Dri-Die' (Section 7). The reaction of O. bursa to the sorptive dust was observed with a stereomicroscope. At first they moved very rapidly and erratically but within 30 seconds they were immobilized, although their legs twitched for up to an hour afterwards.

Seventy-five starlings were captured between 22 March 1975 and 8 October 1975 and three (4%) of these carried specimens of O. bursa. The dates of capture were: 22 March, 18 April and 16 July. Thus O. bursa was present well after the breeding season had finished and there is no reason to presume that they could not survive until the next breeding season.

Four percent measured infestation over winter creates a problem however. This frequency of infestation seems too low to account for 30% infestation of early broods (Section 7). In addition the number of mites detected on each bird was low (one had two mites and the other two had one each) so that the chance of them dropping off with Dri-Die may have been small. Their small size, setae and curved claws would cause mites to remain lodged in the feathers for some time, even when dead. Thus it is possible that some mites were not detected and that the proportion of infested starlings was higher than 4%. The laying of resistent eggs on the plumage of the starling by _O. bursa_ is not thought to be a likely overwintering habit due to the late summer moult (February) of the starling which would result in such eggs being discarded.

11. CULTURING ORNITHONYSSUS BURSA

At the end of the 1974-75 breeding season, I decided to maintain a culture of O. bursa through winter so that I could experiment on the behaviour of mites subjected to varying environmental conditions. Also, the culture could provide specimens for "seeding" early clutches in the 1975-76 season, especially those in the observation and destructive analysis boxes.

A culture cage was built to the specifications of Camin and Ehrlich (1960). This type of cage had been used satisfactorily by those authors to maintain a culture of the chicken mite, Dermanyssus gallinae, for an unstated period of time. The design of this cage was essentially the same as that constructed by Chamberlain and Sikes (1950), in which a colony of O. bursa was successfully reared on the chicken, Gallus gallus. However, I later discovered that these two cages differed in one essential feature; namely the placement of the nest material. In Camin and Ehrlichs' cage nest material was placed between the triangular inner cage and the outer circular one, so that it did not come into direct contact with the host. By contrast, the positioning of the nest material in the Chamberlain and Sikes' cage mimiced that of a natural nest; the host chicken was placed directly on top of the nest material as though it were a nestling in its nest (see Fig. 2, p.463, Chamberlain and Sikes, 1950).

I set up a cage in autumn 1975 and again in summer 1975-76, with dried grass and straw as nest material. On both occasions a day-old chicken was placed in the inner cage with several hundred mites seeded onto it. The chickens were fed twice daily and inspected for mites. In both attempts the mites were soon observed feeding on the chickens, particularly around the eyes and bill as previously described by Sikes and Chamberlain (1954). When the chicks were very young, folded paper was laid over the mesh of the faecal tray so that poultry mash could be placed on it rather than in a beaker. When this paper was removed a day or so later, mites were found concealed within the folds. They were red and engorged and had obviously been feeding from the chicks. The paper was then placed on top of the straw material outside the inner cage and examined on alternate days for the presence of mites. In both years there was a noticeable drop in the number of mites seen after about ten days. The number of mites in the inner cage continued to decrease and by three weeks none could be found. During the removal of faeces and spilt food, mites were often found in the faecal tray. The removal of these wastes almost certainly resulted in the loss of these mites from the culture cage. Mites were also lost when 10day-old chicks were replaced by new, day-old birds. Replacement of chickens followed the practice of Chamberlain and Sikes (1950), and was necessary to prevent undue fouling of the nest material by the increasing volume of faeces excreted as the birds get older. Also newly hatched chickens seemed more content to remain in the close confines of the cage and were less rigorous about preening themselves.

It became apparent that although the cage was suitable for maintaining a culture of D. gallinae, it was unsuitable for O. bursa, possibly because of their different behaviour. For example, D. gallinae visits the host only during the night, travelling from a concealed position to the roosting host and, having fed, returning to its hiding place by dawn. Thus, this mite is capable of detecting its host over appreciable distances and can travel to it to feed. However O. bursa is a continuous ectoparasite, being found either on the host or directly under it in the nest material. Therefore, it would appear from these unsuccessful attempts to maintain a colony of O. bursa in the Camin and Ehrlich cage, that this mite does not travel appreciable distances to find its host, but must be in almost direct contact with it.

Once the behavioural features of O. bursa were appreciated the cage was modified, the internal triangular cage being removed and the outer circular one being filled to seven centimetres with suitable nest material. This modification producing a cage essentially similar to that of Chamberlain and Sikes (1950) was successful and when several thousand mites and a chicken were introduced, the mites were maintained in the cage at quite a high density for over three months. The culture was still healthy at the time of writing.

It appears that the domestic chickens are poor substitute hosts for O. bursa, because the mites rarely become as numerous as they do on starling nestlings, possibly because chickens are nidifigous, whereas starling young are nidicolous. The totally down-covered domestic chickens offer mites a much smaller surface areas on which to feed than do starling nestlings which possess few downy feathers until they are ten days old.

12 General Discussion and Conclusions.

Growth rate and survival of starling nestlings appear to be determined by several interacting factors of which weather, food supply and parental care are probably the main ones.

The effects of weather (especially rainfall) and food supply are closely interrelated because starlings obtain most of their food from the soil and sward, which must be moist to allow probing (East,1972; Coleman, 1972). Although omnivorous, starlings prefer animal matter to plant and because animal matter has twice the calorific value and is nearly twice as efficiently digested by starlings (Taitt, 1973), it is much better food for rapidly growing nestlings. However, dry conditions such as the drought which occurred over the late period of the 1974-75 season probably forced starlings to forage above the soil surface where there may have been insufficient animal food to sustain rapid nestling growth. When animal matter is not readily available starlings are forced to consume grain to compensate (East, 1972). Thus starling breeding appears to be timed to coincide with the moist soil conditions and ample supplies of invertebrates present in October.

In terms of food supply, the early period was the best time for starlings to breed, compared to later in the season. As could be expected therefore, a greater proportion of eggs laid in the early period were successfully hatched and raised to fledging compared with the middle and late period. A similar trend in breeding success for the starling over the season was found by Dunnet (1955) and Anderson (1961) in Aberdeenshire, Scotland, and Kessel (1957) at Ithaca, New York. The early nestlings grew faster, were significantly heavier at fifteen days, fledged earlier than the others and therefore were less likely to die in fouled nests or from predators. Conversely, a higher proportion of the nestlings in the middle and late periods were light in weight when they fledged, probably owing to reduced availability of food. Kessel (1957) noted a similar occurrence at Ithaca with the late young leaving the nest lighter in weight than those of the first brood and their general physical condition appeared poor. Mortality of late nestlings was higher than that of early nestlings. It is possible that the post-fledging survival of the late nestlings could have been greater.

In many small passerine species nestlings can remain alive and develop their feathers normally although badly underweight (Lack, 1948). The chief effect of under-nourishment on a nestling is not usually death in the nest, but a reduced weight when it fledges. Thus, the young which are below weight when they leave the nest might well have less chance of survival. In support of this idea, Perrins (1965) investigating population fluctuations of the great tit, found that most mortality among young tits occurred after they left the nest, but that post-fledging mortality varied greatly in different years, from as high as 90% to as low as 20% or less. Although unable to show exactly how the mortality occurred Perrins suggested that heavier young may carry more fat than lighter ones, and this store of energy would enable these young to survive better than later and lighter fledgings.

Lack (1948) investigating the effect of natural selection on family size in the starling, found that as brood size increased the mean weight of the nestlings decreased. From band returns he was able to show that during the first two months after leaving the nest, the recovery rate of dead starlings was significantly higher for young from broods above the average in size. Thus, it would appear that the lighter fledged nestlings suffer proportionally more mortality than do the heavier fledgings. Such post-fledging mortality of late young would probably be most likely to occur when food is scarce. Therefore, starling breeding is most productive over the early period and this relatively greater success could be further increased by the lower post-fledging survival of late and light-weight nestlings.

Another factor which may affect breeding success more noticeably in the late period is the presence of the parasitic mite Ornithonyssus bursa. As found by Royall (1966) and DeHaven and Guarino (1970) with Dermanyssus gallinae populations, early starling broods were only occasionally infested while most late broods were infested and often with several thousand mites. The dispersal of mites during the season is thought to be predominantly due to the activities of strange starlings about the nest sites. Kluijver (1933), Wallraff (1953) and Kessel (1957) all observed strange birds active about and even entering nests containing nestlings.

Heavy infestations of O. bursa significantly reduced the growth rate and 15 day weight of infested nestlings compared to non-infested and lightly infested young. This situation occurred whether nestlings belonged to early, middle or late periods of the season, but a relatively greater proportion of light nestlings were produced during the late period. However it is believed that although heavily infested nestlings are significantly lighter in weight than other nestlings, this is not due solely to mites.

Wilson (1971) thought that the influence of O. sylviarum populations on myna nestlings depended partly on the ability of the parents to rear young, so that "some parents appeared able to rear chicks equally well whether (the chicks were) infested with mites or not". Wilson also noted that the baviour of individual nestlings had a bearing on their susceptability to mites. Some myna nestlings preened avidly and carried few mites, while other nest mates that preened less were more heavily infested and lighter in weight.

Similarly, I found that the food supply greatly influenced the growth of nestlings when they were infested. During the drought of 1974-75, late heavily-infested nestlings weighed significantly less than lightly infested ones. However in 1975-76 when a wet summer resulted in moist soils, there was no significant decrease in the weight of heavily- and lightly-infested nestlings. Thus nestling welfare when they are infested depends on other interacting factors and not the presence of mites alone. Should a situation arise where some factor other than mites places nestlings under stress they would be less able to resist the effects of the mites, and possibly incur a drop in growth rate and/or survival. If nestlings fledge at a weight that is lighter than normal then it could be expected to decrease their chances of survival after fledging.

In conclusion it appears that under normal circumstances _O. bursa_ does not cause an increase in mortality among nestlings while they are in the nest box. In a stable host/parasite relationship that has evolved over a long period of time undue host mortality would be unexpected and a disadvantage in evolutionary terms since it would deprive the parasite of food. Evidence that the relationship was non-injurious to nestlings before they fledged is seen in the result that a pair of starlings was able to rear three or four nestlings regardless of the degree of infestation without significant differences in 15 day weights. Moss and Camin (1970) did not observe this in _D. prognephilus_ populations on purple martins. _Dermanyssus prognepuilus_ kills young domestic chickens within three hours (Moss, 1966) but the same host can sustain very heavy infestations of _O. bursa_ for several weeks with no deleterious effects. Therefore although mite populations are numerous in the late period and there is the possibility of food shortages, it would seem to be worth the risk to a pair of starlings to expend energy and commence raising a second brood because should they successfully fledge their young, then their genes would form a greater portion of the gene pool.

13 SUMMARY

1. Between March 1974 and March 1976 the relationship between starlings and populations of Ornithonyssus bursa in nest boxes was investigated in the Manawatu district with close attention being paid to nestling growth rate and survival.

2. Ornithonyssus bursa is a haematophagus mite and a continuous parasite during the starling non-breeding season. During the breeding season, the mites take up nest-dwelling with only a small proportion (less than 5%) being found on the nestlings during the day; the rest being hidden in nest material.

3. Estimation of the dizes of mite populations was carried out by counting the numbers seen on nestlings in nest material, and at several locations on the box. Estimation took into consideration the changing distribution of the mites as nestlings aged, their feather development, fouling of the nest material and an increase in the density of mites.

4. Results obtained from estimation were checked for accuracy by total population counts of nests. This revealed that during the initial stages of O. bursa establishment visual measures of numbers under-estimated population size as many mites remained hidden in nest material. However, once the population numbered a hundred or more and nestlings were present, the visual estimates closely approximated population size.

5. The seasonal pattern of infestation of O. bursa involved a slow build up in numbers over the early period of the starling breeding season. Thirty percent of occupied nests were infested with several hundreds of mites. However, by the late period mites had dispersed to about 80% of occupied nests, mainly due to the activities of intruding starlings about the nest boxes. After the second brood hatched, mite populations built up rapidly so that some nests contained tens of thousands of individuals by the time nestlings were 15 days of age.

6. The distribution of O. bursa on nestlings changed as the nestlings grew, developed feathers and preened. Initially mites fed on the feet and ventral surfaces of young nestlings, but this gradually changed to the head, under the wings and around the anus when the nestlings were about 12 days old.

7. Starling breeding was most successful in the early period. A relatively greater percentage of the eggs laid then hatched and were raised to fledging, compared to the middle and late periods. Early nestlings had a significantly faster growth rate and were heavier than later raised nestlings. The performance of middle and late period nestlings apparently dependent on rainfall. As long as food was readily available the weight of nestlings aged 15 days was only slightly less than that of early nestlings. But when hot dry weather reduced the availability of food to foraging parents (as in 1974-75) this caused increased mortality and lower fledging weights.

8. In general nestlings with heavy mite infestations were significantly lighter than non-infested nestlings at 15 days of age.

9. Combined data from the two breeding seasons indicate that a pair of starlings were able to raise three or four nestlings whether they were parasitized or not, with no significant difference in the nestlings' live weight at 15 days of age.

10. Mortality that was clearly due to mites alone was not identified. Normally deaths of infested nestlings were associated with undernourishment and lack of adequate parental care.

11. Comparison of the amounts of ether-extractable lipids and some blood characters in heavily infested and non-infested nestlings revealed no significant differences.

14 REFERENCES

Abasa, R.O. (1969) Survival of Starved Adult Northern Fowl Mites at Different Humidities. Journal of Economic Entomology 62: 1075-1076.

Allard, H.A. (1940) The Starlings Family Life and Behaviour. Journal of Washington Academy of Sciences. 30: 34-46.

Anderson, A. (1961) The Breeding of the Starling In Aberdeenshire. The Scottish Naturalist 70: 60-74.

Baker, A.J. (1975) Lipid Levels in the South Island pied oystercatcher (Haematopus ostralegus finschi). New Zealand Journal of Zoology 2: 425-434.

Benbrook, E.C.(1965) External Parasites of Poultry. In Diseases of Poultry. 5th. Ed., Iowa State University Press, Iowa 1382p.

Bull, P.C. (1973) The Starling: Friend or Foe? New Zealand Journal of Agriculture. 127: 55-59.

Cameron, D. (1938) The Northern Fowl Mite (Liponyssus sylviarum C and F, 1877). Investigation at MacDonald College, with a summary of previous work. Canadian Journal of Research 16: 230-254.

Cameron, T.W. (1951) The parasites of Domestic Animals. J.B. Lippincott Co., Philadelphia. 420p.

Camin, J.H. and P.R. Ehrlich (1960) A cage for maintaining stock colonies of parasitic mites and their hosts. Journal of Parasitology 46: 109-111.

Camin, J.H. (1963) Application of behavioural data to problems of laboratory rearing of parasitic acarines. In Proceedings of the First International Congress of Acarology. Acarologia 6: 350-356.

Chamberlain, R.W. and R.K. Sikes (1950) Laboratory Rearing methods for Journal of Parasitology 36: 461-465.

Christian, J.J.(1950) The adreno-pituitary system and population cycles in mammals. Journal of Mammalogy 31: 247-259.

——— and D.E. Davis (1964) Endocrines, behaviour and population. Science 146: 1550-1560.

Coleman, J.D. (1972) The feeding ecology, productivity and management of starlings in Canterbury, N.Z. Thesis, Ph.D. Canterbury University.

Cross, H.F. and G.W. Wharton (1964) A Comparison of the Number of Tropical Rat Mites and Tropical Fowl Mites that Fed Under Varying Conditions of Humidity. Journal of Economic Entomology 57: 443-445.

DeHaven, R.S. and J.L. Guarino (1970) Breeding of Starlings using Nest-boxes at Denver, Colorado. Colorado Field Ornithologist 8: 1-10.

Dunnet, G.M. (1955) The breeding of the starling in relation to its food supply. Ibis 97: 619-662.

East, R. (1972) Starlings predation on grass-grub (*Costelytra zealandica*, Melolonthinae) populations in Canterbury. Thesis, Ph.D. University of Lincoln.

Esch, G.W. J.Whitfield Gibbons and J.E. Bourque (1975) An analysis of the relationship between Stress and Parasitism. American Midland Naturalist 93: 339-353.

Evans, G.O. J.G. Sheals and D.Macfarlane (1961) The Terrestrial Acari of the British Isles. An Introduction to their morphology, biology and classification. Vol.1 Introduction and Biology, London. (British Museum of Natural History.) vii+219p.

Flynn, R.G. (1973) Parasites of Laboratory Animals. xiv+884p. The Iowa State University Press.

Furman, D.P. (1963) Problems in the Control of Poultry Mites. *In* Advances in Acarology Vol.1. Edited by J.A. Naegele Comstock Publishing Associates.

Hirst, S. (1915) On a widely distributed Gamasid mite (*Leiognathus morsitans* SP. N.), parasitic on the domestic fowl. *Bulletin of Entomological Research*. 6: 55-58.

Humphries, D.A. (1969) Behavioural aspects of the ecology of the sand martin flea *Ceratphyllus styx jordani Smit* (Siphonaptera).

Jacot, A.P. (1933) Aparity among the Oribatidae (Acarina). *The Canadian Entomologist* 12: 263-264.

Kessel, B. (1957) A study of the breeding biology of the European starling (*Sturnus vulgaris L*) in North America. *American Midland Naturalist* 58: 257-331.

Kettle, P.R. (1975) A technique for collecting Ectoparasites from live passerine birds. *The New Zealand Entomologist* 6: 77-78.

Kirkwood, A. (1963) Longevity of the mites *Dermanyssus* gallinae and *Liponyssus sylviarum*. Experimental Parasitology 14: 358-366.

Kluijver, I.H.N. (1933) Bijdrage tot de biologie en de ecologie van den spreeuw (*Sturnus vulgaris vulgaris L*) gendurende zijn voortplantingstijd. *Versl. Meded. Plantenziekt.* (Wageningen) 69: 1-145.

Lack, D. (1948) Natural selection and Family size in the starling. Evolution2: 95-110.

Lipa, J.J. and W. Chemielewski (1966) Aparity observed in the development of Catoglyphus mite (Acarina: Acaridae). *Ekologia Polska* Seria A 14: 741-748.

Lodha, K.R. (1969) The occurrence of tropical fowl mite, Ornithonyssus (Bdellonyssus, Liponyssus) bursa on man in Rajasthan (India). Veterinary Record. 84: 363-365.

Lobb, W.R. and J.Wood (1971) Insects in the food supply of starlings in Mid-Canterbury. *The New Zealand Entomologist* 5: 17-24.

Loomis, E.C. E.L.Bramhell, J.A.Allen, R.A.Ernst and L.L. Dunning (1970) Effects of the Northern Fowl mite on white leghorn chickens. *Journal of Economic Entomology* 63: 1885-1889.

Lucas, A.M. and C.J. Jamroz (1961) Atlas of Avian Haematology. U.S.D.A. Agricultural Monograph 25, Washington vi+271p.

Marples, G. (1936) Behaviour of starlings at nesting site. *British Birds* 30: 14-21.

Matheson,R. (1923) The tropical fowl mite (*Liponyssus* bursa Berlese). *Journal of Economic Entomology* 16: 227-228.

Moss, W.W. (1966) Biology of *Dermanyssus prognephilus* and its host, the purple martin Progne subis. Thesis, Ph.D. University of Kansas.

Moss, W.W. and J.H. Camin (1971) Nest parasitism, Productivity and Clutch size in purple martins. Science 168: 1000-1003.

Murray, M.D. (1950) The tropical fowl mite, *Lyponyssus bursa* (Belese), infecting man in New Zealand. *New Zealand Medical Journal* 50: 392-393.

Nelson, W.A. (1962) Development in sheep of resistance to the Ked *Melophagus ovinus* (*L*) II Effects of adrenocorticotrophic hormone and cortisone. *Experimental* Parasitology 12: 45-51.

Perrins, C.M. (1965) Populations fluctuations and clutch size in the great tit *Parus major L*. *Journal of Animal Ecology* 34: 601-647.

Phillis, W. (1972) Seasonal adundance of *Dermanyssus hirundinis* and *D*. *americanus* (Mesostigmata: Dermanyssidae) in nests of house sparrow. *Journal of* Medical Entomology. 9:111-112.

Royall, W.C. (1966) Breeding of the starling in Central Arizona. *Condor* 68: 196-205.

Selye, H. (1950) Stress and the general adaptation syndrome. *British Medical Journal* 1: 1383-1392.

Sikes, R.K. and R.W. Chamberlain (1954) Laboratory observations on three species of bird mites. *Journal of* Parasitology 40: 691-697.

Taitt, M.J. (1973) Winter food and feeding requirements of the starling. *Bird Study* 20: 226-235.

Von Haartman, L. (1957) Adaptation in hole-nesting birds. *Evolution* 11: 339-347.

Wallraff, H.G. (1953) Beobachtungen zur Brutbiologie des Stares (*Sturnus v. vulgaris L.*) Journal of Ornithology 94: 36-67.

Wilson, P.R. (1971) The ecology of the common myna (*Acridotheres tristis L*) in Hawke's Bay. Thesis, Ph.D. Victoria University, Wellington.

Wilson, P.R. (1975) Starling and Myna. *New Zealand's Nature Heritage* 62: 1730-1734.

APPENDIX I : Some Meteorological Records for Starling Breeding Seasons

		Rainfall(mm) Total Monthly	Mean temp.(C) =($\frac{1}{2}$Max+Min)	Wind (Total Run km.)	Evaporation (0.1mm)
1969-70	Sep.	32.8	12.3	7,032	418.0
	Oct.	37.8	11.1	11,209	871.0
	Nov.	33.3	15.2	8,154	1148.0
	Dec.	92.7	18.0	7,793	1335.0
	Jan.	27.4	19.5	9,008	1623.0
1970-71	Sep.	165.1	11.5	10,026	449.0
	Oct.	91.2	13.2	10,998	594.0
	Nov.	50.8	14.8	8,790	1096.0
	Dec.	71.6	16.4	11,463	1455.0
	Jan.	134.6	18.5	9,820	1473.0
1971-72	Sep.	80.7	11.0	9,222	394.0
	Oct.	126.7	12.5	11,308	697.0
	Nov.	59.8	14.7	9,360	954.0
	Dec.	52.5	16.9	8,233	1345.0
	Jan.	63.5	17.3	10,515	1513.0
1972-73	Sep.	55.1	11.5	11,376	473.0
	Oct.	65.3	13.1	10,316	684.0
	Nov.	28.8	16.1	8,400	852.0
	Dec.	40.4	15.1	10,881	1267.0
	Jan.	50.4	18.0	8,878	1488.0
1973-74	Seo.	147.4	11.9	8,334	472.0
	Oct.	34.3	13.0	10,812	809.0
	Nov.	63.6	15.3	10.992	911.0
	Dec.	30.5	17.7	9,275	1727.0
	Jan.	32.1	17.7	10,019	1555.0

APPENDIX II : Starling Nestling Weights and Growth-rates at 5, 10 and 15 days of age.

	5 days	10 days	15 days
1974-75			
Early.			
N.	67	60	56
Mean wt ± SEM[x1]:	37.1 ± 1.08	65.2 ± 1.25	75.5 ± 1.22
Growth-rate[x2]:	6.22	5.62	2.05
Middle.			
N.	52	42	37
Mean wt ± SEM:	34.3 ± 1.35	60.4 ± 1.63	71.1 ± 1.31
Growth-rate:	5.65	5.22	2.15
Late.			
N.	25	14	8
Mean wt ± SEM:	34.2 ± 4.75	55.5 ± 3.21	67.1 ± 1.61
Growth-rate:	5.63	4.27	2.33
1975-76			
Early.			
N.	89	79	78
Mean wt ± SEM:	34.4 ± 0.88	63.7 ± 0.99	76.2 ± 0.85
Growth-rate:	5.69	6.66	1.70
Middle.			
N.	42	28	21
Mean wt ± SEM:	28.9 ± 1.50	62.7 ± 1.88	70.5 ± 1.42
Growth-rate:	4.58	6.76	1.55
Late.			
N.	40	25	21
Mean wt ± SEM:	25.9 ± 1.32	55.2 ± 2.59	70.0 ± 2.21
Growth-rate:	3.98	5.87	2.95

[x1] — gms.

[x2] — gms/day