DISTRIBUTION AND ABUNDANCE OF GOAT LICE (PHTHIRAPTERA: *Bovicola* spp and *Linognathus stenopsis*) ON THEIR HOST

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ROXANNE J BRASSINGTON

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ABSTRACT

The abundance and regional distribution of louse populations were examined by fleece-parting and post-mortem counts on 20 feral×angora and six saanen×angora goats. The effect of temperature on louse population dynamics was examined in a controlled-temperature experiment using the saanen×angora goats. They were divided into two groups, held at 10 or 25°C and artificially infested with *Bovicola* spp. Fleece-parting counts were made weekly for 16 weeks and a final count was made at post-mortem. Fleece characteristics of the 26 goats were measured.

The distribution of *Bovicola caprae* and *B. limbatus* on all 26 goats, and of *Linognathus stenopsis* on the 20 goats is not uniform over the host's body. Preferences for particular regions are apparent for the two *Bovicola* spp and *L. stenopsis*. The preferred sites for *Bovicola* spp are along and either side of the backline, while the preferred sites for *L. stenopsis* are the shoulder regions, chest and throat. Grooming may account for the observed distribution pattern of *Bovicola* spp, but it does not appear to be the most important factor for *L. stenopsis*.

Fibre density appeared to affect the distribution of *Bovicola* spp females and eggs but not those of *L. stenopsis*. The two genera show different preferences for egg-laying sites and *Bovicola* spp uses a narrower range of fibre diameters for oviposition than *L. stenopsis*.

The magnitude of louse populations varies markedly between goats. Most goats in this study are host to few *Bovicola* spp while only two have >10 000 in the 26 body regions examined. *Linognathus stenopsis* is present in low numbers (<520) on all of the 20 feral×angora goats examined. Grooming efficiency, but not nutrition, may have caused the differential

infestation levels. However, differential infestation is more likely to be influenced by genetic differences between hosts, resulting in skin exudates which are different chemically or in quantity for different goats.

A build-up of lice under cool temperatures is not demonstrated in this study. Temperature is therefore probably not the critical factor influencing the build-up of louse populations on ungulates in winter, and their decline in summer.

Counts of *Bovicola* spp by fleece parting techniques show good correlation with post-mortem counts, and can therefore be used to obtain a reliable estimate of louse infestation levels on individual hosts.

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1 INTRODUCTION

1.1 General

The first goats (*Capra hircus* L.) in New Zealand were liberated in Marlborough in 1773 by Captain James Cook to provide emergency food for visiting ships (MacDiarmid, 1985). In 1867 angora goats were introduced as stock animals for meat and fibre (Rudge, 1976). However, interest in the animals declined as they were difficult to keep contained, and many escaped to breed with the feral population. Now goats are becoming increasingly important as farm animals (Rumble, 1985). Initially this importance solely concerned their ability to control gorse, blackberry and thistles (Wodzicki, 1950). However, the revival of interest is mostly due to the value of their fleece. Feral goats are being captured and selectively bred, or crossed with purebred angora goats to improve their fleece characteristics. They are also used as recipients for angora embryos. There is a small dairy goat industry in New Zealand, which produces milk for export to Australia and milk and cheese for the domestic market (M. Merrall, Veterinary Clinical Sciences, Massey University, pers. comm.).

The goat meat (chevon) industry in New Zealand is small compared to those for beef and sheep meat, but Australia and New Zealand are the largest exporters on the world market (Hawke's Bay Herald Tribune, 19 October 1987). Affco's Mamaku and Omamu meatworks dealt with 22,000 carcasses last season, a decrease from the 50,000 - 60,000 carcasses processed in the late 1970's. Kill numbers are inversely related to the importance of the goat fibre industry. Farmers are currently retaining more animals, especially does, for fibre upgrading programmes. Chevon differs from mutton by having less fat in and around the meat, and

therefore can be promoted as a more healthy meat. Leather made from goat skins is smooth, supple and tough, and there is a demand for this product.

At the end of June 1986, there were 7,408 goat farms in New Zealand, running about 722,600 goats (J. Fegan, Mohair-Cashmere Warehouse, pers. comm.).

1.2 Fibre characteristics and market trends

In the moves towards the development of a goat-fibre industry, it was initially thought that the only option available to goat farmers was to upgrade feral stock to G-1 angoras by sequential crossings with purebred angoras (Young, 1986; de Lacy, 1987). Subsequently, breeding programmes to produce cashmere and cashgora have been developed (Young, 1986).

Upgrading programmes for angoras tend initially to produce larger numbers of undesirable kemp and medullated fibres than in well-bred angoras (Patton, 1980). A recent trial in New Zealand involving 140 registered angora bucks suggested that about half of New Zealand's 16,685 angora bucks are probably unfit for breeding (Carson, 1987). The main criteria for buck acceptability should be a high fleece weight, fine mean fibre diameter, and less than 5% medullation and 2% kemp. However, for the 140 bucks, mean fibre diameter varied from 28-42 microns, medullation from 0-40%, and kemp from 0-12% (Carson, 1987).

Mohair, produced by angora goats, is a luxury high lustre fibre with a mean fibre diameter range of 22-40 microns (Sinclair, 1985). It has diverse uses due to this wide micron range. Kemp and medullation down-grade the fibre because hairs exhibiting these characteristics are brittle

and do not dye well. Current New Zealand production is *ca.* 275 tonnes of mohair per year; the projected supply by 1990 is 750 tonnes. In the third sale of mohair for 1987 (latest figures available), prices ranged from NZ$28.56 per kg for grade A kid to $2.50 per kg for coloured mohair (J. Fegan, pers. comm.). Earnings from mohair were NZ$1.2 million in 1985; the expected level for 1987 is $6 million, and the estimated annual value to New Zealand by 1995 is $90 million (Guilford, 1987).

Cashmere is also a status product of the fibre industry. It is the underfleece from feral goats, with an average fibre diameter of 15.5 microns, although it can range up to 18 microns (Sinclair, 1985). It has low lustre, and its appeal lies in its softness and feel. Its strength is approximately 10% that of the finest sheep's wool and about 40% less than mohair. Feral goats straight from the bush produce an average of only 30g of cashmere per animal (Guilford, 1987). As with all goat fibres, a breeding programme to improve cashmere production is imperative. There is a preference for white cashmere on the export market. However, home spinners prefer the coloured cashmere, and combed cashmere can command prices of NZ$30 per 100g for coloured, and NZ$28 per 100g for white cashmere on the domestic market. New Zealand produced *ca.* 20 tonnes of cashmere in 1987, and is expected to produce over 100 tonnes annually by 1990. The third sale of cashmere for 1987 fetched prices ranging from NZ$84 to $137 per kg of down (J. Fegan, pers. comm.).

Cashgora is a newly-developed fibre produced exclusively in New Zealand and Australia (Guilford, 1987). It has a fibre diameter of 18-22 microns with a lustre midway between cashmere and mohair (Sinclair, 1985) and is produced by feral×angora goats. The challenge facing cashgora farmers at present is to produce a fibre with these characteristics consistently. The market for it is just becoming

established. MAFTech has set up a research and development project for the southern North Island to examine cashgora production systems and to develop research projects to investigate breeding strategies for the production of cashgora. In 1986, New Zealand produced 25 tonnes, but the predicted market potential is for 220 tonnes in 1990 (J. Fegan, pers. comm.). Cashgora is expected to achieve a return of more than NZ$20 per goat per year, and the projected figures for Central Hawkes Bay alone could be over NZ$5 million by 1995 (Guilford, 1987). Prices for cashgora for the third sale for 1987 ranged from NZ$48.50 per kg for cashgora A to $1.00 per kg for inferior coloured cashgora (J. Fegan, pers. comm.).

As outlined above goats are economically important animals, and there is emphasis on research to increase goat production and improve goat health. Rudge *et al.* (1985) list research being carried out in New Zealand at that time. Around Palmerston North alone several researchers are working on goats. Little work has been done on external parasites of goats. Lice are common and the irritation they cause may lead to fleece damage and loss through rubbing and scratching. In addition, the eggs of lice can remain attached to goat fibre even after processing is complete (M. Merrall, pers. comm.). The presence of lice on goats may therefore affect the production, quality and aesthetic appeal of the fibre, although the economic significance of this has not been assessed. It is important to understand the biology and ecology of an animal before it can be controlled effectively; however there is little information on the biology of goat lice. I will therefore review the literature for the biology of lice on cattle and sheep, and include available information on goat lice. The ecology of cattle lice and sheep lice may not be strictly comparable to that of goat lice because these hosts differ from goats in the nature of the microhabitat inhabited by lice.

1.3 Louse taxonomy

Kim & Ludwig (1978) classified lice in the Superorder Psocodea containing three Orders - Anoplura (sucking lice), Mallophaga (biting lice) and Psocoptera (book lice). Lyal (1985b), however, placed lice in a single Order, Phthiraptera, in the Superorder Psocodea, and relegated Anoplura to Suborder status. The taxon Mallophaga was replaced by the Suborders Ischnocera (chewing lice of mammals), Amblycera (chewing lice primarily of birds, but with some families infesting mammals) and Rhynchophthirina (suborder of lice found only on elephants and rhinoceroses). This taxonomic grouping was also suggested by Konigsman (1960) and Clay (1970). I shall follow the taxonomy of Lyal (1985b) since this is the most recent and comprehensive study.

Goats are host to two species of Anoplura and three species of Ischnocera (Ledger, 1980; Drummond, 1983; Lyal, 1985a): *Linognathus stenopsis* (Burmeister, 1838) and *L. africanus* Kellogg & Paine, 1911 (Anoplura: Linognathidae); and *Bovicola (Damalinia) caprae* (Gurlt, 1843), *B. limbatus* (Gervais, 1844) and *B. crassipes* (Rudow, 1866) (Ischnocera: Trichodectidae). The generic taxonomy of the trichodectid lice of goats has been confused by numerous authors redescribing previously known species as new species under different names. Hopkins (1942) reviewed and clarified the generic and specific names and synonyms of trichodectid goat lice and recognised three species, but recorded *Bovicola crassipes* as *Holokartikos crassipes*. The name *Holokartikos* was reduced to a subgenus of *Bovicola* by Lyal (1985b). Only *B. caprae, B. limbatus,* and *L. stenopsis* have been recorded in New Zealand (Tenquist & Charleston, 1981).

1.4 Louse ecology

The general ecology of mammalian lice is not well understood, and very little is known about lice on goats.

1.4.1 Host specificity

Lice are obligate parasites which spend their entire life cycle from egg to adult on the host, and cannot survive for long away from the host. It is convenient to examine louse ecology by examining each host in turn since lice are very host specific and generally are not able to survive on another host species. However, Hallam (1985) recorded a case of sheep lice (*Bovicola ovis*) transferring to goats, with the lice reproducing and the population stabilising after 13 weeks. Goat lice (*B. caprae*) were not able to survive and breed on sheep (Hallam, 1985). Goats may therefore provide a reservoir for the infestation of sheep with lice.

1.4.2 Life cycles

Life cycle dynamics of insects vary depending on temperature and relative humidity (RH), with temperature being more important. At low temperatures, egg development is slow. As temperature increases, the rate of egg development increases until a temperature is reached where eggs are produced at a maximum rate possible for that insect's physiology. At higher temperatures still, the rate of egg production and egg viability decrease and death may occur. Therefore, it is necessary to discuss life cycles occurring under optimal conditions as specified below.

The cattle louse, *Bovicola bovis*, has been reared *in vitro* by Matthysse (1946) and Chalmers & Charleston (1980b). Under optimal conditions (35°C and 75% RH), *B. bovis* had an average cycle from egg to egg of 29 days (Matthysse, 1946) or 27-32 days (Chalmers & Charleston, 1980b). From egg laying to hatching took 7-8 days, first nymphal instar 6-7 days, second

instar 5-6 days, third instar 6-7 days, and moulting to laying the first egg took 3-4 days (Chalmers & Charleston, 1980b). No males were present in Matthysse's (1946) *in vitro* population, yet females laid viable eggs. Matthysse concluded that the normal method of reproduction in *B. bovis* was parthenogenesis. Chalmers & Charleston (1980b) determined the life cycle of *Linognathus vituli in vivo* at ambient temperatures ranging from 3-20°C and relative humidities from 77-94%. The life cycle was completed in 26-31 days. The time taken from egg laying to hatching was 10-12 days; first, second and third nymphal instars took 6-7, 3-5 and 5 days respectively, and moulting to egg laying took 2 days.

The life cycle of the sheep louse, *B. ovis*, was determined *in vitro* and *in vivo* by Scott (1952). At 36.5°C and 70-90% RH, the incubation period was 8-10 days, the first instar had a duration of 8-9 days, for the second it was 5-6 days, the third took 8 days, and the pre-oviposition period was 4 days. The time taken from egg to egg was therefore approximately 34 days *in vivo* and 33-37 days *in vitro*. The sexes were present in approximately equal numbers (Scott, 1952; Hopkins & Chamberlain, 1972), and the normal method of reproduction in *B. ovis* is sexual (Hopkins & Chamberlain, 1972). No data are available on the life cycles and sex ratios of *Linognathus ovillus* and *L. pedalis*, sucking lice of sheep.

The goat biting louse, *Bovicola limbatus*, was maintained *in vitro* at 35°C and 76% RH by Hopkins & Chamberlain (1969). They found the incubation period to be 9-12 days, the first instar lasted for 5-9 days, and the second for 4-9 days. The third instar lasted for 5-12 days for males and 5-9 days for females, and the pre-oviposition period for females was 3.5-7.5 days. The average generation time was 32.2 days, and the male to female ratio was 1:1.7.

At 35°C and 72% RH, *B. crassipes* had an average generation time of 36.7 days (Hopkins & Chamberlain, 1969). The incubation time was 9-11 days, and the first and second instars lasted for 6-11 and 5-9 days respectively. Males remained in the third instar for 6-9 days and females for 6-10 days. The pre-oviposition period for female *B. crassipes* was 3.5-5.5 days, and the male to female sex ratio was 1:1.2. Parthenogenesis was not observed in *B. limbatus* or *B. crassipes* (Hopkins & Chamberlain, 1969). No life cycle data are available for *B. caprae* or *L. stenopsis*.

On the basis of life cycle data, some meaningful comparisons between lice on different host species are therefore possible. The generation time is similar for *B. bovis* and *B. limbatus*. *B. ovis* has a slightly longer generation time, and *B. crassipes* slightly longer again under optimal *in vitro* conditions. Optimal conditions are different for lice from different host species, presumably relating to adaptation to different microhabitat conditions. However, optimal relative humidities are different for *B. limbatus* and *B. crassipes*, which live on the same host, suggesting possible niche separation.

1.4.3 Population dynamics

Of the five species of lice infesting cattle, only one (*B. bovis*) is an ischnoceran; the other four species belong to the suborder Anoplura. Matthysse (1946) showed that cattle lice, like almost all parasite populations, had an over-dispersed distribution. In over-dispersed distributions, most host individuals have very few or no lice, and only a small number of hosts have a large louse population. Differences in infestation levels between host individuals was also noted by Chalmers & Charleston (1980b) for *B. bovis* and *L. vituli*, and these differences appeared to be related to age, weight and health of the host. Sheep also demonstrate differences in susceptibility to louse populations. Some

sheep failed to become heavily infested although they were closely confined with heavily infested animals (Scott, 1952). Lambs were readily infested from their mothers, and old sheep, or those in poor condition, also tended to become heavily infested.

Individual host differences in infestation level may be related to characteristics of the host's skin and fleece. Hopkins & Chamberlain (1972) noted a threefold difference in egg production for *B. ovis* reared *in vitro* depending on which sheep skin was used to obtain scrapings for the lice. An over-dispersed distribution pattern of *Bovicola* species is also found in goats (pers. obs.). Heavily infested hosts can provide a reservoir for lice when populations decrease naturally in spring, or if insufficient control measures are taken.

The nutrition of the host has been suggested as an important determinant of louse population levels. Cattle on a low plane of nutrition have been reported to groom themselves less than well-fed cattle (Utech *et al.*, 1969) and retain a thicker hair coat (Yeates, 1955; Utech *et al.*, 1969). However, the tendency for old or poor-condition sheep to carry larger numbers of lice can hardly be explained in these terms.

Louse population levels on ruminants fluctuate seasonally. Numbers are low in late spring and summer, and begin to increase in autumn to reach their highest level in winter (Matthysse, 1946; Scott, 1952; Chalmers & Charleston, 1980a, b). These fluctuations could be due to a variety of influences. Physical factors affecting oviposition in *B. ovis* were found to be temperature and relative humidity. A temperature of 35-40°C was a necessary pre-requisite to egg laying for *B. ovis* (Murray, 1957b), and embryo development was completed only between temperatures of 30-39°C. Hatching

occurred from 22-42.5°C (Murray, 1960). In Australia, when a sheep is exposed to the sun, the temperature at the tip of the fleece may rise to 70-80°C. On sheep which had been shorn, the temperature close to the skin reached 45-52°C within 5-10 minutes of exposure. These temperatures are high enough for 100% mortality of *B. ovis* adults and nymphs after exposure for 1 h (Murray, 1968). Therefore, an effect of solar radiation and shearing (which itself removes many lice and louse eggs) in spring is a reduction in louse numbers in summer. A rainstorm which thoroughly soaks a sheep's fleece may not only cause direct mortality of 75-100% of *B. ovis* nymphs and adults, but also 10% mortality of eggs for each day 90% relative humidity persists near the skin (Murray, 1963b).

The microclimate on cattle (Chalmers & Charleston, 1980b) and goats (Holst *et al.*, 1982) also becomes less stable in summer because the underfleece is shed, thereby reducing population levels of lice. Climatic factors may therefore influence louse population levels. Hosts respond behaviourally to adverse weather conditions by seeking shade or shelter, thus reducing these effects. I will later describe an experiment examining the effect of ambient temperature on populations of *B. caprae* and *B. limbatus*.

1.4.4 Distribution of lice on a host's body

Not only are there individual differences in host susceptibility to lice, but the louse population on an individual is not distributed evenly over the body. Craufurd-Benson (1941) showed that populations of *Haematopinus eurysternus* (Anoplura) and *B. bovis* were differentiated into breeding colonies and nymphal clusters. The areas on the host most heavily infested with *B. bovis* were the shoulders, topline and tailhead (Craufurd-Benson, 1941; Matthysse, 1946; Chalmers & Charleston, 1980b). *Haematopinus eurysternus* was able to survive in summer in the

ears of cattle (Craufurd-Benson, 1941; Matthysse, 1946), on the tail, and around the horns (Craufurd-Benson, 1941). In winter the main area of infestation by *H. eurysternus* was on the top of the neck, but lice were also abundant on the sides of the neck, dewlap, topline, tail, poll and perineum (Matthysse, 1946). *Linognathus vituli* was most abundant on the shoulders and dewlap (Matthysse, 1946; Chalmers & Charleston, 1980b). In mixed populations, *L. vituli* congregated on the lower and *B. bovis* on the upper body regions; however in single-species infestations each species was present in approximately even numbers over the whole body, and this was interpreted as indicating some antagonism between species (Lewis *et al.*, 1967). It was claimed that in heavy infestations, the lice tended to congregate in species-specific colonies, but in moderate infestations, considerable intermingling of species occurred with no apparent antagonism (Lewis *et al.*, 1967). However, in their study, only a few cattle were examined over a short period of time, average numbers of lice, not individual counts, are presented, and the cattle were prevented from self-grooming. The distribution of *B. bovis* and *L. vituli* on the body of cattle is probably determined largely by the combined effects of coat density and accessibility for grooming by the host (Chalmers & Charleston, 1980b). Grooming by the host may play a large part in reducing louse numbers (Utech *et al.*, 1969; Chalmers & Charleston, 1980b; Murray, 1987) and can therefore affect the distribution of lice over the host's body, as well as reducing the total population level. No data are available for the distribution of lice on an individual goat, or the different densities of lice present between goats.

1.4.5 Louse diets

Lice have been reported to cause damage to their host (see section 1.5), and it may therefore be important to chemically control louse populations. The identification of a feeding

habit provides a useful basis for studying the effects of novel eradication treatments, particularly those administered systemically to the host (Sinclair, 1982, 1983) and, perhaps, explain how damage is caused.

Anoplura suck blood from the host, and their mouthparts and digestive system are highly modified for this purpose (Stojanovich, 1945). There are many and varied reports on the diet of chewing lice. Hopkins (1949) stated that Mallophaga have long been known to feed on hair or feathers, but he did not differentiate between Ischnocera and Amblycera. Ischnocera have also been reported to feed on hair by Peterson & Bushland (1956) and Drummond (1983). It is difficult to observe Ischnocera in the process of feeding due to their small size and the position they adopt at the skin surface (Sinclair, 1983). Therefore, methods employed to determine the food substances are *in vitro* feeding experiments, gut content analyses, or histological techniques.

Oormazdi & Baker (1979) reported that although *B. bovis* may ingest fine calf-hair, the main food of this louse appeared to be the stratum corneum and skin debris of cattle. However, they found no damage to the cuticle of fine hair under microscope examination. *B. bovis* did not feed on dry blood or on the dead bodies of lice (Oormazdi & Baker, 1979). Their evidence was based on pigmentation of the abdomen of lice which had been held *in vitro* in containers with potential food substances. These substances had been ground and stained with 1% toluidine blue. Lice which were offered ground calf skin scales had dark blue abdomens. Three lice which had been confined with ground secondary hair, and two lice confined with primary hair, had lightly stained intestinal contents. Oormazdi & Baker (1979) apparently made no attempt to clean hairs prior to them being ground and stained, and it is highly likely that the hairs were coated

with skin secretions such as apocrine or sebaceous gland secretions, or small fragments of epithelial debris.

There appears to be some controversy over the inclusion of wool in the diet of *B. ovis*. McKenna & Fearn (1952) stated that *B. ovis* did not cut or ingest wool fibres, and Waterhouse (1953) considered that it may rarely ingest but not digest wool. Drummond (1983) stated that this louse did ingest wool. McKenna & Fearn (1952) and Drummond (1983) did not give any evidence for their viewpoints. These are 'popular press' publications, and in my view represent opinion rather than fact. Waterhouse (1953) examined the digestive system and gut contents of several species of lice and reported the main food of mammalian lice to be epithelial debris and skin secretions. Hopkins (1970) was able to successfully rear *B. ovis* for 10 months *in vitro* on a diet prepared from skin scrapings obtained from a shorn sheepskin. A very comprehensive study using several different techniques assessed the dietary components of *B. ovis* (Sinclair, 1983). He determined that *B. ovis* ingested loose epithelial debris, skin secretions and material which they actively chewed from the skin surface. The faeces of lice contained undigested lipid complex from the epidermis, and epidermal squames. However, the presence of lipase in the gut of *B. ovis* suggests that at least some lipid is digested. Wool fibres were not ingested (Sinclair, 1983).

The only studies available on the diet of goat chewing lice are the *in vitro* studies of Hopkins & Chamberlain (1969), Hopkins *et al.* (1976), and Benitez Rodriquez *et al.* (1981). Hopkins & Chamberlain (1969) successfully reared a colony of *B. limbatus* and *B. crassipes* on a diet of skin scrapings obtained from a closely-shorn goat skin. The colonies were maintained through 11 and 10 generations respectively. *Bovicola crassipes* and *B. limbatus* were also reared successfully on artificial diets prepared from a variety of

ingredients using the flesh and skin extracts of different animals as a base, in an effort to standardise rearing procedures. Benitez Rodriquez *et al.* (1981) maintained *B. caprae in vitro* on artificial diets. The optimal culture medium for *B. caprae* was a mixture of dried flesh scrapings, brewer's yeast, and hair.

1.5 Effects on the host of infestation with lice

There have been various, often unsubstantiated, reports of reduced liveweight gains in louse-infested hosts, and even deaths of hosts have been attributed to lice. If these reports are true, then the importance of louse control to farmers cannot be overstated, but scientific evidence for such effects is very limited.

Matthysse (1946) observed that *Bovicola bovis* caused a skin reaction in cattle, with resultant loosening and falling out of the hair. *Linognathus vituli* apparently loosened the hair less than *B. bovis* but more than *Haematopinus eurysternus* and *Solenopotes capillatus* (Anoplura) (Matthysse, 1946). These observations may possibly be explained by the natural loss of the hair coat in spring, or by the cattle rubbing so vigorously as to remove hair. Matthysse himself reported the skin of lousy cattle to be raw from constant biting and scratching, but such severe reactions are extremely rare (W A G Charleston, Department of Veterinary Pathology & Public Health, Massey University, pers. comm.).

There appears to be no significant effect of louse infestation on liveweight gain in cattle (Scharff, 1962; Kettle, 1974; Cummins & Tweddle, 1977; Tweddle *et al.* 1977; Chalmers & Charleston, 1980c; Cummins & Graham, 1982). Scharff (1962) and Utech *et al.* (1969) stated that infestations with *H. eurysternus* can cause severe anaemia and

even death; and Scharff reported an increase in liveweight gain in a heavily infested steer after treatment with derris root powder. A veterinarian had diagnosed the steer as suffering from severe anaemia, but apparently no attempt was made to rule out causes other than lice.

As for cattle, there appears to be no effect of lice infestations on liveweight gain in sheep (Kettle & Pearce, 1974; Kettle & Lukies, 1982b; Wilkinson *et al.*, 1982; Niven & Pritchard, 1985). However, heavy infestations of lice on sheep can cause intense irritation eliciting restlessness and vigorous rubbing or scratching which can damage the fleece (McKenna & Fearn, 1952; Kettle & Pearce, 1974; Sinclair, 1976) (see section 1.6). Decreased clean wool yield and increased processing losses have been described for Merinos in Australia (Wilkinson *et al.*, 1982) but this has not been observed in New Zealand sheep (Kettle & Lukies, 1982b). Increased secretion of yolk and suint occur, reducing the scoured yield of affected fleeces (Kettle & Pearce, 1974; Kettle & Lukies, 1984). Yellowing and loss of brightness can also result from louse infestations, and downgrade the wool (Kettle & Lukies, 1982a).

There are no data in the scientific literature on the effect of louse infestations on goats. Thorold (1963) claimed that lice (*L. africanus* and *B. caprae*), their oviposition, and excreta caused mohair to become matted, stained and lustreless, besides weakening and breaking the fibres. Goat farming manuals frequently contain claims that louse infestations cause problems such as skin irritation, rubbing and scratching (Eberhardt, 1975; Salmon, 1978; MacKenzie, 1980; Drummond, 1983; Rumble, 1985; Pond, 1986; and many others). Shields & Shields (1949), Gregory (1976), Hetherington (1979), and Coleby (1985) claimed that lice do not form large infestations on well-fed and healthy goats, because, according to Gregory (1976), lice are "unable to

live in the oil which is present at high levels" in the fleece of healthy goats. Lice may cause the condition of goats already in poor health to deteriorate further (Shields & Shields, 1949), and Drummond (1983) stated that heavy infestation by Anoplura, which suck blood, can lead to the host's death. No evidence was given by Drummond. However, all authors report that goats are easy to treat for lice by applying insecticides to the hair coat. These reports are not based on scientific evidence, and no information is given on the basis or sources of these claims. On the basis of data given for cattle and sheep, it would seem reasonable to assume that lice would have no effect on liveweight gains in goats. Anoplura may cause a further deterioration in the condition of unhealthy animals, but death caused by Anoplura must be proved by post-mortem examinations eliminating all other causes.

1.6 Economic effects of louse infestation

There is little information available on the economic effects of louse infestation. It has been stated that the occurrence of parasites influences the aesthetic acceptance or the marketability of a product (Morris & Meek, 1980) and so causes a reduction of income to the farmer.

Steelman (1976) estimated losses to the United States economy to be US$97,800,000 per year solely from lice, although what form the damage took was not stated. A figure quoted on its own, with no further information, is not particularly useful. It is difficult to imagine lice causing this much loss of income, although this figure may include the cost of control measures and costs related to damaged fences. Von Rotz *et al.* (1983) reported that *L. vituli* (Anoplura) caused a focal exocytosis and that leather produced from cattle infested with this louse revealed somewhat dilated pores. However,

dilated pores were also apparent in leather from uninfested cattle. *Bovicola bovis* left no obvious changes in the skin and leather. It is therefore unlikely that *L. stenopsis* or *Bovicola* spp would affect the appearance of goat leather.

Treatment of lice is compulsory for sheep farmers in New Zealand (Kettle & Pearce, 1974), and this represents an annual cost of about NZ$7.5 million for labour and materials (Kettle, 1985). No such legislation pertaining to goats has been introduced. The economic significance of the effects of lice on wool quality is not known, and is impossible to assess reliably (Kettle, 1985); this would also apply to goats.

1.7 Aims

The overall purpose of this study was to determine some basic ecological factors affecting the distribution of *Bovicola caprae, B. limbatus* and *Linognathus stenopsis*. Understanding the ecology of an animal may enable more effective measures to be undertaken to control or eradicate it.

1. A non-random distribution of lice has been noted on cattle (Craufurd-Benson, 1941; Matthysse, 1946; Chalmers & Charleston, 1980b) and sheep (Kettle & Pearce, 1974). A major aim of this study was to examine the distribution of lice on a goat, and determine their preferences for particular areas.

2. If preferences for particular areas are apparent, there must be some factor or factors causing the distribution pattern. A second aim was to determine fibre characteristics over the goat's body, and relate these to the observed distribution of lice.

3. Lice lay their eggs on fibres, and the occurrence of suitable fibres in the fleece may help to account for any non-random distribution of the lice. A third aim was to examine the size of hairs used for oviposition and the proportion of eggs in each area, and relate these to the number of female lice in each area.

4. Mammalian lice exhibit seasonal fluctuations in abundance, with the highest population levels occurring in winter (Matthysse, 1946; Scott, 1952; Chalmers & Charleston, 1980a,b). The fourth aim of this study was to investigate the effect of temperature on the build-up of louse populations.

5. Differences in louse population levels between goats were observed during the course of this study. A further aim was formulated, to determine physical parameters of goat skin and hair which may account for differences in louse populations on individual hosts.

6. A satisfactory method to accurately assess levels of louse infestation on live hosts is needed. The final aim of this study was to evaluate current counting techniques for estimating louse numbers on live hosts (Kettle & Pearce, 1974; Chalmers & Charleston, 1980b) by comparison with post-mortem counts.

2 METHODS

2.1 Live and post-mortem sampling procedures

As part of a trial by Pomroy *et al.* (in press) examining the efficacy of treatment of gastro-intestinal nematodes, 20 white G-4 feral×angora wether goats were drenched with IVOMEC* on 22 April 1986 and run on pasture at Tuapaka Farm, Massey University until 5 June 1986. They were then brought under cover, fed on hay, and drenched the following day with VALBAZEN**. It was noted that these goats carried lice, and as they were being killed to determine the effects of the drench VALBAZEN, they provided an opportunity to assess louse numbers by two different techniques and to examine characteristics of the fleece which might affect the distribution of lice. On 12 June, an estimate of louse abundance on each goat was made by dividing the goat's body into 26 regions (Fig. 1) (Kettle & Pearce, 1974). A parting approximately 5 cm long in the fleece was made in each region on each side of the goat (26 regions) and the numbers of lice present were counted by eye.

The 20 goats were killed and skinned on 15 June 1987. After being placed hair-side-down on a table, the skins were marked by felt-tip pen around a template (5x5 cm) in each of the 26 body regions. These squares were cut from the skin with scissors and, along with all cut hair collected from within that area (Fig. 2), placed in labelled containers and stored at 2-5°C. Skins were discarded after sampling. Processing of the skins in this manner was time consuming and up to three skins at any one time were laid on the floor separately, (folded in half twice, flesh-side-out) *ca.* 2 cm

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* IVOMEC ® Merck Sharp & Dohme Ltd.

** VALBAZEN ® SmithKline Animal Health Products.

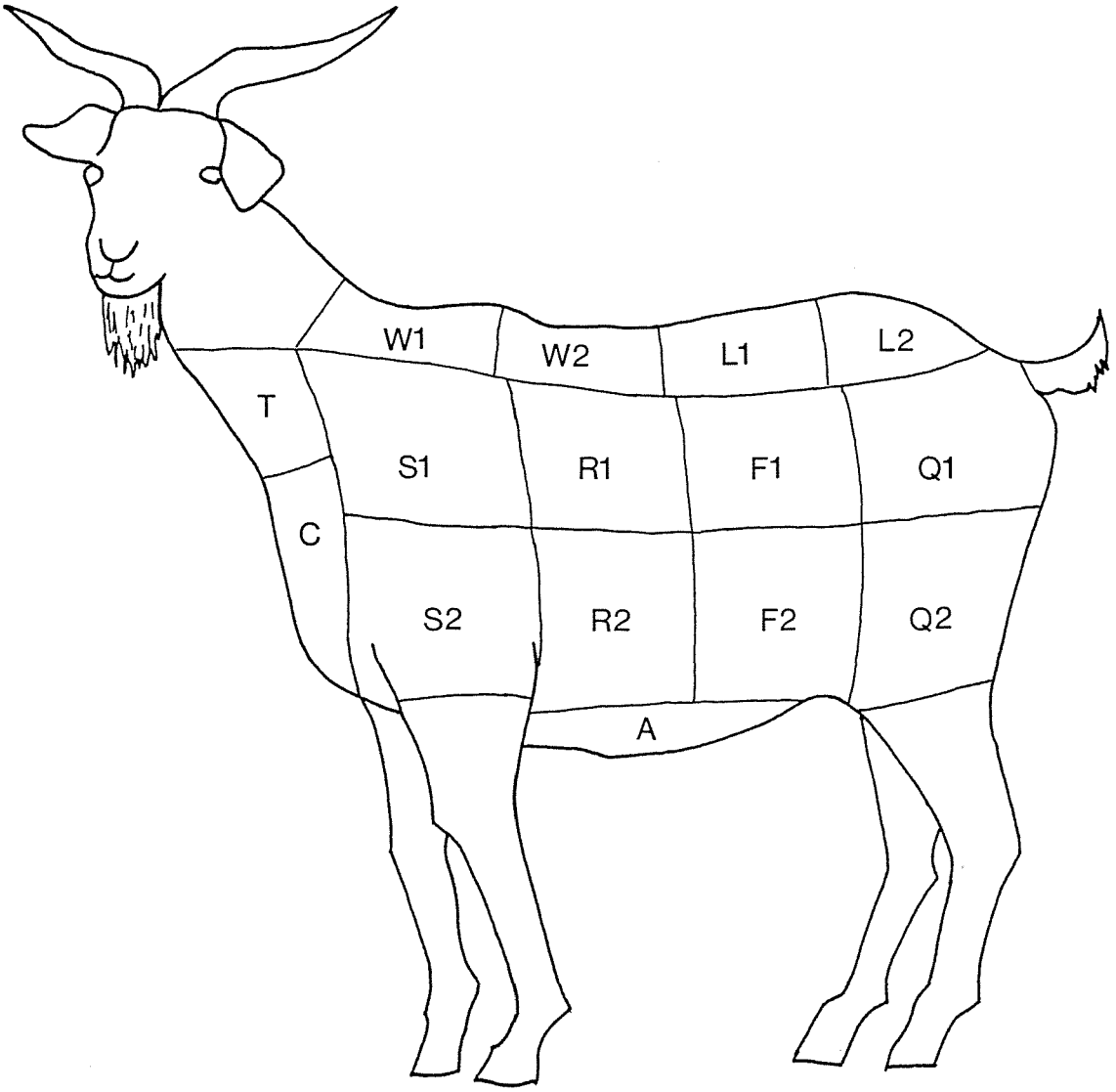
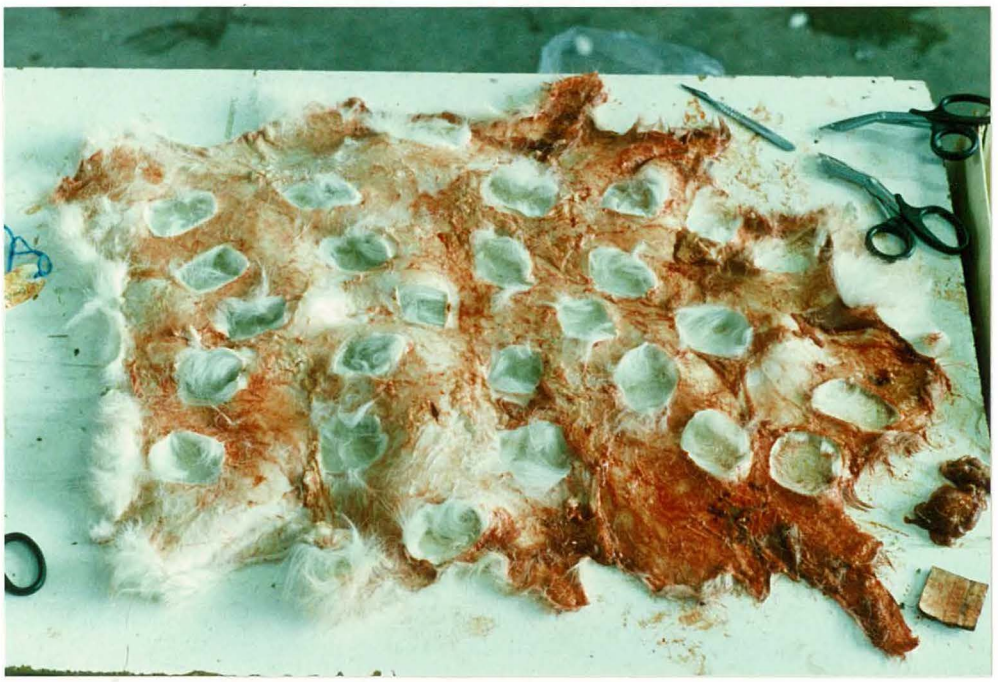


Fig. 1: Regions of the goat's body sampled for louse abundance. Regions W (withers) and L (loin) are replicated along the backline (1 & 2). Replicates for all other regions are the corresponding left and right sides of the body. S = shoulder, R = ribs, F = flank, Q = hindquarters, A = abdomen, C = chest, T = throat. 1 denotes upper and 2 lower regions except for W and L where they indicate replicates.

Fig. 2: Goat skin after sampling one 5x5 cm square from each of the 26 regions. Template is at the bottom right corner. Head end is towards the right. Photo by R. Fordham.



apart to prevent cross contamination, awaiting sampling. An individual skin could remain on the floor for up to 1 h prior to sampling. Subsequently, the hair in each sample was cut close to the skin and retained, and the skin examined for lice under a dissection microscope. Any lice remaining on the skin were removed with fine forceps and returned to the container. The skin was then discarded and the sample stored at room temperature.

2.2 Louse identification and counts

Before each sample was digested to retrieve the lice, hair was removed for the measurement of fibre diameter (see sections 2.3 and 2.4).

Each sample of hair and lice was digested in 10% KOH for *ca.* 16 h (Palma, 1978) at room temperature; the resultant sludge was washed with distilled water through 2 sieves in sequence (1707 micron and 240 micron mesh size respectively). The material retained by the fine sieve was rinsed into a petri dish. Lice in the petri dish and any adhering to the sieves (which were examined under a dissection microscope at x15 magnification) were transferred in distilled water to their original container. After a minimum of 1 h, the water was replaced with 70% ethanol, and the lice stored until they were identified and counted using a dissection microscope (x15-30 magnification). Each louse was removed from the sample by pipette as it was counted.

Linognathus stenopsis (Fig. 3) was easily separated from *Bovicola* spp (Fig. 4) on the basis of size and gross morphology. Juvenile, male and female *L. stenopsis* were identified (Ferris, 1932) and counted separately.

Separation into species is virtually impossible for juvenile

Fig. 3: Female *Linognathus stenopsis*. Note shape of the head, strongly-hooked first and second tarsi, and long setae covering the body and head. Length = 6 mm.

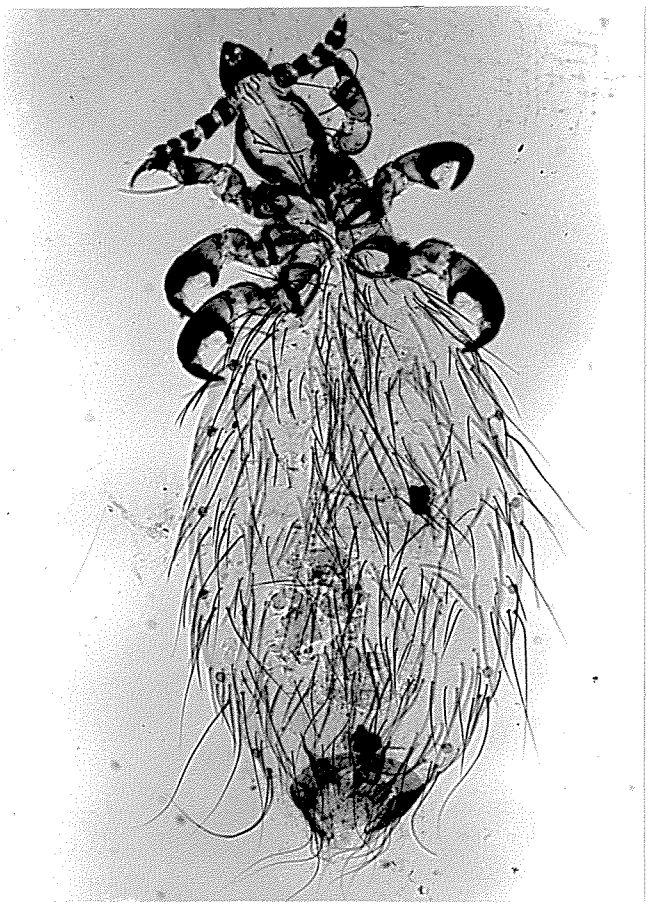
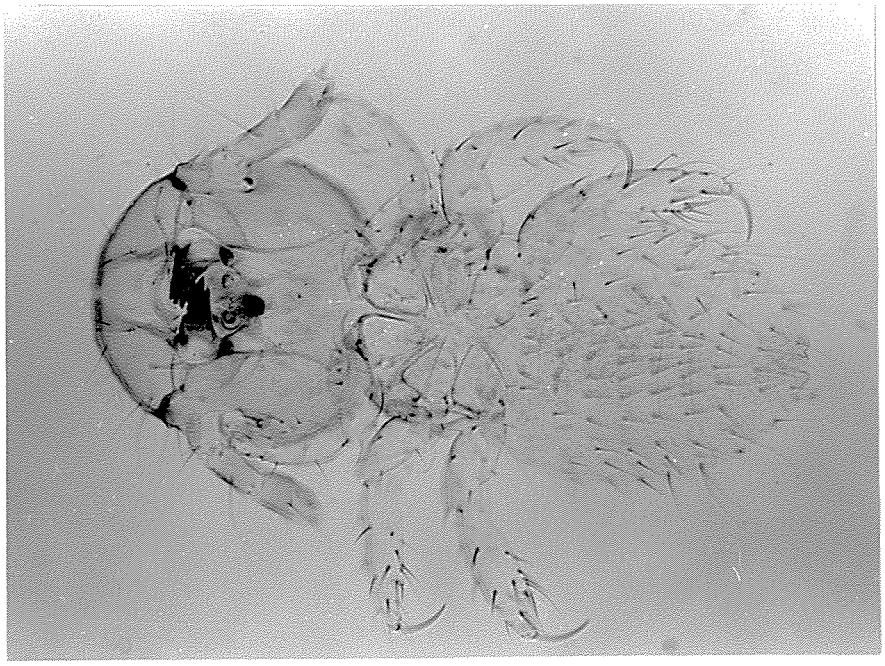


Fig. 4: Female *Bovicola* spp. Note shape of the head, and sclerotisation of the head and abdomen. Length = 3.8 mm.

Fig. 5: First-instar *Bovicola* spp. Note total absence of abdominal sclerotisation. Mandibles are clearly visible. Length = 1.1 mm.



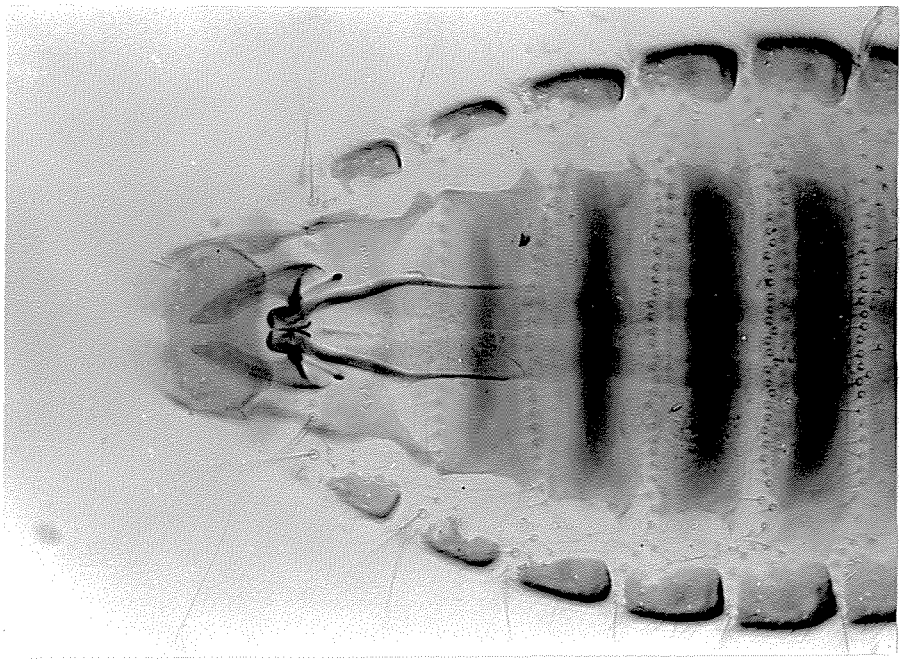
and female *Bovicola* spp (R. Palma, pers. comm.). Juvenile *Bovicola* were smaller than adults and had unsclerotised abdomens (Fig. 5). Females were larger than males and had rounded abdomens (Fig. 4), whereas males had pointed abdomens. The males of *B. caprae* (Emerson & Price, 1975; Lyal, 1986) and *B. limbatus* (A.C.G. Heath, MAFTech, Wallaceville, pers. comm.) were identified by the shape of their penile stylets (Figs 6 & 7 respectively). Juveniles and females were counted separately as *Bovicola* spp, and males were identified to species and counted. *Bovicola limbatus* males were present in very small numbers so the two *Bovicola* species were combined for analysis.

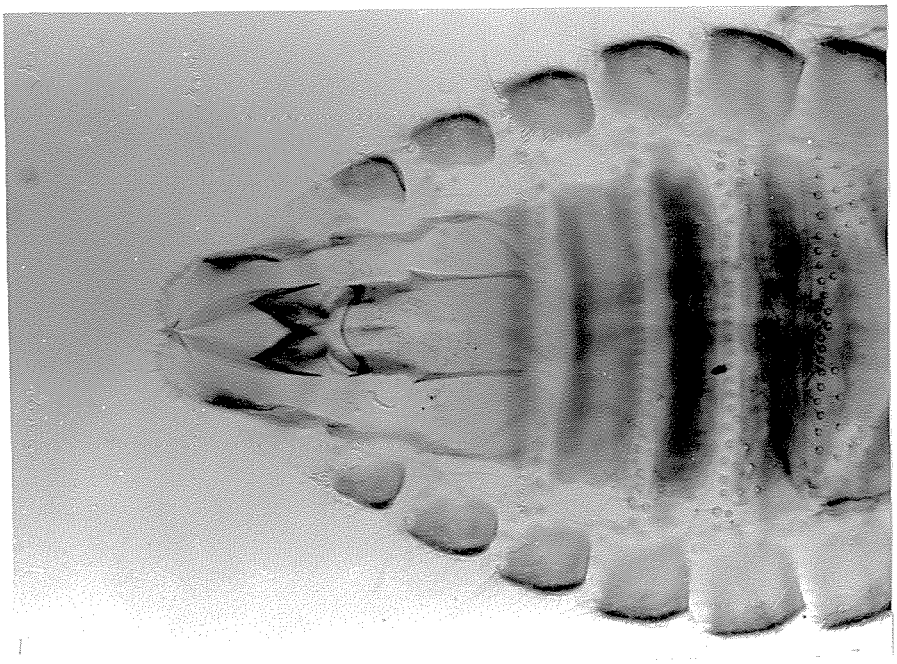
Numbers of lice in the 520 samples were compared using analysis of variance (ANOVA) ('Genstat' - Rothamsted Experimental Station, 1980) between goats and regions to determine the relative abundance and distribution of lice; each genus was treated separately. Replicate samples from each goat also enabled analysis of the interaction of louse numbers between goat and region using ANOVA. A logarithmic transformation was incorporated into the Genstat program to correct for the multiplicative effect between goats with a heavy louse burden and those with few lice.

The number of *Bovicola* spp in each region was compared between sides by X^2. There was a significant difference in louse numbers between sides on each goat (see section 3.1). For each side, the number of *Bovicola* spp in each region was converted to a percentage of the number of that genera in all 13 regions on the corresponding side of each goat. The percentages were transformed using the arcsine transformation (Sokal & Rohlf, 1981) and then compared between sides by X^2 for each goat. A correlation coefficient (r) was obtained for the transformed percentages of *Bovicola* spp in each region between the left and right sides of each goat. There was no significant difference between the percentage of lice

Fig. 6: Penile stylets of *Bovicola caprae*.

Fig. 7: Penile stylets of *Bovicola limbatus*.





on the left and right sides of each goat, and the two sides were significantly correlated (see section 3.1). The data were therefore pooled for each goat, and the transformed percentages of *Bovicola* spp in each region analysed using ANOVA to determine an overall pattern of louse distribution.

Numbers of *Linognathus stenopsis* in the 520 samples were analysed (after logarithmic transformation) using ANOVA for differences between goats or regions, and for an interaction effect. The number of *L. stenopsis* on most goats was too small to permit X^2 comparisons for each region between left and right sides; a comparison of the total counts of *L. stenopsis* on each side of each goat was therefore performed.

The numbers of *L. stenopsis* in the pooled samples of each region were converted to a percentage of the total number of *L. stenopsis* contained in all the samples obtained at post-mortem for each individual goat. The percentages were then ranked for each goat, and compared by Friedman's two-way ANOVA by ranks for differences in louse numbers between regions.

A correlation between the numbers of *Bovicola* spp and *L. stenopsis* in each region was determined for each goat. The correlation between the number of *Bovicola* spp and *L. stenopsis* over all goats was also determined for each individual region. The density of lice (D) per cm^2 was determined for each goat by dividing the total number of lice (*Bovicola* spp or *L. stenopsis*) obtained at post-mortem (N) by 26 (regions) and 25 (5x5 cm sample), i.e. $D = Nx(26x25)^{-1}$.

The number of *Bovicola* spp counted in twenty-six 5 cm hair partings on each goat was correlated with the counts of these lice in 5x5 cm squares at post-mortem, and a regression analysis was carried out. A square root transformation was performed on the data from the post-mortem counts (Sokal &

Rohlf, 1981).

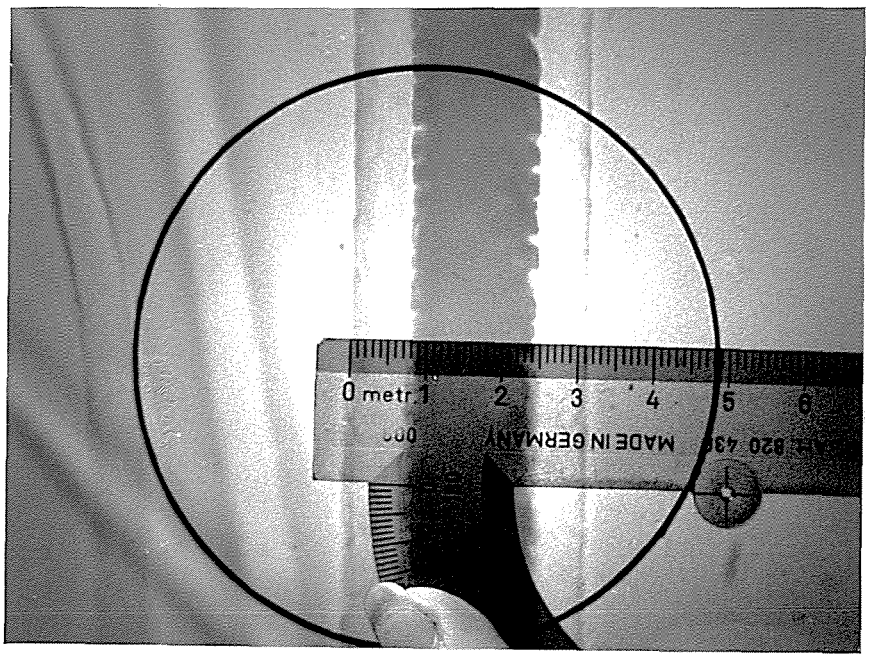
2.3 Fibre diameter measurement to obtain an estimate of fibre density

Fibres were measured and then classified into primary and secondary fibre types. A secondary to primary ratio (SP ratio) was used as an estimate of fibre density. A random sample of hairs was taken from most containers and a 1-2 mm snippet of hair cut from the growing end of the fibres (i.e., the end which had been cut from the skin). This subsample was prepared for measurement of fibre diameter on a Visopan (Reichert) projection microscope following the standard set down by the International Wool Testing Organisation (1952a, b). Hairs were spread in paraffin oil under a coverslip on a microscope slide and diameters measured at x500 magnification. Measurements were in units of 4 microns (0-4, >4-8, >8-12, *etc*). The sample was traversed from left to right and only hairs leaning towards the right of the slide were measured to prevent any hair from being recorded twice. Diameters of at least 150 hairs were measured per sample.

Most, but not all, primary fibres have a visible medulla (Fig. 8), (absent in secondary fibres, Fig. 9), so it was not always possible to separate the fibres on the basis of medullation. The diameter-frequency distribution was bimodal for all samples, with primary fibres being larger; a typical distribution is shown in Fig. 10. The separation between primary and secondary fibres was arbitrarily chosen as the point at which the frequency began to increase again after the first peak (i.e. at >36-40 micron in Fig. 10). The separation point therefore varied between samples. In some samples there was no continuity between the diameters of primary and secondary fibres at all.

Fig. 8: Medullated primary fibre being measured on the Visopan projection microscope. Diameter of fibre is 62 microns. The white 'Becke' line on the right edge of the hair shows that it is focussed correctly. Fibres are only measured within the 8 cm circle on the screen. Photo by R. Fordham.

Fig. 9: Secondary fibre showing lack of medullation. Diameter of fibre is 16 microns. Small diameter fibres do not have a 'Becke' line because both sides of the hair can be in focus at the same time. Photo by R. Fordham.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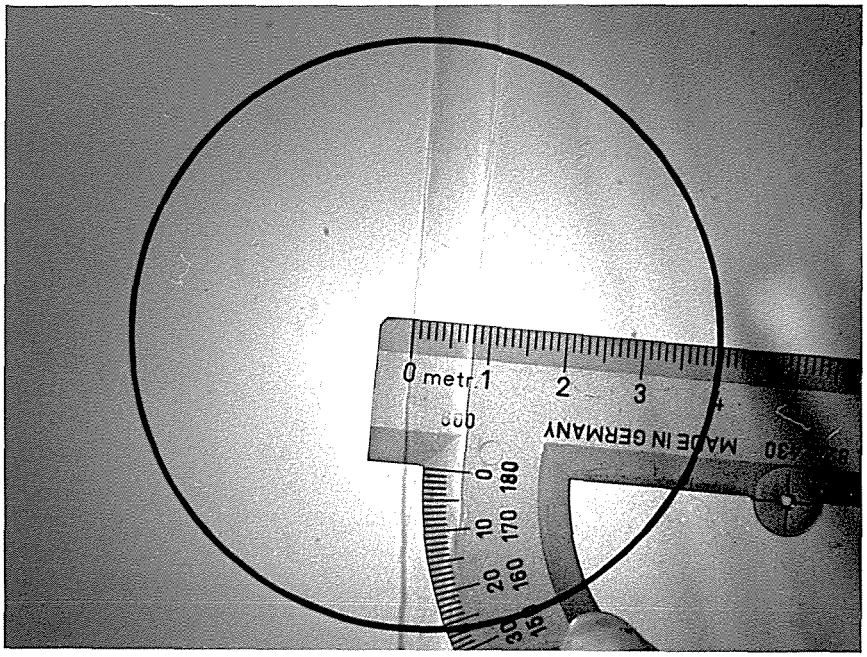
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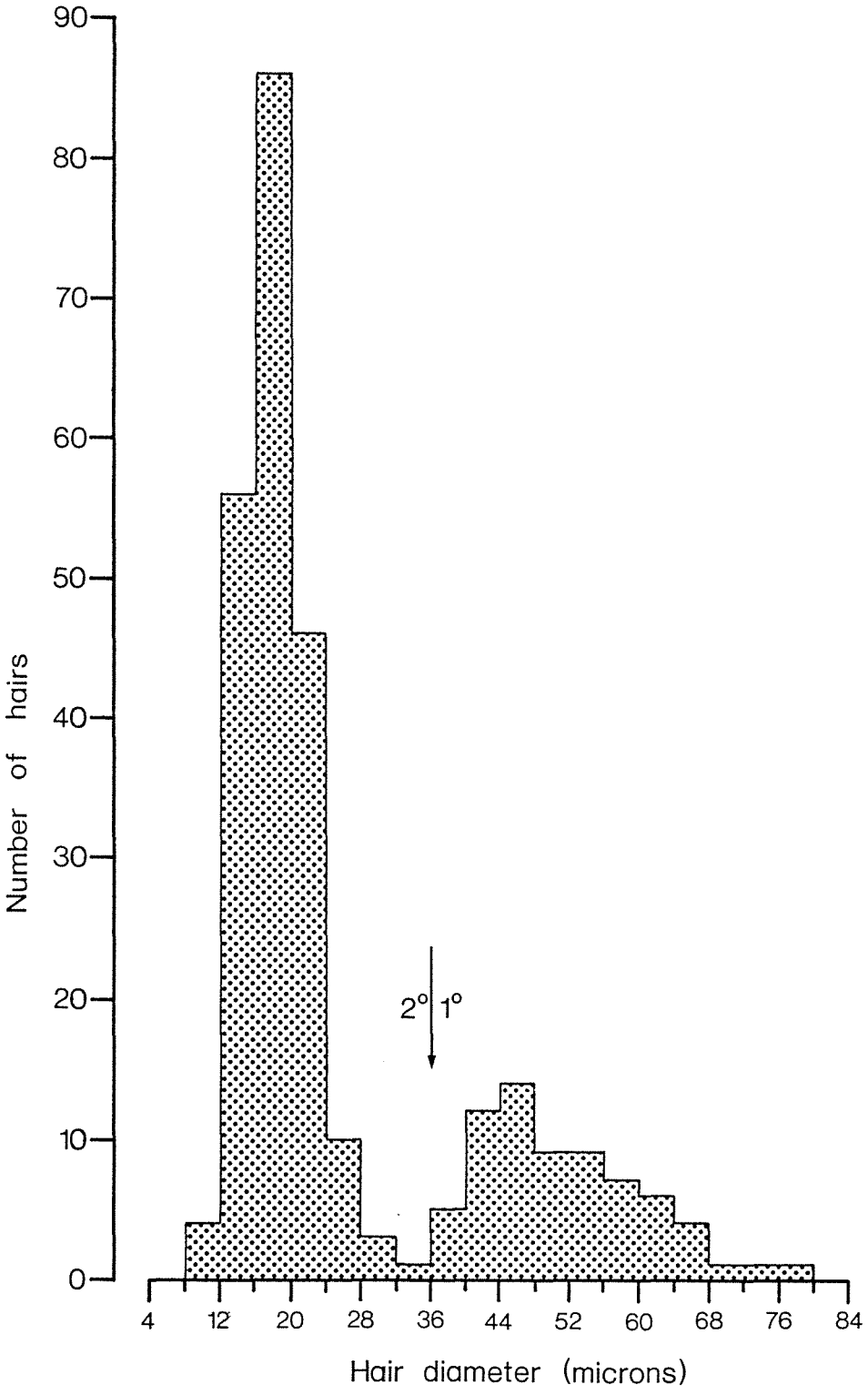


Fig. 10: Typical bimodal frequency distribution of fibre diameters for one region on a goat. The separation between primary (1°) and secondary (2°) fibres was taken as the point where the frequency began to increase again after the first peak.

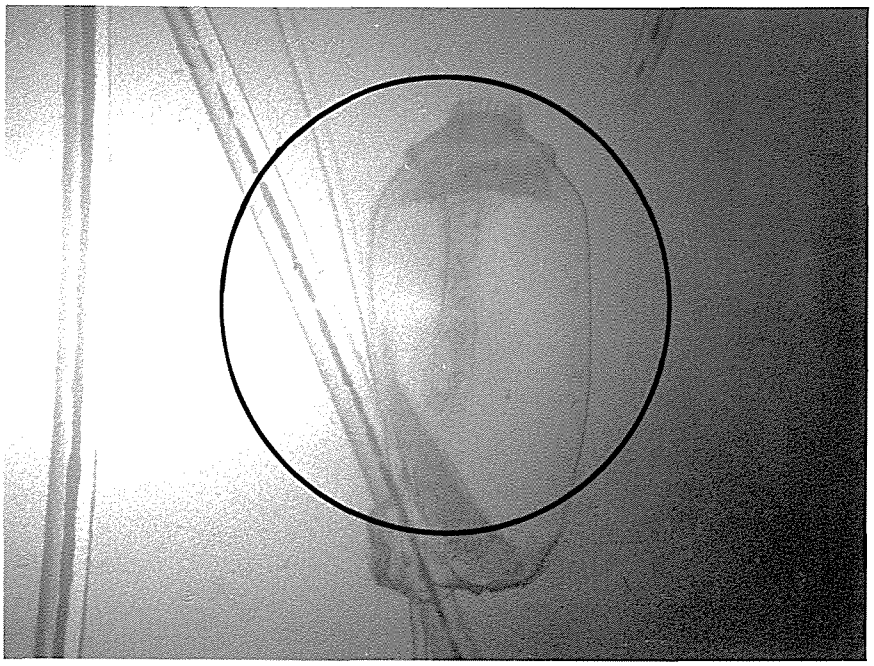
The SP ratios (see section 3.2) were analysed using ANOVA to test for differences between goats and between regions. It was not possible to test for an interaction effect because replicate data were not always available. Data from the left and right sides were pooled where available. Correlations between the mean and total SP ratios for each region, and between the mean SP ratio and the SP ratio for the midside patch for each goat were determined. The number of *Bovicola* spp or *L. stenopsis* was also correlated with the SP ratio for the midside patch. Regression analysis was performed for the significantly correlated variables. A X^2 analysis also compared the mean and total SP ratios between goats and between regions.

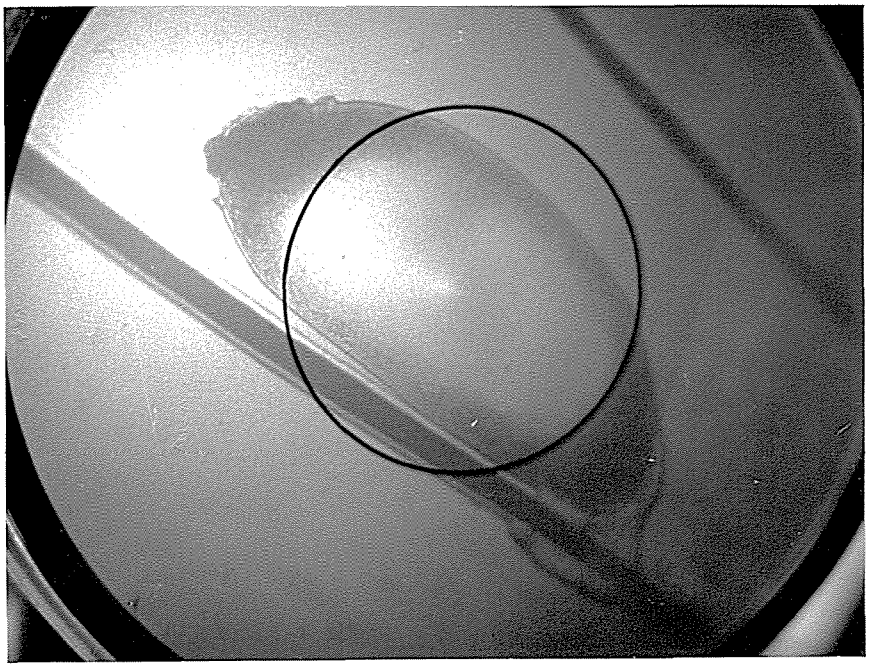
2.4 Diameter of hairs with eggs attached

The diameter of hairs with eggs attached was examined to determine the preferred diameter of fibres used for oviposition. Up to 30 louse eggs attached to hairs were removed at random from each of 8-13 samples from the right side of each goat. The hairs were prepared for measurement of diameters as described above. Hairs were measured at the base of the cement attaching the egg to the hair. For eggs which were attached to more than one hair, the individual diameter of each hair was recorded. When an egg was attached to 2, 3 or 4 hairs the diameter of the two largest hairs was summed to obtain a single figure for comparisons of fibre diameter. The eggs of *Bovicola caprae* and *B. limbatus* could not be distinguished from each other. The eggs of *Bovicola* spp and *Linognathus stenopsis* were separated on the basis of their size, the shape of the egg and operculum, and the shape and smoothness of the cement attachment (Figs 11 & 12). No differentiation was made between hatched, unhatched and sterile eggs. Not all eggs were able to be distinguished, and only those eggs which were identified to genera were

Fig. 11: Egg of *Bovicola* spp attached to two hairs. Note the shape of the egg, the operculum and the cement attachment. Length of egg = 0.9 mm. Photo by R. Fordham.

Fig. 12: Egg of *Linognathus stenopsis*. Note the shape of the egg, the operculum and the smooth cement attachment. Length of egg = 1.3 mm. Photo by R. Fordham.





included in the analysis. A *t*-test was used to compare the mean diameter of fibres used for oviposition by *Bovicola* spp and *L. stenopsis*, and to compare the mean diameters of single and multiple fibres used for oviposition by each genus. Correlations between the percentages of eggs of *Bovicola* spp and *L. stenopsis*, between the percentages of eggs and females of each respective genus, and between the percentage of eggs and mean SP ratios in each region were calculated. Regression analysis was performed on the significant correlations.

2.5 Distribution and abundance of lice under controlled ambient temperatures

As a winter build-up in louse populations has been noted (see section 1.4.3), an experiment was conducted to examine the effect of ambient temperature on louse numbers.

2.5.1 Experimental procedure

Six G-4 Saanen×Angora six-month-old wether goats were obtained; only six animals were examined due to a shortage of space in the controlled temperature rooms. They had been drenched with IVOMEC on 25 January 1987. On 26 January, they were transported to the Animal Physiology Unit at Massey University and separated into two groups. Goats of similar size and hair characteristics were paired, and one of each pair randomly allocated to a different group. Each group of three goats was kept in a room which had been light-proofed with black polythene, and experienced a 12:12 light:dark cycle from two 1.6 m cool white fluorescent tubes. The thermostats were adjusted so that the cool-room goats (CRG) were exposed to temperatures of 15 $\pm$ 2°C and the warm-room goats (WRG) were exposed to 25 $\pm$ 2°C; ambient temperatures were recorded on maximum-minimum thermometers near the goats. On 19 February, the cool-room temperature was lowered to 10 $\pm$

2°C for the remaining 20 weeks of the experiment. These temperatures were chosen to approximate to winter and summer mean temperatures experienced in the Manawatu (Gerlach, 1974).

The goats were housed in adjoining 1.25 x 0.95 x 0.95 m wire mesh cages 0.5 m above the floor (Fig. 13) and held by a dog-collar with one chain attached to each front corner to prevent escape. Unfortunately, it was not possible to prevent self-grooming with these chains which had to be long enough to enable the goats to feed. The cages were separated with 3 mm thick clear perspex to prevent physical contact between the goats but still enable them to see each other. Food bins were suspended from the front of each cage, and the goats were fed every second day with 1.5 kg of lucerne chaff with *ca.* 2 g mineral supplement (59% NaCl, 37% Na_2SO_4, 4% $NaMoO_4$) added to prevent copper poisoning. Once the goats were infested with lice, food bins with higher sides were used to prevent physical contact when feeding. The rooms were washed down and fresh water given to each goat at every feeding. The goats were acclimated to their environments for about six weeks prior to infesting with lice. Liveweights were measured every 2-3 weeks and a health check was made by a veterinary surgeon on three occasions during the 5.5 months of the experiment. Internal temperatures and respiratory rates were recorded at these times. A course of 5 cc of STREPTOPEN* was given daily to each CRG from 29 April to 4 May as two animals (CRG 1 and CRG 2) had a slight noise in their lungs related to respiratory problems. This condition cleared under the treatment.

2.5.2 Examination and infestation with lice

On 18 February, all six goats were examined as described in section 2.1, and no lice were found. When they were re-

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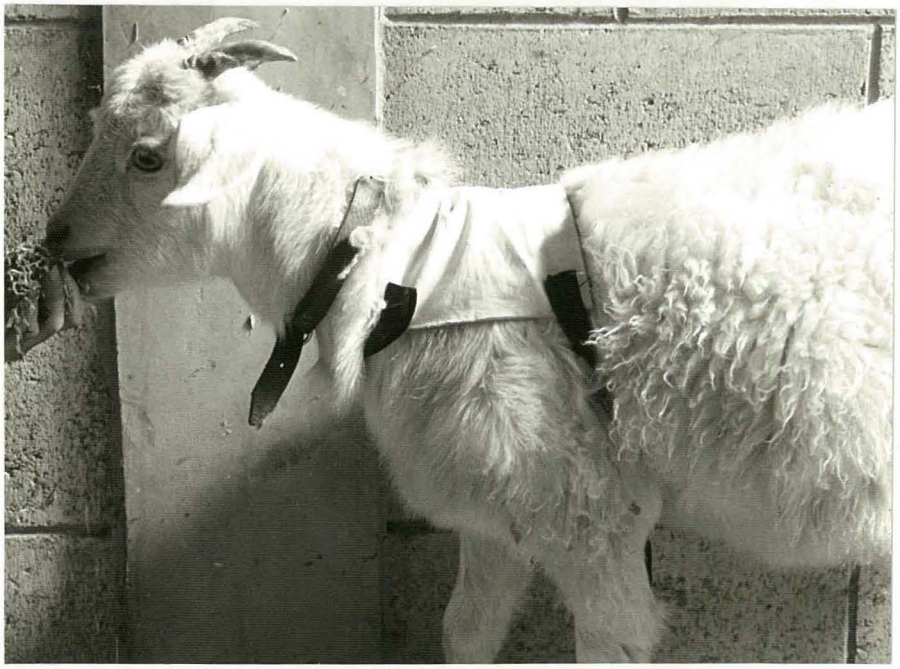
* STREPTOPEN ® Glaxo Animal Health (N.Z.) Ltd.

Fig. 13: Cages used to house the experimental goats. Food bins with higher sides were used once the goats were infested with lice, and clear perspex placed between the adjoining cages to prevent physical contact between the goats. Photo by R. Fordham.

Fig. 14: Calico saddle placed on the experimental goats after their artificial infestation with 240 *Bovicola* spp each. Photo by R. Fordham.



examined on 10 March, two CRG and one WRG were found to have *Bovicola* spp. These could not be identified to species as only female lice were found. However, no lice were found on the remaining three goats. All six goats were re-examined on 12-13 March to attempt to quantify louse numbers prior to the artificial infestation.

Lice were collected on 13 March from domesticated 'feral' goats at the D.S.I.R. (Grasslands Division) 'Ballantrae' farm, Woodville, by cutting off hairs with *Bovicola* spp attached and placing them in a plastic bag. Live lice were sorted under a dissection microscope and randomly assigned to one of six groups, each comprising 200 female and 40 male lice. Each group of 240 lice was placed on a goat at the back of the neck. The lice were placed on gauze under a calico saddle which was tied onto the goat by straps around the neck and behind the forelegs (Fig. 14). This was removed five days later and examined for lice adhering to the gauze. If any were found, they were transferred to hair on the goat's neck. Because two goats resisted their initial infestations, each was re-inoculated with 240 lice on 7 April, and again on 23 May. Excess lice and hairs from the first and second collection days were digested in KOH (Palma, 1978) and the males identified, to determine the proportional representation of each *Bovicola* species. The louse populations present on each goat were determined weekly by counting them in twenty-six 5 cm fleece partings (Kettle & Pearce, 1974) for 18 weeks until 9 July. For unavoidable reasons the louse counts were made by several people from 1 May to 12 June 1987, but from 16 March to 24 April, and from 19 June to 9 July the counting was done by the author.

Skin temperatures were measured in several body regions on the torso of each goat over 4 days using a hand-held digital thermometer or a mercury thermometer held for 30 s against the skin and covered with hair. Not all regions were

measured on all goats each time due to thermometer problems. A subjective assessment of skin scurf abundance was made for each goat on 26 June.

On 10 July, the goats were killed with sodium pentobarbitone, skinned, and the populations of lice on each sampled as follows. Twenty-six hair and skin samples were collected from each goat as described previously (section 2.1). On this occasion, each skin was sampled before the next one was removed from the goat, and the left-over skin was then placed in a labelled plastic bag and frozen. Louse counts and measurements of hair diameter were made as described in sections 2.2 and 2.3. Similar analyses were performed.

2.5.3 SP ratios of goats in the controlled temperature rooms

The secondary to primary hair ratios (SP ratios) were determined for the six saanen×angora goats by the same procedure as for the 20 feral×angora goats (see section 2.3). Two-way ANOVA was performed on these data to test for differences in SP ratios between goats and between regions. The numbers of *Bovicola* spp present on each of the three goats which maintained lice throughout the trial (see section 3.6.1) were correlated with SP ratios.

2.5.4 Estimation of grease and suint content of the fleece

Because of individual differences in louse infestations between the six experimental goats, the grease and suint (cold-water-soluble fraction, Daly & Carter, 1954) content of each fleece was determined to obtain information on the variability of these factors between goats.

The left-over skin was thawed, and patches of hair shaved from the midline and sides and mixed together. Duplicate samples of 2-4 g were weighed to 0.0001 g accuracy and placed

in a thimble in a refluxing tube. The grease content of each sample was extracted for 6 h in petroleum ether by soxhlet apparatus (Daly & Carter, 1954) and collected in oven-dried (at 65°C overnight) and weighed flasks. The flasks were oven-dried at 65°C overnight, cooled in a desiccator and re-weighed to 0.0001 g accuracy. The amount of fat present in the sample was recorded as a percentage of the weight of hair. Once the fat had been extracted, the hair was removed from the thimble, placed in a beaker and covered with distilled water. This sample was vigorously stirred with a glass rod, and the solution poured into an oven-dried (at 90°C for 3 h) and weighed Whatmans No. 1 filter paper. Washing was repeated until the solution was clear (at least 5 washings). The filter paper was then redried at 90°C for 3 h and weighed, and the suint and dirt retained on the filter paper recorded as a percentage of the original sample weight.

3 RESULTS

3.1 Louse numbers

3.1.1 *Bovicola* spp

The total number of *Bovicola* spp counted in the 26 regions on all goats at post-mortem was 85,741. There were 53,771 juvenile and 19,728 female *Bovicola* spp. The majority of the males were *B. caprae* (12,039); there were only 203 *B. limbatus* males (*ca.* 1.7% of all males). Because the proportion of *B. limbatus* males was so low relative to the number of *B. caprae* males and the total number of lice, the data were recombined and recorded as *Bovicola* spp males. The numbers of *Bovicola* spp in the 5x5 cm squares on the left and right sides of each goat were significantly different when compared by X^2. However, when the data were converted to percentages and transformed by arcsine, there was a significant correlation between the percentages of *Bovicola* spp in each region on the left and right sides of each goat, and the two sides did not differ significantly for each goat (Table 1).

The raw data were analysed using two-way ANOVA with replicates to examine differences in *Bovicola* numbers between goats, and between regions on individual goats, and to compare the pattern of distribution of lice between goats. The 20 goats differed significantly in their total louse numbers (Table 2, Fig. 15). There were significantly more lice in some regions on the goats' bodies than in others (F = 75.17, $p < 0.001$) (Table 3). However, there was a significant interaction between the number of lice on a goat and the number of lice in a region (F = 1.89, $p < 0.001$), implying that the numbers of lice in a given region altered depending on which goat was examined. An interaction effect

Table 1: Correlations, between the left and right sides, of the transformed percentages of *Bovicola* spp in the twenty-six 5x5 cm squares sampled at post-mortem on each of the 20 feral x angora goats. r = correlation coefficient, t = significance of r. X^2 values = comparison of the transformed percentages of *Bovicola* spp between the left and right sides of each goat; none are significant. (* - $p < 0.05$, ** - $p < 0.025$, *** - $p < 0.01$, **** - $p < 0.005$)

Goat No.	r	t (df=11)	X^2 (df=12)
7	0.679	3.068***	15.09
9	0.946	9.679****	4.07
11	0.588	2.411**	20.22
13	0.554	2.207*	16.02
23	0.763	3.915****	11.91
97	0.975	14.553****	2.09
98	0.720	3.441****	13.13
99	0.830	4.935****	6.26
100	0.585	2.392**	10.72
101	0.681	3.084***	12.83
102	0.561	2.248**	14.47
103	0.708	3.325****	10.67
104	0.535	2.100*	12.84
105	0.916	7.573****	4.14
106	0.621	2.628**	19.28
107	0.644	2.792***	20.38
108	0.704	3.288****	15.10
109	0.691	3.170****	10.09
110	0.758	3.854****	10.23
111	0.736	3.606****	7.36

Table 2: Number of *Bovicola* spp and *L. stenopsis* in 5x5 cm squares in all 26 regions on each of 20 feral x angora goats. The correlation between the numbers of *Bovicola* spp and *L. stenopsis* present in every region for each goat is shown (r). (* - $p < 0.05$, ** - $p < 0.01$)

Goat No.	*Bovicola* spp	*L. stenopsis*	r
7	889	97	- 0.257
9	2 492	83	- 0.009
11	229	272	0.052
13	3 135	86	0.138
23	1 604	111	- 0.072
97	884	40	0.006
98	2 345	0	-
99	3 285	4	0.148
100	3 920	33	0.342*
101	7 381	22	- 0.179
102	5 881	110	- 0.471**
103	5 960	511	0.011
104	10 055	101	- 0.230
105	5 061	304	- 0.196
106	3 478	1	- 0.113
107	5 102	8	- 0.312
108	1 394	27	0.166
109	5 776	95	- 0.205
110	2 598	2	0.150
111	14 272	386	- 0.145

Table 3: Total numbers of *Bovicola* spp and *L. stenopsis* in 5x5 cm squares in 13 regions on each of 20 feral×angora goats (R and L summed for each region). *r* shows the correlation between the numbers of each genus present in a particular region on each goat. Regions: W = withers, L = loin, S = shoulder, R = ribs, F = flank, Q = hindquarters, A = abdomen, C = chest, T = throat. 1 donates upper body region, 2 donates lower body region (see Fig. 1). (* - $p < 0.05$, ** - $p < 0.01$)

Region	*Bovicola* spp	*L. stenopsis*	*r*
W	11 582	77	0.174
L	8 456	29	0.447*
S1	10 736	233	0.297
S2	6 877	431	0.100
R1	12 410	188	0.071
R2	7 438	109	0.294
F1	8 115	125	0.173
F2	4 020	153	0.222
Q1	5 811	131	0.023
Q2	3 505	212	0.044
A	2 130	74	0.246
C	3 141	269	0.571**
T	1 520	262	0.349
Total	85 741	2 293	

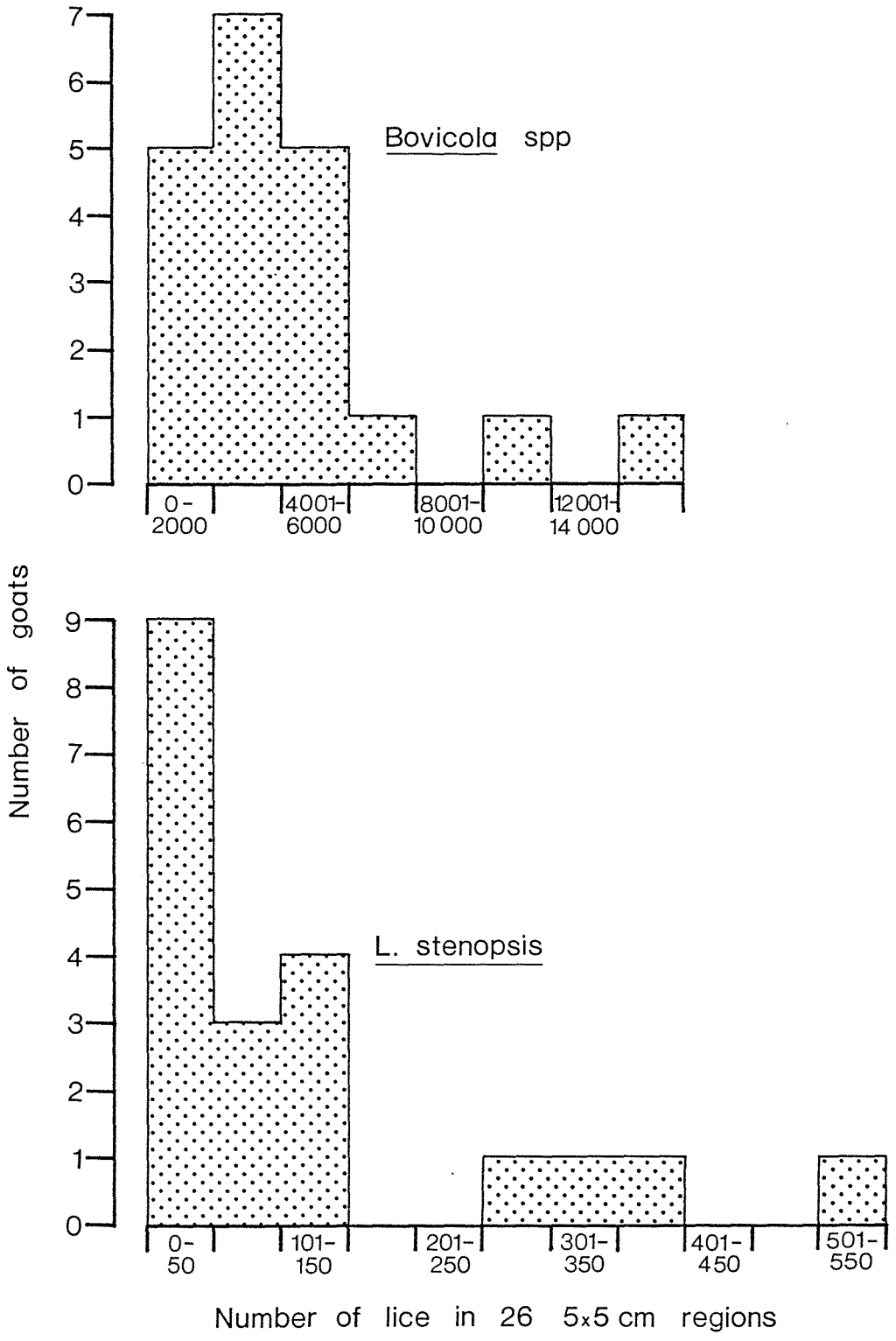


Fig. 15: Frequency histogram of the number of lice in all twenty-six 5x5 cm regions on the 20 feralxangora goats. Note the over-dispersed distribution pattern.

can also be caused by large differences between replicates (Sokal & Rohlf, 1981). As has been stated, the numbers of *Bovicola* spp in the replicates for each goat were significantly different, but the transformed percentages did not differ significantly. The numbers of lice on the left and right sides were pooled to obtain one count per region, in 13 regions for each goat, and converted to a percentage of the total number of lice counted on each goat (Table 4). All further analysis was performed on the pooled data, not the replicate samples, unless otherwise stated.

The percentages of *Bovicola* spp in each region (Table 4) were compared (after arcsine transformation) by two-way ANOVA without replication. As all goats had a common base (100%) it was possible to test for differences in the proportions of lice between regions, and these were found to be significantly different ($F = 40.52$, $p < 0.001$). The mean percentages of lice in each region are shown in Fig. 16. The observed pattern also reflects my intuitive feeling that some regions more frequently had higher proportions of *Bovicola* spp (the anterior dorsal regions), and others had lower proportions (the abdomen, chest and throat).

The mean density of *Bovicola* spp per cm^2 is given for each goat in Table 5. The female to male ratio (data combined for all 20 goats) was 1.612:1. The juvenile to adult ratio was 1.682:1.

3.1.2 *Linognathus stenopsis*

The log-transformed louse counts for *L. stenopsis* for all 26 regions on each of the 20 goats were analysed using two-way ANOVA with replicates for differences between goats, between regions on an individual goat, and for the distribution of lice on a goat's body. The populations of *Linognathus stenopsis* differed significantly between goats (Table 2).

Table 4: Number of *Bovicola* spp in thirteen 5x5 cm regions (data for left and right sides pooled) as a percentage of the total number of *Bovicola* spp on each of the 20 feral×angora goats at post-mortem. Regions as defined in Table 3. *N* = total number of *Bovicola* spp counted on each goat.

Goat No.	Region						
	W	L	S1	S2	R1	R2	L1
7	23.7	15.1	5.7	1.5	10.2	7.1	15.2
9	16.8	14.8	18.6	6.5	14.3	3.9	10.6
11	16.6	12.7	7.9	3.9	31.4	7.9	10.0
13	17.9	7.9	11.0	6.7	17.6	5.0	10.3
23	19.5	14.5	15.3	5.5	18.3	5.0	10.0
97	2.0	5.4	14.9	21.7	15.7	5.1	13.3
98	12.5	3.5	17.9	8.6	20.6	8.8	11.2
99	8.2	12.1	8.3	8.9	15.0	5.6	9.8
100	12.7	5.6	10.7	7.4	14.5	5.6	10.9
101	23.1	12.8	15.0	3.4	11.5	11.1	7.5
102	15.2	20.0	11.6	3.5	9.9	3.3	11.3
103	16.2	13.4	11.0	7.8	18.6	8.2	8.7
104	8.5	4.6	9.0	11.3	17.4	16.1	6.9
105	19.8	11.6	16.2	4.5	15.0	6.2	11.6
106	10.2	3.9	15.8	7.2	14.5	3.0	12.3
107	14.8	16.1	10.5	9.7	13.2	14.8	10.8
108	6.0	18.1	7.0	10.4	12.6	2.8	17.4
109	18.9	9.4	12.7	4.8	11.6	6.5	9.7
110	11.2	5.5	15.7	10.4	15.0	7.9	9.8
111	6.8	6.6	13.3	11.8	13.2	10.1	7.2

Table 4 ctd.

Region						
F2	Q1	Q2	A	C	T	*N*
6.9	5.4	1.8	4.4	1.6	1.5	889
2.1	9.3	0.6	0.4	1.3	1.0	2492
1.7	3.1	0.9	0	2.2	1.7	229
4.7	9.4	2.1	2.2	3.0	2.2	3135
2.2	5.9	0.7	0.4	1.3	1.4	1604
5.3	2.8	0.8	2.4	9.4	1.0	884
2.9	4.3	1.2	1.5	4.4	2.6	2345
10.2	10.7	8.1	1.7	1.1	0.4	3285
5.3	7.4	3.1	3.7	5.9	7.3	3920
1.7	4.9	4.3	1.7	2.1	0.9	7381
6.7	9.3	3.5	2.0	2.9	0.9	5881
4.2	6.4	1.5	1.9	1.5	0.6	5960
8.9	5.8	5.7	2.6	1.6	1.7	10055
4.1	4.5	1.7	2.4	1.8	0.6	5061
5.4	11.6	2.0	1.7	8.7	3.7	3478
2.0	2.9	0.7	2.5	1.4	0.7	5102
1.6	16.5	1.8	1.2	3.5	1.1	1394
5.9	5.0	4.2	3.9	3.1	4.2	5776
4.0	7.4	3.8	2.0	5.5	1.7	2598
3.0	7.1	8.7	3.7	7.1	1.4	14272

Table 5: Mean density of *Bovicola* spp on the 20 feral x angora and six saanen x angora goats, and mean density of *Linognathus stenopsis* on the 20 feral x angora goats, counted in all twenty-six 5x5 cm regions at post-mortem. $D = Nx(26x25)^{-1}$ where D = density of lice and N = total number of lice in 26 samples from each goat. CRG = cool-room goat, WRG = warm-room goat (for six saanen x angora goats).

Goat	*Bovicola* spp	*L.stenopsis*	Goat	*Bovicola* spp
7	1.37	0.15	CRG 1	0
9	3.83	0.13	CRG 2	0.008
11	0.35	0.42	CRG 3	4.18
13	4.82	0.13	WRG 1	8.14
23	2.47	0.17	WRG 2	0
97	1.36	0.06	WRG 3	0.70
98	3.61	0		
99	5.05	0.006		
100	6.03	0.05		
101	11.36	0.03		
102	9.05	0.17		
103	9.17	0.79		
104	15.47	0.16		
105	7.79	0.47		
106	5.35	0.002		
107	7.85	0.01		
108	2.14	0.04		
109	8.89	0.15		
110	4.00	0.003		
111	21.96	0.59		

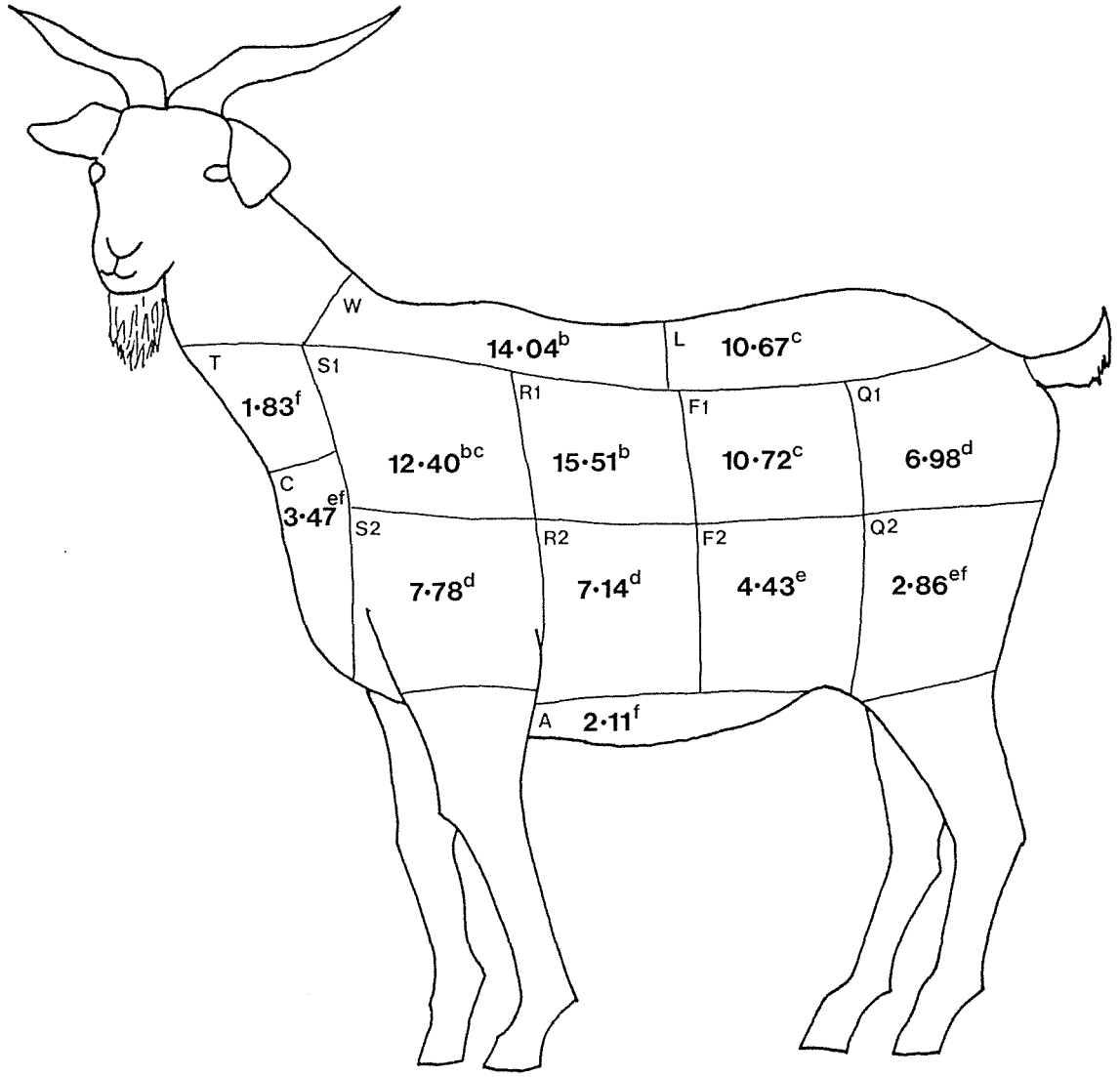


Fig. 16: Number of *Bovicola* spp in thirteen 5x5 cm regions (left and right sides pooled) as a percentage of the total number of lice on each goat. Values are the mean percentages in each region for the 20 feral×angora goats. Means with the same superscript are not significantly different. Regions as defined in Table 3.

Linognathus stenopsis was not uniformly distributed over the goats' bodies (F = 21.15, p <0.001) (Table 3) and there was a significant interaction between the numbers of lice in a region and the number of lice on a goat (F = 2.78, p < 0.001). Therefore, the numbers of lice on a goat and in a region were not independent, and it was not possible to determine a relative distribution of *L. stenopsis* on a goat. However, because there were low numbers of *L. stenopsis* on all goats, it was not possible to analyse their distribution more fully for individual goats. The replicate counts of *L. stenopsis* in each region for all goats were combined to obtain a mean for each region (Fig. 17). *Linognathus stenopsis* appeared to be more common in the anterior ventral regions of throat, chest and shoulders, with the lowest numbers on the abdomen and along the backline.

It was also not possible to analyse the louse counts of each side by region individually for each goat. The counts on each side were summed, and the sums compared by X^2 between goats. There was no significant difference between the total counts of *L. stenopsis* for the right and left sides for each goat (X^2 = 0.092, p > 0.05), accordingly left and right side counts for each region of each goat were pooled to obtain counts for 13 regions.

The numbers of *L. stenopsis* in the thirteen 5x5 cm regions were converted to a percentage of the total number of lice on each of 19 feral$_x$angora goats at post-mortem (Table 6). Goat 98 had no *L. stenopsis* and was excluded from the analysis. Friedman's two-way ANOVA by ranks (X_F^2) on the pooled data from 15 goats also showed that there were highly significant differences in the proportions of *L. stenopsis* present in each region (X_F^2 = 689.09, p < 0.001). Five goats (goats 98, 99, 106, 107 and 110) were removed from the analysis of X_F^2 as they had <10 *L. stenopsis* in the 26 body regions sampled.

Table 6: Number of *Linognathus stenopsis* in thirteen 5x5 cm regions (data from left and right sides pooled) as a percentage of the total number of *L. stenopsis* on each of the 19 feral×angora goats at post-mortem. (No *L. stenopsis* were present on goat 98.) Regions as defined in Table 3. *N* = total number of *L. stenopsis* counted on each goat.

Goat No.	Region						
	W	L	S1	S2	R1	R2	F1
7	1.0	1.0	9.3	47.4	9.3	4.1	5.2
9	1.2	1.2	7.2	44.6	2.4	7.2	4.8
11	5.5	0.7	15.4	22.8	13.2	2.9	3.3
13	0	3.5	7.0	17.4	10.5	5.8	12.8
23	0.9	0	14.4	33.3	3.6	3.6	3.6
97	2.5	0	10.0	15.0	2.5	5.0	7.5
99	25.0	0	0	0	0	25.0	25.0
100	6.1	0	6.1	3.0	33.3	6.1	0
101	4.5	4.5	9.1	18.2	13.6	0	0
102	0	1.8	3.6	12.7	1.8	3.6	0.9
103	3.5	2.0	9.0	17.6	9.2	6.7	8.8
104	0	0	5.9	15.8	0	9.9	4.0
105	3.3	1.0	12.8	11.2	8.2	2.0	5.9
106	0	0	0	0	0	0	0
107	0	0	0	0	0	12.5	0
108	11.1	0	14.8	14.8	11.1	7.4	14.8
109	3.2	1.1	4.2	18.9	9.5	7.4	5.3
110	0	0	0	0	50.0	0	0
111	5.2	1.3	11.1	12.2	6.7	3.4	2.8

Table 6 ctd.

Region						
F2	Q1	Q2	A	C	T	*N*
2.1	2.1	1.0	3.1	9.3	5.2	97
6.0	0	12.0	0	6.0	7.2	83
3.3	5.9	16.9	0.7	8.1	1.1	272
29.1	4.7	7.0	2.3	0	0	86
0.9	3.6	8.1	0.9	17.1	9.9	111
12.5	17.5	2.5	22.5	0	2.5	40
25.0	0	0	0	0	0	4
9.1	0	0	9.1	21.2	6.1	33
4.5	0	0	0	13.6	31.8	22
8.2	0.9	10.9	1.8	27.3	26.4	110
8.4	8.2	11.0	6.3	6.7	2.7	511
12.9	2.0	4.0	3.0	20.8	21.8	101
5.6	12.2	12.5	1.0	13.2	11.2	304
100.0	0	0	0	0	0	1
37.5	0	25.0	0	12.5	12.5	8
0	3.7	0	0	11.1	11.1	27
10.5	4.2	5.3	3.2	20.0	7.4	95
50.0	0	0	0	0	0	2
1.0	2.8	5.7	2.8	14.5	30.3	386

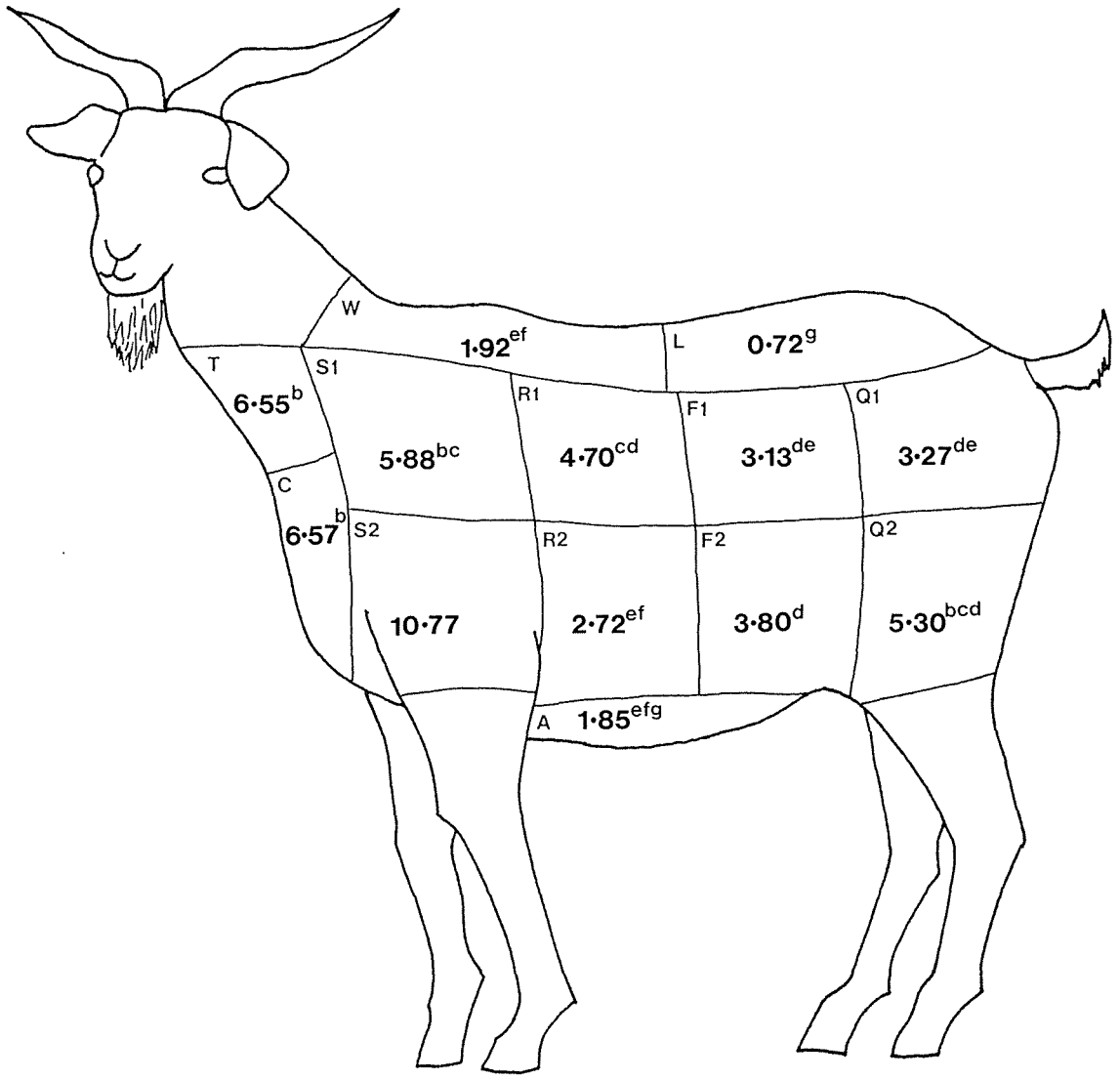


Fig. 17: Mean number of *Linognathus stenopsis* in thirteen 5x5 cm regions for the 20 feral$_x$angora goats (replicate samples for each region from each goat). Goat 98 was included for this analysis. Means with the same superscript are not significantly different. Regions as defined in Table 3.

The value '10' was chosen as an arbitrary cut-off point to represent a 'functional' lack of *L. stenopsis*. The mean density of *L. stenopsis* per cm^2 is given for each goat in Table 5. The female to male ratio was 1.311:1, and the proportion of juvenile to adult *L. stenopsis* was 1.244:1.

3.2 Interaction between *Bovicola* spp and *Linognathus stenopsis*

The counts of *Bovicola* spp and *L. stenopsis* in each region on individual goats were compared, but on only two goats was there a significant correlation (Table 2). A comparison of *Bovicola* spp and *L. stenopsis* numbers in each region across all 20 goats was also made but in only two instances was there a significant correlation (Table 3). There was a significant correlation between the total counts of *Bovicola* spp and *L. stenopsis* on each goat (r = 0.400, t = 1.85, $p <$ 0.05) but it was not significant when the five goats with <10 *L. stenopsis* were excluded (r = 0.378, $p >$ 0.05). The number of *Bovicola* spp was low (<1000 lice in the 26 regions) on three goats (goats 7, 11 and 97), and the number of *L. stenopsis* on all goats was low. There were more *Bovicola* spp than *L. stenopsis* on all goats except goat 11 which had low numbers of both. The 20 goats were again separated into two groups on the basis of total numbers of *L. stenopsis*. The total number of lice for each region was ranked for the 15 goats which had >10 *L. stenopsis* and the 5 goats with <10 *L. stenopsis* (goats 98, 99, 106, 107, 110). There was no significant difference in the distribution of *L. stenopsis* on goats with relatively high and relatively low densities, on the basis of ranks (X^2_F = 0.802, $p >$ 0.05), which suggests that the presence of *L. stenopsis* did not affect the distribution of *Bovicola* spp. Due to the low numbers of *L. stenopsis* on all goats it was not possible to do the reverse

comparison.

3.3 Fibre diameters of 20 feral x angora goats

3.3.1 Hair profiles and characteristics

The diameters of fibres were measured for most regions on all goats, and classified into secondary and primary fibre types on the basis of fibre diameter frequency distributions (see section 2.3, Fig. 10). The secondary to primary hair ratio (SP ratio) was determined for each region for which data were available (Table 7), and used as an estimate of fibre density such that the higher the SP ratio, the greater the density of fibres, and therefore, greater microhabitat stability. A high SP ratio could also indicate a lesser degree of cashmere shedding than a low ratio.

The means of SP ratios for each goat (SP_{xg}) and each region (SP_{xr}) are shown in Table 7. Total SP ratios were determined for each goat (SP_{tg}) and each region (SP_{tr}) by dividing the total number of secondary fibres measured, by the total number of primary fibres measured, on either each goat or region (Table 7). A ratio obtained from the total number of fibres measured should reduce the effect of extreme values within a row or column of Table 7, and provide a better index of the overall fibre characteristics of each goat. There was no significant difference between SP_x ratios and SP_t ratios for goats ($X^2 = 2.9$, $p > 0.05$) or regions ($X^2 = 2.0$, $p > 0.05$). SP_{xr} and SP_{tr} were highly correlated ($r = 0.967$, $t = 16.10$, $p < 0.005$) as were SP_{xg} and SP_{tg} ($r = 0.995$, $t = 33.04$, $p < 0.005$); therefore, either SP_x or SP_t could be used as an index of fibre density.

In the goat fibre industry, samples from the midside patch are used to estimate the quality of fibre produced by an

Table 7: Secondary (2°) to primary (1°) hair ratios (SP ratio) for most regions on each of 20 feral x angora goats. The tabulated figure is the number of 2° fibres to each 1° fibre. - = no sample. Mean SP ratios were calculated for each region on all goats (SP_{xr}), and for all regions on each goat

Goat No.	Regions						
	W	L	S1	S2	R1	R2	F1
7	2.48	6.29	6.07	8.81	3.95	4.31	5.45
9	2.44	3.26	6.46	3.41	3.67	3.99	3.45
11	3.03	2.92	4.73	3.12	4.56	4.65	4.89
13	1.72	3.45	5.06	4.73	4.22	3.29	5.06
23	3.49	2.66	2.55	2.95	4.12	2.91	4.07
97	2.09	2.31	3.45	3.38	2.92	2.33	2.49
98	2.30	2.20	3.04	3.41	2.84	3.81	3.88
99	4.90	7.90	5.92	4.12	6.77	5.07	4.20
100	2.59	2.77	4.20	2.77	4.35	4.41	3.80
101	2.36	2.77	2.81	4.29	2.12	2.91	2.84
102	3.98	3.19	3.41	-	2.88	3.86	4.54
103	2.14	2.62	1.54	-	2.87	2.13	-
104	2.38	4.26	4.80	5.26	7.03	4.42	7.51
105	2.81	3.57	3.10	2.99	2.74	2.62	3.53
106	2.57	2.20	1.69	3.77	2.64	2.76	3.89
107	1.74	2.24	-	3.32	-	-	2.88
108	1.12	2.19	2.16	2.35	1.77	1.68	1.73
109	2.98	2.68	2.54	2.17	3.75	3.75	2.65
110	3.72	3.30	3.08	3.32	2.98	2.17	2.20
111	2.12	3.15	3.52	5.53	3.12	4.80	4.37
SP_{xr}	2.65	3.30	3.69	3.87	3.62	3.47	3.86
SP_{tr}	2.61	3.00	3.39	3.50	3.56	3.39	3.67

Table 7 ctd.

(SP_{xg}). Total SP ratios (SP_{tr} and SP_{tg}) were obtained by dividing the total number of 2° hairs measured by the total number of 1° hairs measured for each row or column. Regions as defined in Table 3.

Regions							
F2	Q1	Q2	A	C	T	SP_{xg}	SP_{tg}
4.21	5.26	3.20	3.02	3.28	2.98	4.46	4.16
3.28	4.46	4.65	3.04	2.97	3.04	3.70	3.55
3.25	5.49	3.42	2.90	2.93	2.46	3.69	3.60
4.76	3.82	4.61	2.53	3.78	4.16	3.94	3.77
2.75	2.77	3.30	2.68	4.39	4.97	3.35	3.18
2.72	2.16	2.43	1.90	2.26	2.63	2.54	2.49
3.26	2.69	3.27	3.32	3.50	2.15	3.05	3.01
4.39	5.73	5.99	6.02	5.11	3.31	5.34	5.09
4.70	4.04	4.77	2.79	2.45	-	3.64	3.46
2.40	2.62	3.04	2.16	2.32	2.44	2.70	2.64
5.04	3.83	4.11	4.16	2.69	3.65	3.78	3.70
2.09	2.71	4.61	1.22	2.01	1.15	2.28	1.99
4.08	5.31	5.43	3.59	3.74	4.06	4.76	4.68
2.76	4.00	3.58	2.01	2.25	3.03	3.00	2.93
3.80	3.95	4.00	4.28	4.11	3.45	3.25	3.21
-	2.66	-	2.27	2.51	-	2.50	2.37
1.42	1.62	2.24	1.49	1.67	0.86	1.72	1.66
2.83	2.91	2.86	1.44	1.50	2.91	2.69	2.47
3.64	2.97	2.42	2.64	2.18	2.47	2.85	2.86
3.28	6.68	3.77	2.24	2.49	2.94	3.69	3.46
3.40	3.78	3.77	2.79	2.91	2.88		
3.27	3.53	3.71	2.60	2.88	2.78		

animal. The midside patch equates with regions R1R and R1L in this study. For all goats, the SP ratio for regions R1R and R1L combined (SP_m) (Table 8) was highly correlated with the SP_{xg} (Table 7) (r = 0.831), or SP_{tg} (r = 0.822) although SP_m and SP_{xg} differed significantly on each goat (X^2 = 128.7, $p < 0.005$). SP_{tg} also differed significantly from SP_m on each goat (X^2 = 136.5, $p < 0.005$). The regression equations for the SP ratios are SP_{xg} = 1.45 + 0.53 SP_m and SP_{tg} = 1.40 + 0.51 SP_m. However, an examination of the data (Table 7) shows no other regions have SP ratios that more consistently agree with SP_{xg} or SP_{tg} than region R1. To simplify the data and enable other workers to make comparisons with it, I will use the midside patch, and consequently SP_m, as a measure of the fibre characteristics of the 20 goats.

There was no correlation between SP_m and the number of *Bovicola* spp in the midside patch on each goat (r = 0.213), or the number of *L. stenopsis* in the midside patch on goats with >10 *L. stenopsis* in their 26 regions (r = -0.103). For *Bovicola* spp, the correlation between the number of lice in the midside patch and the mean fibre diameter of either primary or secondary hairs (Table 8) was poor (r = 0.101 and 0.033, respectively). There was also no significant correlation between the number of *L. stenopsis* in the midside patch (on those goats which had >10 *L. stenopsis* in their 26 regions) and the mean fibre diameters of primary (r = 0.195) or secondary fibres (r = 0.090).

3.4 Diameter and distribution of hairs with eggs attached

The diameter of hairs with eggs attached was determined when the eggs were attributable to either *Bovicola* spp or *L. stenopsis*. While eggs generally occurred on single hairs, they were sometimes found attached to bundles of hairs, which

Table 8: Secondary (2°) to primary (1°) hair ratio (SP_m) and mean fibre diameters (S.D. in brackets) for the mid-side patch (R1R and R1L), for each of the 20 feral$_x$angora goats. - = no sample.

Goat No.	SP_m (2°:1°)	Mean fibre diam. (microns) (mid-side) 1° only	2° only
7	3.95:1	46.5 (12.8)	17.4 (3.6)
9	3.67:1	56.9 (12.1)	13.2 (3.9)
11	4.56:1	62.0 (14.5)	21.2 (5.5)
13	4.22:1	56.6 (11.4)	16.9 (3.3)
23	4.12:1	56.6 (8.4)	18.0 (4.7)
97	2.92:1	61.5 (14.5)	18.0 (3.4)
98	2.84:1	58.5 (13.3)	19.2 (3.9)
99	6.77:1	62.6 (14.9)	19.7 (4.8)
100	4.35:1	52.2 (10.4)	20.2 (4.9)
101	2.12:1	61.7 (9.2)	20.2 (4.9)
102	2.88:1	56.6 (15.7)	17.7 (3.8)
103	2.87:1	72.5 (21.9)	16.0 (3.2)
104	7.03:1	60.7 (20.8)	21.1 (4.5)
105	2.74:1	66.1 (24.3)	23.4 (3.6)
106	2.64:1	56.4 (15.2)	17.5 (3.6)
107	-	-	-
108	1.77:1	55.1 (10.4)	20.1 (4.4)
109	3.75:1	76.5 (12.7)	17.1 (2.8)
110	2.98:1	59.3 (11.6)	22.2 (5.6)
111	3.12:1	44.8 (9.5)	17.7 (4.1)

were arranged in a uniform manner. Where eggs were attached to two hairs the louse's gonopods would have had to stretch around both. The hairs in bundles of three or four were always bound tightly together in a close-packed arrangement, such that a triangle or square shape, respectively, was formed. In bundles of two to four hairs, the diameters of the two largest hairs with eggs attached were summed to obtain an estimate of the diameter of fibre which the gonopods would have surrounded in order to attach the egg. For eggs attached to more than four hairs, several arrangements occurred depending on the relative size of each hair. It was therefore not possible to accurately estimate the diameter experienced by the lice of bundles of over four hairs.

3.4.1 Eggs of *Bovicola* spp

More eggs were cemented to single hairs (*ca.* 65%) than to multiple hairs (Fig. 18). The mean diameter of single hairs with eggs attached was 47.5 microns (S.D. = 11.0, n = 809) (Fig. 19). When an egg was attached to two hairs, the mean summed diameters of the two hairs was 49.0 (S.D. = 13.8, n = 305). Data for the sum of the diameters of the two largest hairs when eggs were attached to three or four hairs respectively gave mean diameters of 43.2 (S.D. = 10.4, n = 117) and 42.2 (S.D. = 11.4, n = 24). There was no significant difference in the diameter of hairs used for oviposition when the diameter of single hairs was compared with the combined diameters of two hairs with an egg attached (t = 1.761, $p > 0.05$), but there was a significant difference when compared with three hairs (t = 4.102, $p < 0.005$) or four hairs (t = 2.237, $p < 0.025$). However, there was no significant difference when the diameter of single hairs was compared with combined data for eggs attached to two, three or four hairs (t = 0.633, $p > 0.05$). The mean diameter of all multiple hair groups was 47.1 microns (S.D. = 13.2, n = 446).

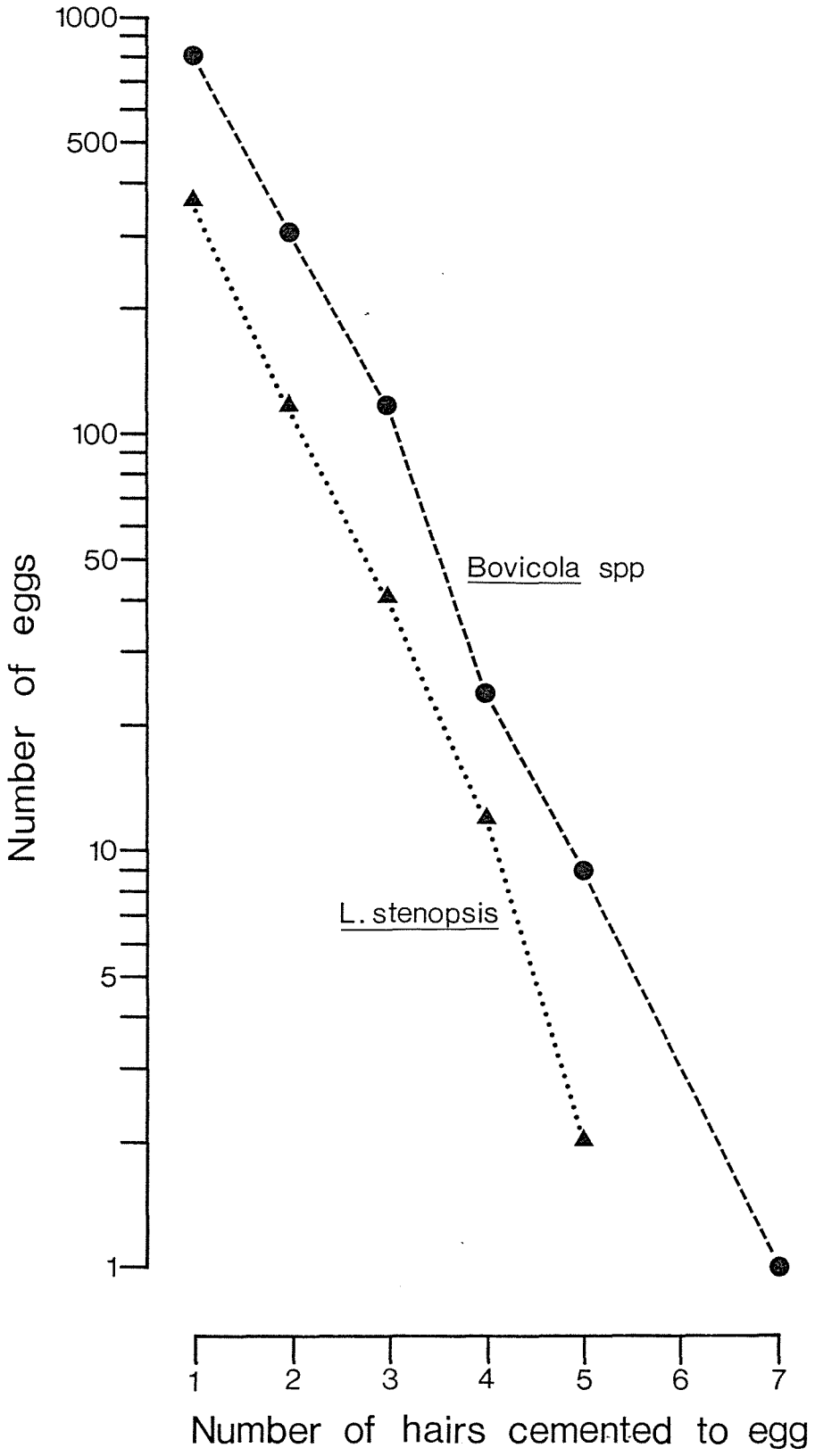


Fig. 18: Number of eggs which were laid by each genus on single hairs or on bundles of up to seven hairs on the 20 feral x angora goats.

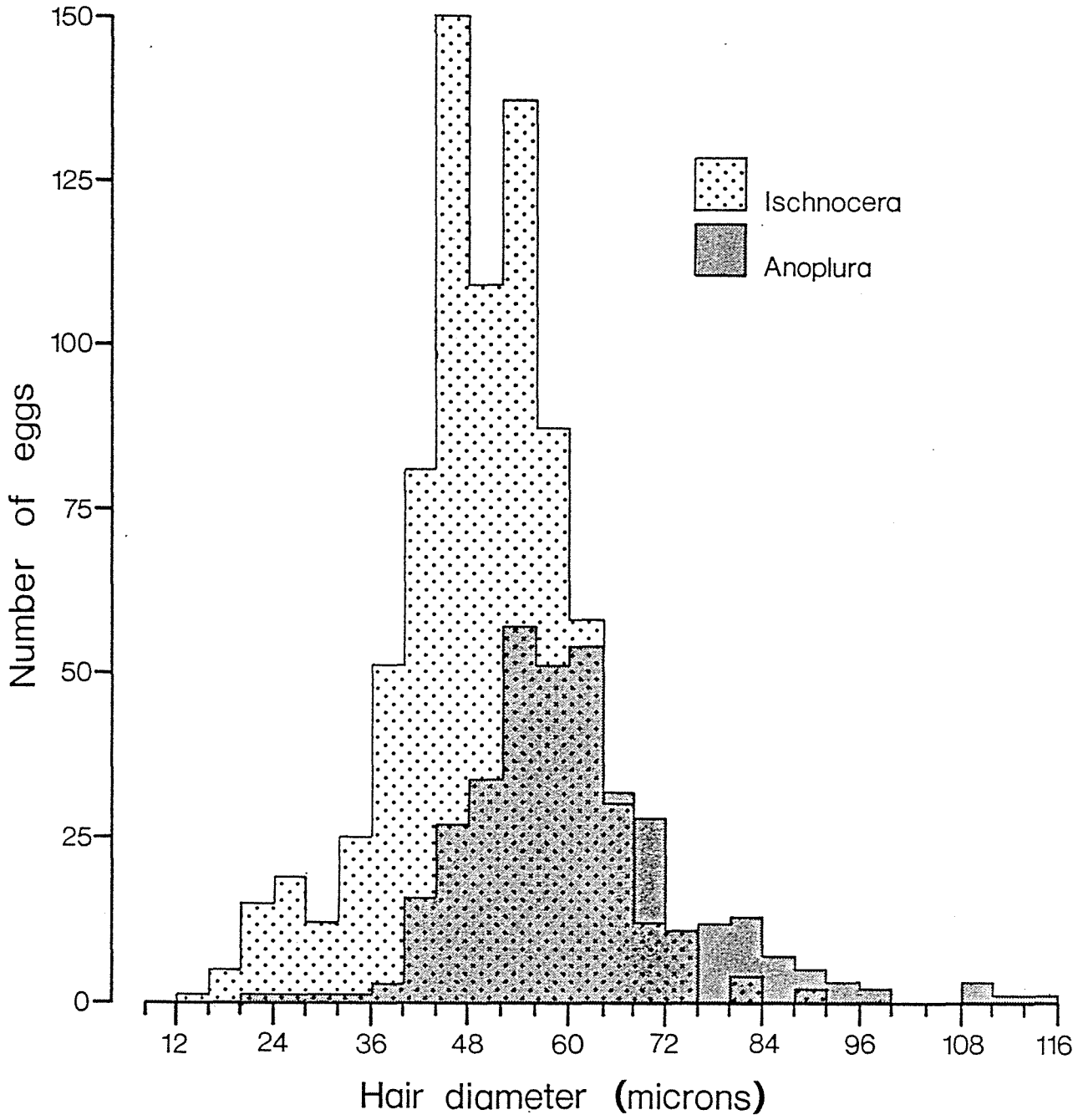


Fig. 19: Frequency histogram of the diameter of single hairs used for egg attachment on the 20 feral$_x$angora goats.

3.4.2 Eggs of *Linognathus stenopsis*

More eggs were cemented to single hairs (*ca.* 68%) than to multiple hairs (Fig. 18). The mean diameter of single fibres with eggs was 59.0 microns (S.D. = 13.6, n = 364) (Fig. 19). When an egg was cemented to two hairs, the mean sum of their fibre diameters was 70.0 (S.D. = 16.3, n = 117). Data for the sum of the diameters of the two largest hairs when eggs were attached to three or four hairs gave mean diameters of 69.6 (S.D. = 14.4, n = 41) and 57.3 (S.D. = 13.2, n = 12), respectively. There was a significant difference when the diameter of single hairs used for oviposition was compared with the diameter of two hairs (t = 6.595, $p < 0.005$), or three hairs (4.487, $p < 0.005$) used for oviposition. There was no significant difference between the diameter of single hairs and the diameter of four hairs used for oviposition (t = 0.437, $p > 0.05$). The mean diameter used for oviposition when the data for eggs cemented to two, three or four hairs was combined was 69.0 microns (S.D. = 15.9, n = 170). There was a significant difference in the mean fibre diameter between eggs cemented to single hairs and to multiple hairs (t = 7.11, $p < 0.005$).

3.4.3 Comparison of fibre diameters used for oviposition by *Bovicola* spp and *Linognathus stenopsis*

Linognathus stenopsis laid their eggs on fibres of a significantly greater diameter than *Bovicola* spp, when attached to single hairs (t = 14.23, $p < 0.001$, n = 1173) or two, three and four hairs (t = 16.11, $p < 0.001$, n = 616).

3.4.4 Regional differences in oviposition by *Bovicola* spp and *Linognathus stenopsis* corrected for louse numbers

The number of eggs identifiable to genus in the samples from each region on all goats was determined and converted to a percentage of the total number of identified eggs (Table 9).

Table 9: Total numbers of eggs and females identified to genus in each region as a percentage of the total number of identified eggs and total number of females in the 5x5 cm samples respectively. Regions as defined in Table 3.

Genus	Region													
	W	L	S1	S2	R1	R2	F1	F2	Q1	Q2	A	C	T	Total
Bovicola spp														
No. of eggs	88	103	105	87	130	104	151	127	151	51	61	21	6	1185
% of total eggs	7.43	8.69	8.86	7.34	10.97	8.78	12.74	10.72	12.74	4.30	5.15	1.77	0.51	100%
No. of females	1662	1770	1801	1798	2274	1821	2269	1603	1547	1278	884	643	376	19,726
% of total females	8.43	8.97	9.13	9.11	11.53	9.23	11.50	8.13	7.84	6.48	4.48	3.26	1.91	100%
Linognathus stenopsis														
No. of eggs	0	0	33	65	25	72	10	71	23	75	69	37	33	513
% of total eggs	0	0	6.43	12.67	4.87	14.04	1.95	13.84	4.48	14.62	13.45	7.21	6.43	100%
No. of females	27	9	59	123	65	33	34	52	51	90	29	74	78	724
% of total females	3.73	1.24	8.15	16.99	8.98	4.56	4.70	7.18	7.04	12.43	4.01	10.72	10.77	100%

Only data from those 15 goats which had >10 *L. stenopsis* in the 26 regions are included. There were significant differences between genera in the relative distribution of eggs between regions (X^2 = 51.4, $p < 0.005$), but no correlation between genera (r = -0.253). For example, more than 10% of *Bovicola* spp eggs were found in each of the regions of upper ribs (R1), flank (F1) and hindquarters (Q1), and lower flank (F2) (see Fig. 1), while regions each with more than 10% of the *L. stenopsis* eggs were the lower flank (F2), ribs (R2), hindquarters (Q2), and shoulder (S2), and the abdomen (A). The lowest percentages of eggs were laid in regions C (chest), T (throat), A and Q2 by *Bovicola* spp, and in regions W (withers), L (loin), R1, F1 and Q1 by *L. stenopsis*. There was a significant positive correlation (r = 0.602, t = 2.50, $p < 0.025$) between SP_{xr} (Table 7) and the percentage of the total identifiable eggs laid in each region by *Bovicola* spp (E) for all goats (Table 9). The relationship is best described by a linear regression ($E = -10.29 + 5.31\ SP_{xr}$) and thus there was a tendency for more eggs to be laid by *Bovicola* spp in regions with a higher SP ratio than in regions with a lower ratio. There was poor correlation between mean SP ratios and the percentage of *L. stenopsis* eggs laid in each region (r = 0.154).

The percentage of *Bovicola* spp females (B) and the percentage of eggs laid in each region (E) were significantly correlated (r = 0.707, t = 3.32, $p < 0.005$), and the linear regression equation relating the two is $E = -0.87 + 1.03\ B$. For *Bovicola* spp, there was also a significant correlation (r = 0.640, t = 2.76, $p < 0.01$) between the percentage of females (B) and SP_{xr} for each region; the linear regression equation relating the two is $SP_{xr} = 2.65 + 0.10\ B$. However, there was no significant correlation between the percentage of female *L. stenopsis* and the percentage of eggs laid in each region (r = 0.449, t = 1.67, $p > 0.05$) (Table 9).

3.5 Validation of the live sampling technique

The number of *Bovicola* spp counted in twenty-six 5 cm partings on each of the 20 feral×angora goats at the final live count (L) was compared with the counts (D) obtained from the samples collected at slaughter on the following day for each corresponding region (Fig. 20). A regression analysis was performed using a square root transformation on the raw data because counts frequently follow a Poisson distribution, and a square root transformation is used to normalise these data (Sokal & Rohlf, 1981). Other transformations (log-log and log-normal) were also performed, but the square root transformation produced a regression line with the most balanced residuals and the best correlation coefficient. The least squares regression equation relating L and D was $L = 1.703 + 0.878 \sqrt{D}$. There was a significant correlation between live and post-mortem counts ($r = 0.580$, $t = 16.20$, $p < 0.005$).

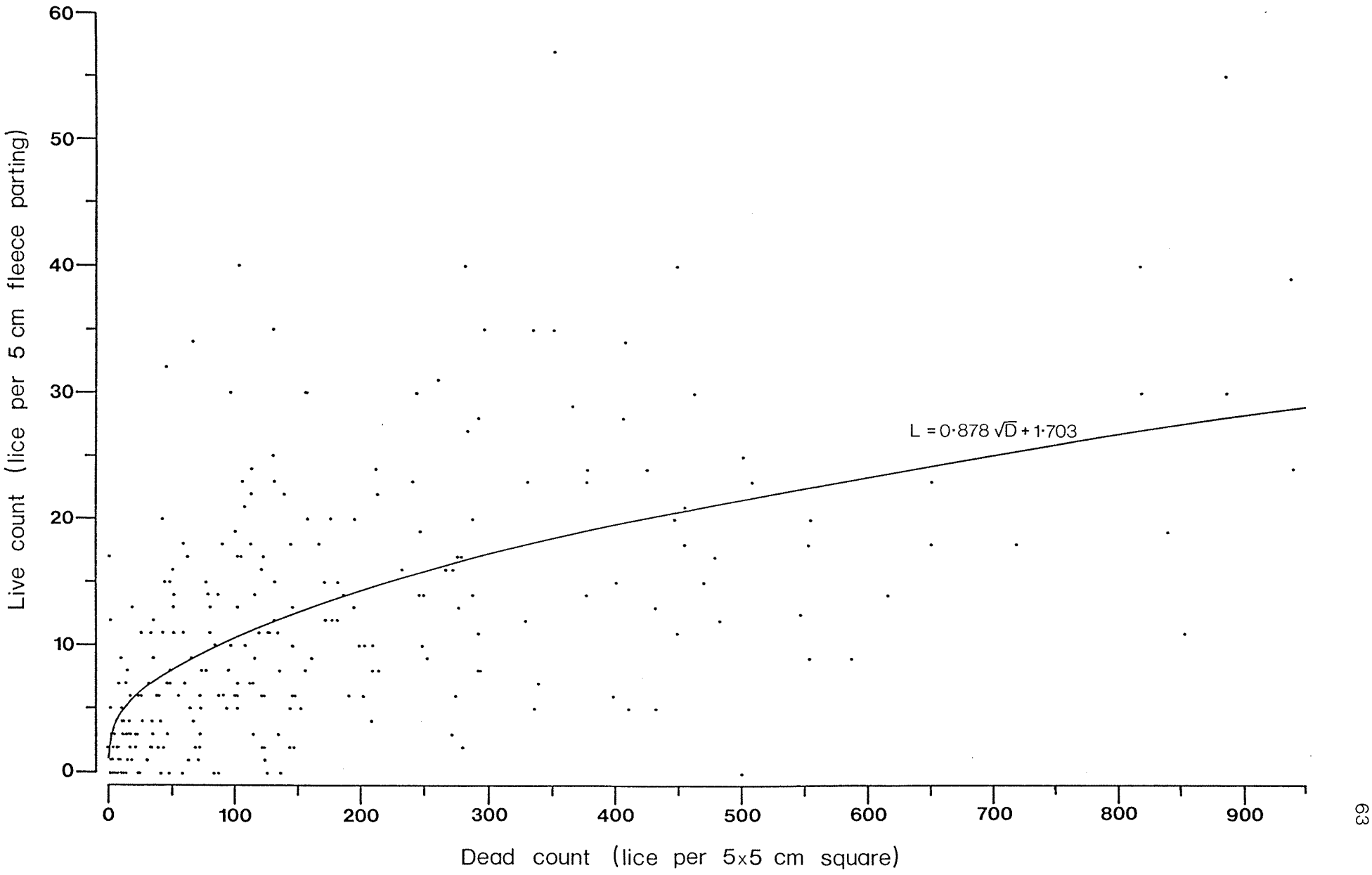
The correlation between the total number of lice in 13 regions counted by fleece partings and the total number of lice in 5x5 cm samples from the 26 regions at post-mortem was also significant ($r = 0.884$, $t = 8.02$, $p < 0.005$). As the live counts were less accurate and more open to sampling error than the dead counts, the linear regression equation ($\sqrt{L} = 4.57 + 0.16 \sqrt{0.5D}$) allows the level of louse populations on live hosts (L) to be predicted from post-mortem counts.

3.6 Distribution and abundance of lice under controlled temperatures

3.6.1 Louse population change

Two cool-room goats (CRG 2 and CRG 3) and one warm-room goat

Fig. 20: Comparison of *Bovicola* spp numbers determined by sampling similar regions on the fleece prior to (L) and after (D) death, for the 20 feral×angora goats. Curve is the line of best fit.


Live count (lice per 5 cm fleece parting)
60
50
40
30
20
10
0
L = 0·878 √D + 1·703
0
100
200
300
400
500
600
700
800
900
Dead count (lice per 5x5 cm square)

(WRG 1) were found to have a small number of *Bovicola* spp prior to the artificial infestation. Only females were found, so identification to species was not possible. No lice were discovered on the remaining three goats. Table 10 shows the number of lice counted on the goats prior to inoculating each with 200 female and 40 male lice on 14 March 1987. The successive counts of lice after inoculation are recorded in Table 11. Two goats (CRG 1 and WRG 2) were re-inoculated with lice on two occasions as noted in Table 11. The excess males from each collection of lice were identified to give an indication of the proportion of each species in the infestation population. On 13 March 1987, there were 68 *B. caprae* and 12 *B. limbatus* males remaining, and 49 *B.caprae* and 65 *B. limbatus* from the inoculation on 7 April. On 28 May, the inoculation contained 23 *B.caprae* males and no *B. limbatus*.

Table 10: Number of lice in 13 fleece partings (on one side only) on the six saanen×angora experimental goats prior to artificial infestation with lice on 14 March 1987. CRG = cool-room goat, WRG = warm-room goat.

Date	CRG 1	CRG 2	CRG 3	WRG 1	WRG 2	WRG 3
10/3	0	2	26	3	0	0
12/3	0	13	16	2	0	0
13/3	0	2	12	1	0	0

Table 11: Change in numbers of *Bovicola* spp on six saanen x angora experimental goats over time after inoculation with 200 female and 40 male *Bovicola* spp on 14 March 1987. Louse numbers are those observed in 5 cm partings of hair in 26 regions on each goat. Goats CRG 1 and WRG 2 were twice re-inoculated (denoted by *) with 200 female and 40 male lice. CRG=cool-room goat, WRG=warm-room goat.

1 = counted by R Brassington
2 = counted by W Charleston & R Fordham
3 = counted by B Adlington & R Fordham
4 = counted by B Adlington & Y Brettschneider

		Goat					
Date		CRG 1	CRG 2	CRG 3	WRG 1	WRG 2	WRG 3
16/3	1	1	12	22	16	1	5
20/3	1	0	7	24	7	1	4
27/3	1	0	19	23	10	0	3
3/4	1	0	11	58	27	0	10
7/4		*				*	
10/4	1	0	12	76	76	1	17
17/4	1	0	16	119	122	0	35
24/4	1	0	31	148	104	0	38
1/5	2	0	6	58	31	0	6
8/5	3	0	10	100	109	0	14
15/5	2	0	10	79	46	0	24
22/5	4	0	11	215	182	0	48
23/5		*				*	
29/5	4	0	11	240	327	0	42
5/6	4	0	4	218	299	0	65
12/6	4	0	4	296	438	0	58
19/6	1	0	9	278	646	0	62
26/6	1	0	3	380	812	0	97
3/7	1	0	0	362	851	0	71
9/7	1	0	0	407	777	0	123

Table 12 gives the total number of lice in the 26 regions for each experimental goat from the post-mortem samples. Temperature did not affect louse numbers in the expected manner. The goat with the greatest number of *Bovicola* spp was in the warm room, followed by a CRG. The third highest infestation was again on a WRG, and a CRG had the next lowest number of *Bovicola* spp. Luckily, the two goats which consistently rejected their louse infestations were in separate rooms under different temperatures.

Table 12: Number of *Bovicola* spp found in 5x5 cm squares in all 26 regions on each of six saanen×angora goats at the conclusion of the temperature experiment. CRG = cool-room goat, WRG = warm-room goat.

Goat	*Bovicola* spp		*B.caprae*	*B.limbatus*	Total
No.	juvenile	female	male	male	
CRG 1	0	0	0	0	0
CRG 2	3	2	0	0	5
CRG 3	1579	876	245	17	2717
WRG 1	3022	1675	585	6	5288
WRG 2	0	0	0	0	0
WRG 3	262	152	39	0	453
Total	4866	2705	869	23	8463

There were large and statistically significant differences in the numbers of lice at the conclusion of the experiment on the four goats which retained lice throughout most of the trial. Two-way ANOVA with replicates, on the log-transformed data showed a significant difference between regions in the number of lice (F = 8.11, $p < 0.0001$), and a significant interaction between numbers of *Bovicola* spp in regions and on individual goats suggesting that the distribution of lice over the goat's body was not consistent between goats (F = 1.98, $p < 0.05$). Again there were large differences in the counts of lice on the left and right sides which may account for the significant interaction term. The number of lice in each region, converted to a percentage of the total number of lice counted on each side for the three goats with a total of >10 *Bovicola* spp, and the mean percentages of lice in each region are shown in Table 13. Two-way ANOVA with replicates was performed on the percentage data in Table 13, after transformation by (arcsine ($0.1\sqrt{\% + 0.5}$)). Converting to percentages reduced the variation due to goats, and thus the interaction between goat and region was not significant (F = 1.06, $p > 0.05$). However, there were highly significant differences between the percentages of *Bovicola* spp between regions (F = 7.59, $p < 0.005$). The highest mean percentages of lice were all in the upper body regions (R1, S1, L, F1 and Q1), and the lowest were in regions T, C, A, and the lower body regions F2 and R2 (Fig. 21). This is similar to the trend found on the 20 feral$_{x}$angora goats (see section 3.1.1, and Fig. 16).

The mean density of *Bovicola* spp per cm^2 is given for each goat in Table 5. The proportion of juvenile to adult *Bovicola* spp for the four goats was 1.316:1, and the female to male ratio was 2.730:1.

Table 13: Numbers of *Bovicola* spp in each region, as a percentage of the total number of *Bovicola* spp, counted at post-mortem, in thirteen 5x5 cm regions on each side of three saanenxangora experimental goats. The mean percentage and standard deviation (S.D.) are given for each region. CRG = cool-room goat, WRG = warm-room goat. Regions as defined in Table 3. Rt = right side, Lt = left side. *n* = total number of *Bovicola* spp counted per side on each goat.

Region	CRG 3		WRG 1		WRG 3		Mean	S.D.
	Rt	Lt	Rt	Lt	Rt	Lt		
W	1.3	2.7	6.3	14.6	4.4	8.3	6.2	4.4
L	18.5	6.6	19.7	13.2	15.1	7.5	13.4	5.0
S1	8.9	9.1	6.2	24.1	12.4	21.5	13.7	6.7
S2	11.0	4.3	2.7	2.2	8.0	6.6	5.8	3.1
R1	16.0	24.1	23.0	14.0	16.4	24.6	19.7	4.3
R2	1.6	6.7	4.4	5.0	7.6	0	4.2	2.7
F1	14.3	17.5	11.4	1.6	8.9	10.1	10.6	4.9
F2	3.9	8.5	2.6	1.1	4.0	6.1	4.4	2.4
Q1	5.7	8.2	13.3	7.5	9.8	10.5	9.2	2.4
Q2	4.0	4.8	6.9	5.3	4.0	0.1	4.2	2.1
A	3.2	0.9	1.9	1.7	8.4	2.2	3.1	2.5
C	9.6	5.9	1.6	8.7	0	0.1	4.3	3.9
T	1.9	0.6	0.2	1.0	0	0.1	0.6	0.7
n	1286	1431	1983	3305	225	228		

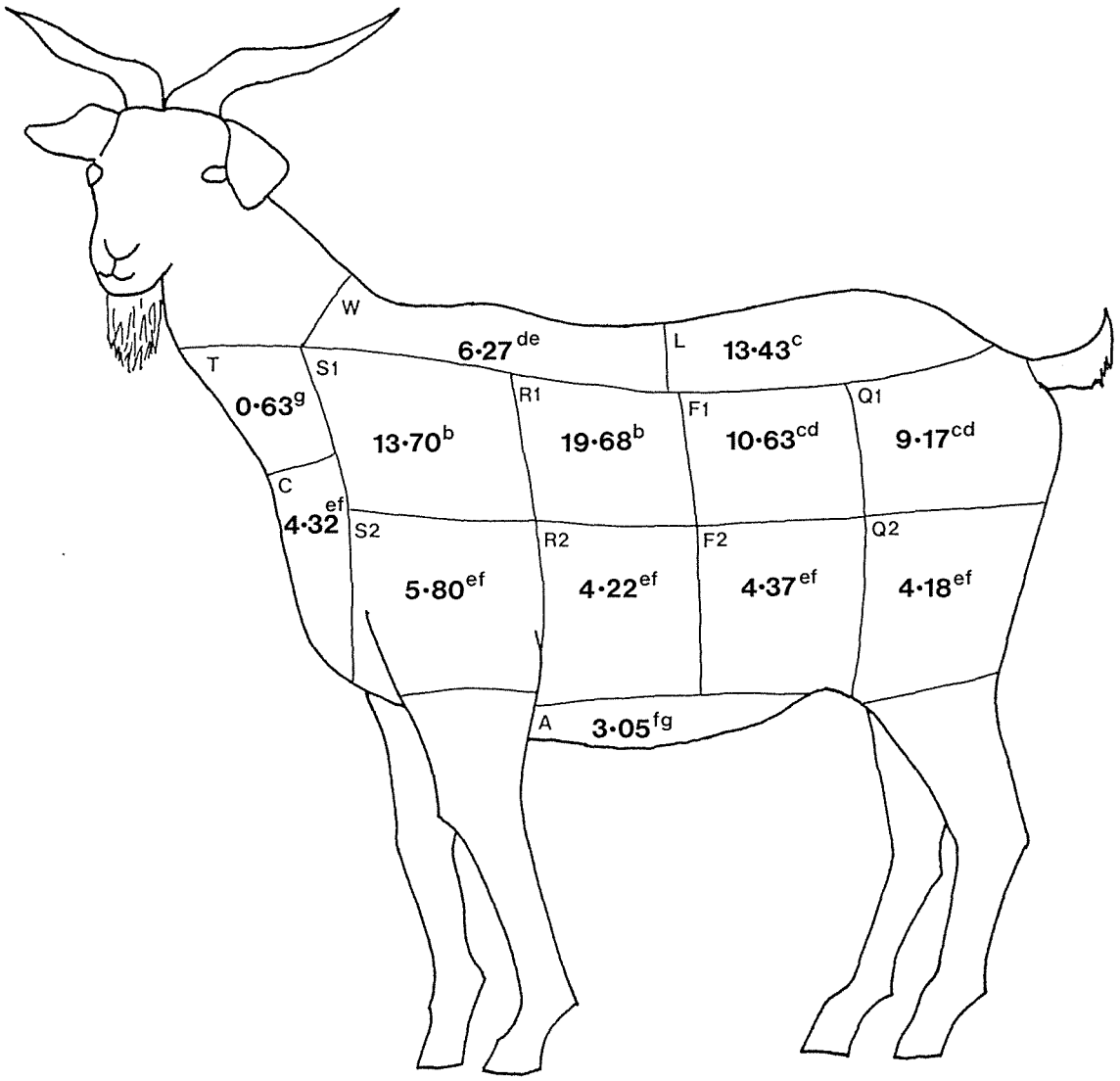


Fig. 21: Mean percentages of *Bovicola* spp in each region on three saanen×angora experimental goats. Means with the same superscript are not significantly different. Regions as defined in Table 3.

3.6.2 SP ratios on experimental goats under controlled temperatures

Two-way ANOVA was performed on the SP ratios (Table 14) from all six saanen×angora goats. Significant differences in SP ratios were found between goats (F = 5.17, p < 0.001) and between regions (F = 5.88, p < 0.001) (Table 14), but interaction was not tested. There was no correlation between numbers of *Bovicola* spp and SP ratios (r = -0.008) or between the percentages of lice (from Table 13) and SP ratios (r = 0.171) on the three experimental goats with >10 *Bovicola* spp present in the post-mortem samples.

3.6.3 Validation of the live sampling technique for experimental goats under controlled temperatures

The number of *Bovicola* spp counted in twenty-six 5 cm partings on each of the six goats at the final live count (L) was compared with the counts (D) obtained from the samples collected at slaughter on the following day for each corresponding region (Fig. 22). Regression analyses were performed on the raw and transformed (log-normal, log-log, and square root) data. The square root transformation provided the regression equation with the most balanced residuals ($L = -0.44 + 1.98\sqrt{D}$) and the best correlation coefficient (r = 0.747) which was highly significant (t = 11.347, p < 0.005).

3.7 Physical characteristics of the louse habitat

3.7.1 Observations on the appearance of the coat

There was considerable variation in the amount of skin scurf present on the six experimental goats. There was abundant loose scurf throughout the fleece on CRG 1. CRG 2 had large flakes of loose greasy scurf predominantly around the back of the neck (regions W1, S1 and S2). The hair on CRG 3 was

Table 14: Secondary (2°) to primary (1°) hair ratios (SP ratios) for all twenty-six 5x5 cm regions on each of six saanen$_x$angora goats. The tabulated figure is the number of 2° fibres to each 1° fibre. Mean SP ratios were calculated for each region on all goats, and for all regions on each goat. Regions as defined in Table 3. Rt = right side, Lt = left side. Means with the same superscript are not significantly different.

Goat		Region					
		W	L	S1	S2	R1	R2
CRG 1	Rt	0.99	1.31	2.00	2.07	1.96	1.22
	Lt	1.05	2.36	2.16	2.00	2.36	1.66
CRG 2	Rt	2.17	1.75	1.96	2.37	2.56	2.92
	Lt	2.02	2.20	2.40	2.59	2.24	2.23
CRG 3	Rt	2.18	0.98	2.38	1.86	2.63	2.74
	Lt	2.85	2.04	3.00	2.02	2.82	2.72
WRG 1	Rt	0.56	1.52	1.40	2.06	1.65	1.11
	Lt	1.09	1.81	1.78	1.93	2.12	2.09
WRG 2	Rt	1.40	2.12	2.38	1.20	1.83	1.60
	Lt	1.18	2.30	1.69	2.02	1.84	2.09
WRG 3	Rt	1.62	1.93	2.46	2.47	2.36	2.52
	Lt	1.65	1.67	2.38	1.80	2.31	1.70
Mean		1.56^{uv}	1.83^{vwx}	2.17^{xyz}	2.03^{wxy}	2.22^{yz}	2.05^{wyz}

Table 14 ctd.

Region							
F1	F2	Q1	Q2	A	C	T	Mean
2.28	1.68	2.16	1.80	1.70	1.16	1.17	1.79[a]
1.74	2.47	1.82	1.91	1.92	2.50	1.04	
2.90	3.20	1.78	3.08	1.13	2.97	1.76	2.26[b]
2.62	2.43	2.46	2.11	1.98	1.66	1.17	
2.47	3.08	2.18	1.59	1.32	2.40	2.22	2.16[b]
2.23	1.88	1.83	1.93	0.68	1.34	2.90	
1.68	2.51	1.75	1.09	0.61	1.73	0.44	1.53[a]
1.88	1.73	2.06	1.76	1.13	1.29	0.95	
2.88	2.02	2.08	1.81	1.43	1.75	1.47	1.88[a b]
1.75	2.28	2.12	2.07	1.39	2.12	2.13	
1.91	2.85	1.41	1.32	1.72	1.33	2.06	2.03[a b]
2.88	2.66	2.36	1.85	1.78	1.75	2.04	
2.22[y z]	2.40[z]	2.00[w x]	1.86[v w x]	1.40[u]	1.83[v w x]	1.61[v u]	

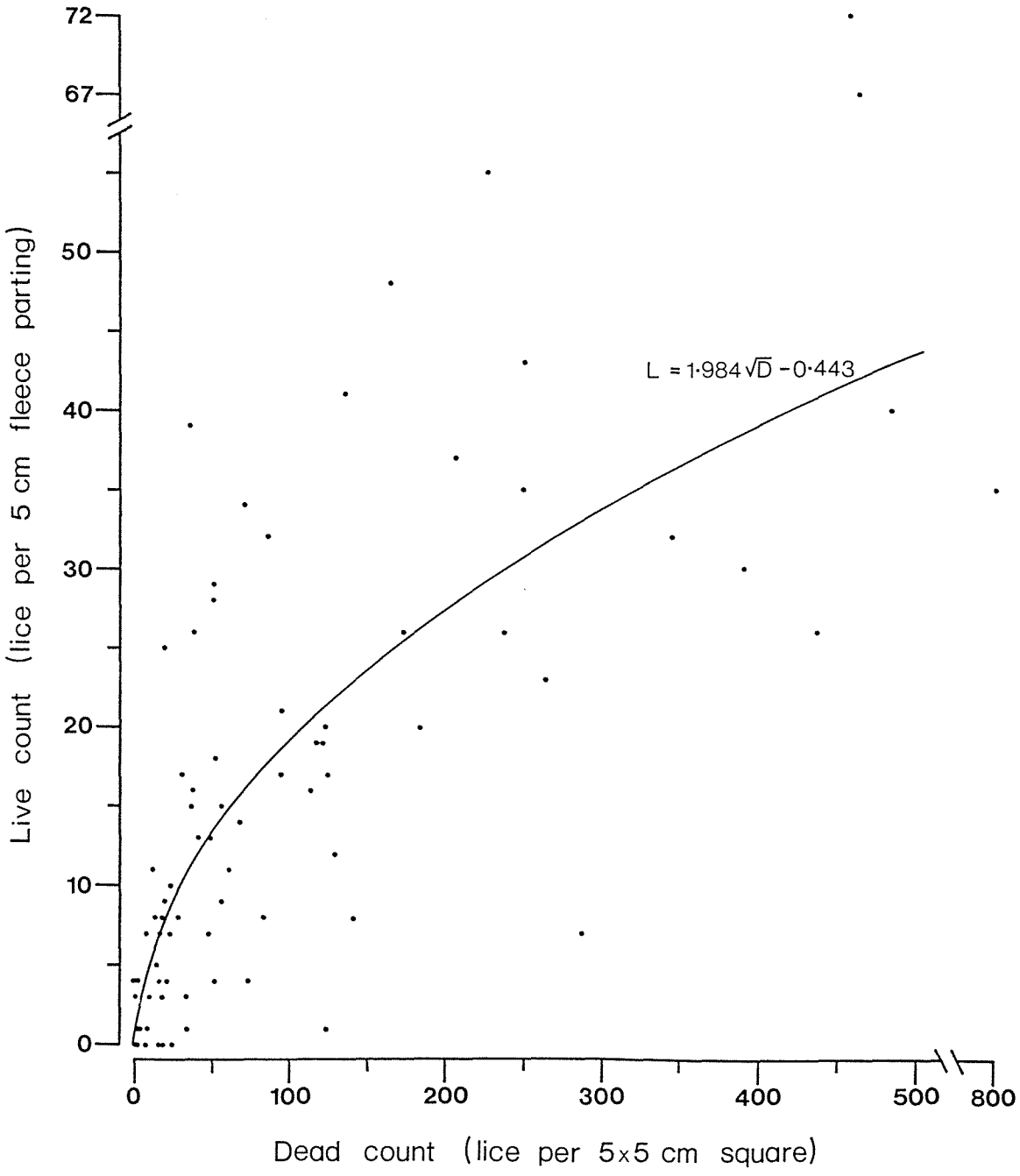


Fig. 22: Comparison of *Bovicola* spp numbers determined by sampling similar regions on the fleece, prior to (L) and after death (D), for the four saanenxangora experimental goats. Curve is the line of best fit.

matted, especially on the hindquarters and around the toggles, and scurf was abundant throughout the fleece.

The fleece on WRG 1 was matted, and there were small pieces of dry scurf throughout the fleece. WRG 2 had a small matted area around regions F1 and L1. There was an abundance of dry scurf over the whole of the body. There was a small amount of dry scurf all over the body of WRG 3. There was no apparent relationship between the degree of scurfiness and the presence or absence of lice.

Shedding of cashmere was apparent on WRG 1, WRG 2 and CRG 3, and to a lesser extent on WRG 3 and CRG 2. There was very little shedding on CRG 1 and shedding was not consistently related to temperature in this study.

3.7.2 Goat health

All six goats had internal temperatures and respiratory rates within the normal range (Table 15). There was no relationship between goat weight and total louse numbers in the twenty-six 5x5 cm regions (Friedman's 2-way ANOVA by rank, $X_r^2 = 2.93$, $p > 0.05$).

3.7.3 Skin temperatures

There were lower skin temperatures on the two goats which lost their louse infestations (CRG 1 and WRG 2) and the goat with very few lice (CRG 2) than on the other three goats (Table 16). Table 17 shows the statistical significances in skin temperatures between goats. There was a significant correlation between the mean skin temperature (T_x) and the number of *Bovicola* spp (B) on each experimental goat ($r = 0.830$, $t = 2.976$, $p < 0.025$). Lice were present in greater numbers on the goats with a higher skin temperature ($T_x = 33.39 + 0.03 \sqrt{B}$).

Table 15: Internal temperatures, respiratory rates and liveweights of the six saanenxangora experimental goats. CRG = cool-room goat, WRG = warm-room goat.

Date	Goat					
	CRG 1	CRG 2	CRG 3	WRG 1	WRG 2	WRG 3
Temperature (°C) *						
29/4	39.1	38.7	38.6	-	-	-
3/6	39.1	39.0	38.7	39.1	39.0	38.9
1/7	38.2	38.3	38.2	38.3	38.7	38.5
Respiratory rate (per minute) **						
3/6	28	36	28	36	24	28
Initial weight (kg)						
24/2	21.15	23.80	15.70	11.60	19.10	16.60
Final weight (kg)						
9/7	23.94	25.90	21.50	16.83	18.93	19.84
Weight gain (kg)						
	2.79	2.10	5.80	5.23	-0.83	3.24

* Critical internal temperature for goats is > 39.3°C. @

** Critical respiratory rate is > 42/minute continuously. @

@ M. Merrall, pers. comm.

Table 16: Mean skin temperatures (°C) of six saanen×angora experimental goats. (Means calculated from *n* sample points per goat.) CRG = cool-room goat, WRG = warm-room goat.

	Goat					
	CRG 1	CRG 2	CRG 3	WRG 1	WRG 2	WRG 3
Mean	32.6	32.9	35.2	35.5	34.0	35.1
n	24	15	23	21	20	20
S.D.	3.9	2.7	2.6	1.9	2.1	1.9

Table 17: *t*-test values comparing skin temperatures between six saanen×angora goats (from Table 16). CRG = cool-room goat, WRG = warm-room goat.
(* - $p < 0.025$, ** - $p < 0.01$, *** - $p < 0.005$)

	Goat					
	CRG 1	CRG 2	CRG 3	WRG 1	WRG 2	WRG 3
CRG 1	-	0.26	2.68**	3.10***	1.47	3.04***
CRG 2		-	2.62*	3.40***	1.38	3.35***
CRG 3			-	0.29	1.67	0.43
WRG 1				-	2.43**	0.00
WRG 2					-	2.39*
WRG 3						-

3.7.4 Grease and suint content in the fleeces of the experimental goats

The CRG appeared to have more grease (Table 18) and suint (Table 19) in their fleeces than the WRG, although there were few significant differences between goats. Neither factor was correlated with louse numbers (see Table 13).

Table 18: Percentage of grease in the fleeces of the six saanen×angora experimental goats. Replicate values from each region or combination of regions are listed (except for region L on WRG 2). The means and 95% confidence intervals (CI) of all regions combined are given for each goat. CRG = cool-room goat, WRG = warm-room goat. Regions as defined in Table 3.

Goat	Regions				Mean	CI
	W	Q	S+R+F	L		
CRG 1	7.45	17.80	7.52	12.17	10.21	2.42
	7.80	10.36	7.32	11.27		
CRG 2	12.37	5.49	7.70	7.28	8.15	1.61
	10.68	5.34	7.75	8.59		
CRG 3	6.54	13.06	2.88	5.48	7.12	3.52
	4.95	17.30	3.23	3.52		
WRG 1	7.95	2.38	2.03	3.02	5.02	3.44
	16.77	2.96	1.98	3.03		
WRG 2	6.18	4.54	3.45	3.27	4.04	0.90
	4.75	2.44	3.63			
WGR 3	4.09	5.40	2.84	3.34	3.74	0.58
	2.82	4.38	3.30	3.73		

Table 19: Percentage of suint in the fleece of the six saanen×angora experimental goats. Replicate values from each region or combination of regions are listed. The means and 95% confidence intervals (CI) of all regions combined are given for each goat. - = no data. CRG = cool-room goat, WRG = warm-room goat. Regions as defined in Table 3.

Goat	Regions			Mean	CI
	Q	S+R+F	W+L+S+R+F		
CRG 1	1.03	2.65	2.55	2.40	0.43
	2.78	2.70	2.15		
	3.18				
	2.18				
CRG 2	2.89	2.27	2.31	2.43	0.23
	2.55	2.26	2.30		
CRG 3	2.52	3.86	3.05	3.04	0.63
	2.43	4.08	2.29		
WRG 1	-	2.13	1.37	1.79	0.61
	-	2.32	1.32		
WRG 2	0.58	1.69	1.96	1.41	0.55
	0.53	1.89	1.78		
WRG 3	2.26	2.12	2.24	2.18	0.11
	2.35	2.16	1.96		

4 DISCUSSION

4.1 Distribution and numbers of *Bovicola* spp and *Linognathus stenopsis*

4.1.1 The pattern of louse distribution on a goat's body

Congregations of lice, both in species-specific colonies and mixed colonies, in some regions, but not in others have been reported on cattle (Craufurd-Benson, 1941; Matthysse, 1946; Chalmers & Charleston, 1980b) and sheep (Kettle & Pearce, 1974), but no reports are available for goat lice. In this study, there was considerable variation in the distribution of *Bovicola* spp on the 20 feral×angora goats and the three infested experimental goats; and in the distribution of *Linognathus stenopsis* on the 20 goats. Despite the fact that there were statistically significant differences in the distribution of lice between goats, inspection of the data converted to percentages revealed that some regions had a distinct tendency to fall within the upper or lower quartiles. On this basis it seemed reasonable to pool the data from all goats to obtain an overall pattern which, although somewhat artificial, provides a more comprehensible picture of the general distribution of lice on the host. From this it is clear that the two genera show distinct and different regional preferences. *Bovicola* spp numbers were greatest along the backline and anterior regions on either side of the backline, and lowest on the abdomen, throat and chest. *Linognathus stenopsis* were most abundant on the shoulder regions, chest and throat, and rare on the abdomen and along the backline. *Bovicola caprae* and *B. limbatus* co-existed with *Linognathus stenopsis*, although *L. stenopsis* was in low numbers on all the goats in this study (and not present on goat 98 or the experimental goats). The dose of IVOMEC administered to the 20 feral×angora goats in April 1987 was probably responsible for the very low numbers of *L.*

stenopsis at post-mortem in June. IVOMEC markedly reduces numbers of sucking lice but has relatively little effect on *Bovicola* spp (W. A. G. Charleston, pers. comm.). From the point of view of this study, the low numbers of *L. stenopsis* were most important as they make interpretation of the data on *L. stenopsis*, and also comparisons with *Bovicola* spp, difficult.

4.1.1.1 Microclimatic factors affecting louse distribution

Lice can only live in areas on the goat where suitable microhabitats occur. The factors determining louse distribution on the host are little understood but are likely to include microclimatic effects such as temperature and humidity and their stability, availability of suitable oviposition sites, accessibility of nutrients, and vulnerability to host defence mechanisms such as grooming or immunological reactions. Competition or antagonism with other louse species is another possible factor. No measures of relative humidity in the fleece were made in this study, and the thermometers used to measure skin temperature on the six experimental goats did not give reliable enough results for differences between regions to be determined.

The stability of a louse's environment with respect to temperature and humidity is determined by the depth and density of the host's pelage, and ambient temperature and humidity. SP ratios were used in this study as an estimate of coat density on the grounds that a higher SP ratio would indicate a more dense coat, and therefore, a potentially more stable environment.

SP ratios vary with season, and are affected by previous lactation and body condition (McDonald, 1985). The 20 goats in this study were killed and sampled on 12 June 1986 (winter), when the proportion of secondary fibres in the fleece should be high and shedding should be at a minimum.

Therefore the stability of the fleece should be high. During the Australian winter, SP ratios on cashmere goats under natural lighting conditions ranged from 4:1 to 6:1 (McDonald, 1985; McDonald *et al.*, 1987), and were low (between 0:1 and 1.5:1) from October through to January. Dairy goats (e.g. saanens) have a low SP ratio, the SP ratio increases on feral goats which produce cashmere, and peaks on angora goats producing mohair (Smith, 1983). Therefore, the 20 feral×angora goats in this study should have SP ratios higher than those of McDonald *et al.*, (1987), and the six saanen×angora goats should have SP ratios ranging between the two extremes (saanen and angora) depending on which genes have more phenotypic expression. However, the SP ratios for all 26 goats (killed in winter) were lower than those of McDonald *et al.* (1987) taken in winter, indicating a less dense coat. They used a definite cut-off point between secondary and primary fibres of $\leq$18 microns and their results therefore may not be strictly comparable because of the floating cut-off used in this study.

Seasonal tendencies in SP ratios were not examined directly in this study although mean SP ratios on the two groups of experimental goats could provide some information on seasonal effects. The lowest mean SP ratio on the three warm-room goats was 1.53:1 which was close to the low summer SP ratio of McDonald *et al.* (1987). However, the lowest mean SP ratio on the cool-room goats (1.79:1) also approached this figure. The temperatures experienced by the two groups of experimental goats did not appear to cause differences in SP ratios. The 20 feral×angora goats had mean SP ratios higher than the summer SP ratios, but much lower than the winter SP ratios, of goats studied by McDonald *et al.* (1987). However, as SP ratios are not available for the 26 goats in this study throughout the rest of the year, it is difficult to draw conclusions based on the observed SP ratios at post-mortem. The lowest mean SP ratio in a region on the 20 feral×angora

goats was 2.65:1, and is still considerably higher than the summer SP ratios of McDonald *et al.* (1987). The lowest SP ratio in a region on the six saanen$_{x}$angora goats was 1.40:1. Although there were regional differences in coat density on these 26 goats, lice occurred in all regions examined. Regions A (abdomen), C (chest) and T (throat) had a sparser covering of hair than all the other regions on the body (pers. observation), and therefore were the coolest and least stable. These regions also tended to have the lowest SP ratios, the lowest number of *Bovicola* spp, and low numbers of *L. stenopsis*. There was no significant correlation between louse numbers and SP ratios for the midside patch. Gojmerac *et al.* (1959) were also unable to find a correlation between hair density and lousiness on cattle.

Mean secondary fibre diameter also varies throughout the year, with a peak diameter occurring around October to November, and a finer micron measurement occurring from January to February and again from June to July (McDonald, 1985; McDonald *et al.*, 1987). If their results can be extrapolated to this study, then the mean secondary fibre diameters of my 26 goats should have been approaching their minimum at the time they were killed. Gojmerac *et al.* (1959) obtained a positive correlation between louse numbers and fibre diameter for Holstein cattle, with more lice on cattle bearing coats of thicker fibre. However, their results are based on only 5 hosts, and there was no correlation between louse numbers and fibre diameter on cattle of other breeds. A relationship between louse numbers and mean secondary diameters was not confirmed by Chalmers & Charleston (1980b) who concluded that the distribution of lice on the body of cattle in their study was largely determined by the combined effects of coat density and regional accessibility for grooming. For goats, I also found no correlation between mean fibre diameter for the midside patch and numbers of *Bovicola* spp or *L. stenopsis* for the same area. Although

fibres of a suitable diameter are necessary for oviposition, the distribution of lice was apparently not related to this because primary fibres are interspersed with secondary fibres all over the body. Therefore lice in any area should be able to find hairs of a suitable diameter on which to lay eggs.

4.1.1.2 Fibres for oviposition

No attempt was made to differentiate between the eggs of *Bovicola caprae* and *B. limbatus*. The eggs of *Bovicola* spp and *Linognathus stenopsis* were laid more often on single hairs than on multiple hairs. *Linognathus stenopsis* preferred significantly larger hairs than *Bovicola* spp. *Bovicola* spp cemented hairs together to obtain a mean diameter similar to that of single hairs (*ca.* 47 microns). However, when *L. stenopsis* cemented hairs together, they obtained a mean diameter significantly greater than that for single hairs. It may be that *L. stenopsis* is less particular than *Bovicola* spp in the diameter of fibres used for oviposition, and is capable of using a very wide range of diameters according to what is available. Also, because *L. stenopsis* is larger than *Bovicola* spp, it is able to use a wider range of fibres.

The unavailability of hairs with a suitable diameter can inhibit oviposition. In an experiment with *Bovicola ovis* (Murray, 1957b), lice were held in one of three cages containing fibres with diameters of 0.02, 0.1, or 0.2-0.35 mm. The greatest number of eggs were laid on the finest fibres, and it was observed that the lice were unable to hold the larger fibres between their gonopods and abdomen. The differences in fibre diameter used in the experiment were very large and do not simulate the range of fibres available on the host. Murray (1957c) examined the oviposition behaviour of *B. ovis* maintained *in vitro* with hairs from the leg, axilla and inguinal regions of a sheep. He concluded that the diameter of the base of some of the hair fibres from

these regions was too great to permit *B. ovis* to attach its eggs. However, fibre diameter played little part in determining the regional distribution of *B. ovis* on sheep, since the coarser fibres were interspersed with finer ones. The lateral distribution was primarily influenced by skin temperature; the temperature of the extremities being too low for oviposition and morphogenesis under cool ambient conditions. Longer, thicker fleeces had greater vertical regions of suitable temperature for oviposition. Thus, hair density and length can influence oviposition in *B. ovis* (Murray, 1957c).

In this study, the two genera had different preferences in egg-laying sites. Where *Bovicola* spp laid the most eggs, *L. stenopsis* eggs were few in number, and *vice versa*. There was a significant correlation between the percentages of eggs and female *Bovicola* spp in each region. This finding agrees with that of Murray (1957b) who reported that ovipositing females of *B. ovis* were attracted to eggs and other ovipositing lice. There was no correlation between egg and female *L. stenopsis* numbers in any region, which is surprising, and may be an artifact of the sampling method (i.e. lice are mobile but eggs are not). However, the dose of IVOMEC administered to the 20 feral×angora goats in April which was probably responsible for the low populations of *L. stenopsis* would also have affected any correlation of females with egg numbers.

Fibre diameter should have little influence on the distribution of eggs over the goat's body. The density of fibres in the various regions, determined by SP ratios, was well correlated with the percentages of *Bovicola* spp eggs but not with *L. stenopsis* egg numbers. If a large number of secondary fibres had been shed prior to sampling, a great number of eggs might have been lost. Although the shed secondary fibres on goats tend to remain attached to the

outside of the fleece for some time, the loss of microhabitat stability in the shed fibres may limit morphogenesis and hatching of eggs. Differential shedding by the various regions would then affect the number of eggs lost by each region. However, sampling in this study occurred in June when all shedding should be at a minimum, so the numbers of eggs in each region should not be affected by this. The lack of a relationship between the proportion of *L. stenopsis* eggs and fibre density may again be due to the low population levels of this louse.

4.1.1.3 Effect of host-grooming on the distribution of lice

Grooming is thought to play a large part in determining the distribution of lice on the host's body (Murray, 1957a, 1987: Lewis *et al.*, 1967; Utech *et al.*, 1969; Chalmers & Charleston, 1980b). My results also indicate that *Bovicola* spp were more abundant in regions that were inaccessible for grooming. However, *Linognathus stenopsis* were most common in the lower shoulder regions which would be reasonably accessible for host-grooming. They are larger with a more rounded abdomen than *Bovicola* spp, which is dorso-ventrally flattened, and on the basis of size might be more easily groomed from the fleece by the host's tongue. However, they are able to grasp the host with their embedded mouthparts and, therefore, are able to resist removal by host-grooming. The haustellum has eversible spines which hold the mouthparts in place (Nelson *et al.*, 1977), and which make removal from the skin difficult (pers. observation). They also have large, strong, hooked tarsi that grasp hairs. Chalmers & Charleston (1980b) found that *Linognathus vituli* on cattle were more concentrated on the neck, and less on the shoulders, than *B. bovis*, during winter. They also stated that "sucking lice, when feeding, are comparatively difficult to dislodge from the skin, and consequently the relative importance of grooming in determining population

distributions may be relatively less, and coat factors relatively more, important, than with *B. bovis*". *Linognathus stenopsis* occurred in the largest numbers in areas accessible to grooming. Although their distribution differed from that of *Bovicola* spp, the data did not provide any evidence for one genus influencing the distribution of the other. It may well be that with *L. stenopsis*, grooming is unimportant in determining their distribution and that other factors such as localised host response to feeding, thickness of the epidermis and accessibility of blood capillaries, or fibre density, are more important.

The tarsi of *Bovicola* spp are able to grasp hairs strongly so that they are difficult to remove from the pelage (pers. observation). They are also very mobile, negatively phototactic, and bury quickly into the fleece once it is parted. Grooming may well be an important determinant of *Bovicola* spp distribution, and these lice appear to exhibit behavioural and morphological adaptations enabling them to better survive grooming.

4.1.1.4 Intra- and inter-specific competition and population dynamics

Hopkins (1949) stated that populations of parasite species tend to be lower on hosts where a close relative also occurs, than on hosts where it is the only member of its group present, which suggests inter-specific competition between closely-related species. Intra-specific competition may play a role in setting the upper limits of population size, but no obvious sign of competition is apparent on hosts with low infestations (Marshall, 1981). In the present study, there was no evidence to support intra- or inter-specific competition or antagonism. Given the relatively low density of the louse populations, it is unlikely that such interactions would be important.

Mock (1974, cited in Marshall, 1981) recorded populations of *B. bovis* rising until intra-specific competition eventually limited the available space and food, at a level of 80 adults and hundreds of nymphs and eggs per square cm over the whole body! None of the 26 goats in this study ever supported comparable infestations.

A sex ratio and juvenile to adult ratio may give an indication of whether a population is increasing, stable, or declining. Matthysse (1946) and Marshall (1981) reported that *Bovicola bovis* nymphs and males were more common during periods of population increase than at any other time, and that when populations are low during summer they consist almost entirely of adult females. Matthysse (1946) considered *B. bovis* to be primarily parthenogenetic since he was able to breed a population *in vitro* from virgin females. A sex ratio of approximately 1:1 was found to occur in *B. ovis* (Scott, 1952).

It is not known whether *B. limbatus* or *B. caprae* are parthenogenetic, and unfortunately a sex ratio for *B. caprae* is not available in the literature. It is therefore difficult to interpret the observed sex ratio. Hopkins & Chamberlain (1969) reported a male to female sex ratio of 1:3 for *B. limbatus*. In this study, the sex ratio for *B. caprae* and *B. limbatus* combined was 1:1.6, which is considerably lower. Certainly on all goats there were only low numbers of *B. limbatus* males, but it was not possible to distinguish between females of the two species. The number of *Bovicola caprae* males would have contributed most to the combined sex ratio I observed, and it is therefore probable that the observed ratio is close to the actual sex ratio of *B. caprae*. The juvenile to adult ratio for *Bovicola* spp in this study was also relatively low (1.7:1). As the populations of lice were relatively low on 18 of the 20 goats, the observed sex ratio and juvenile to adult ratio fit reasonably well with

the observations of Matthysse (1946) and Marshall (1981) during times of population increase. The actual state of the population on these goats is not known, but as slaughter was in June, the louse populations would be expected to be increasing.

For *Linognathus stenopsis*, the sex ratio (1 male to 1.3 females) and juvenile to adult ratio (1.2:1) were also low. No comparative data for *Linognathus stenopsis* are available. Again, the low values appear to fit those observed during periods of population increase (Matthysse, 1946; Marshall, 1981).

4.1.2 Differences in infestation levels between hosts

Individual variation in host susceptibility is well-documented (Matthysse, 1946; Hopkins, 1949; McKenna & Fearn, 1952; Scott, 1952; Scharff, 1962; Sinclair, 1976; Chalmers & Charleston, 1980c; Kim, 1985; Wassom *et al.*, 1986; Murray, 1987), although the basis for this is not understood. Tweddle *et al.* (1977) suggested for cattle that acquired resistance to populations of *Haematopinus eurysternus* and *Linognathus vituli* resulted in lower numbers of lice on older animals. Although acquired resistance in older hosts may be important in regulating Anoplura populations since they suck blood, it would be less likely to affect Ischnocera populations which do not. All goats in this study were of a similar age so that age of the host would be unlikely to account for the observed differences in host susceptibility. Low numbers of *L. stenopsis* on the goats was probably mainly influenced by the dose of IVOMEC in April, rather than any acquired resistance in such young animals, although that does not explain the observed differences in levels of infestation between goats.

Poor health of a host may also induce high louse populations, according to Utech *et al.* (1969), who suggested that a low

nutrient intake (and therefore ill-thrift), resulting in reduced self-grooming, was the main reason for high populations of lice on underfed cattle.

The 20 feral×angora goats in this study had access to hay *ad libitum*, and any differences in louse numbers between goats could not have been due to differences in the plane of nutrition. However, on the basis of faecal egg counts they all suffered from sub-clinical nematode parasitism (Pomroy *et al.*, in press). There was no relationship between the ranks of the nematode egg counts and the total numbers of lice of each genus for each goat. The two goats which ranked highest on the egg counts (goats 104 and 111) also had the highest number of *Bovicola* spp, but not of *L. stenopsis*. Those goats with the lowest nematode egg counts (goats 101 and 23) did not have the lowest number of either genus of louse. Although no study has equated faecal egg counts with the health of the host, the rank of faecal egg counts and therefore the possible relative health of each host could not account for the observed differences in louse numbers between goats. These goats were all free to self-groom, but no observations were made on the relative frequency of grooming by each animal.

The six saanen×angora goats also showed large difference in their infestation levels at the end of the experiment. In each treatment group there was one goat which was consistently resistant to louse infestation. A thorough examination of these two goats two days after the third inoculation, failed to reveal any of the 240 lice alive. Ten to 15 dead lice were found on the gauze of the harness. This rapid death of the parasites suggests that there was something fundamentally different about these two goats from the other four, which had only one or two dead lice on the harnesses when they were removed. This difference could have been inherent (i.e. genetic) and possibly related to skin

temperature, grease content of the fleece, an acid or alkaline skin surface or body secretions of these goats which were noxious to the lice. The difference could also have been behavioural, in that some hosts may be more efficient at grooming than others, though such a rapid and complete loss of lice on three occasions makes this a most unlikely explanation.

The range of skin temperatures between the goats was small, and it is difficult to imagine that such a small difference could account for the profound result. The skin temperatures on all six goats should have been suitable for the lice to reproduce and for morphogenesis and hatching of eggs to occur. Heath (1973) found that for *Bovicola caprae in vitro*, the optimal temperature for oviposition, morphogenesis and hatching of eggs was 30°C, and low relative humidity (10%) was preferred. The skin temperature of the goats with most lice was considerably higher than this.

It has been claimed that the skin of lousy goats becomes dry and scurfy causing constant irritation (Salmon, 1978; Rumble, 1985). MacKenzie (1980) suggested that lice might be useful scavengers, clearing away the unhealthy skin of goats in poor condition. This was also implied by Gojmerac *et al.* (1959) who reported a greater amount of skin scurf on cattle during the summer months than during the winter months when louse populations were high. Scurf was present on all six goats in this study and its abundance did not appear to be related to the presence of lice. Ischnoceran lice do remove old dry skin cells, but the irritation they cause to the host may also promote more scurf and sloughed cells in the fleece.

Chalmers & Charleston (1980a) found that within cattle herds, lighter animals tended to carry more lice than heavier ones, but in this study there was no clear relationship between goat weight and louse infestation level.

Shull (1932) reported that the skin of Holstein cattle was drier (less greasy) than the skin of Jerseys, and was therefore more suitable for lice. Kettle (1985) stated that the presence of lice on sheep cause the sheep to produce more grease. In this study, the mean percentages of grease or suint in the fleeces of the six saanen$_{x}$angora goats was not related to louse population levels. The cool-room goats had slightly higher grease and suint levels than the warm-room goats but all six were variable in these two factors, and there were few significant differences.

4.2 Climatic effects on louse populations

The build-up of lice on ruminants in winter has long been recognised (e.g. Matthysse, 1946; Murray, 1963a, b, 1968) and, at least in part, attributed to lower ambient temperatures favouring louse population build-up. The experiment with six saanen$_{x}$angora goats was carried out to investigate this, at temperatures which approximated to local summer and autumn-winter mean daily temperatures. It is difficult to draw firm conclusions on the effect of ambient temperature with only six experimental animals (a larger experiment could not be carried out due to lack of resources), especially when there were such large individual differences in louse burdens. However, goats with the highest and third highest numbers of lice at the end of the experiment were in the warm room, and the second highest infestation occurred on a cool-room goat. From this, it is evident that even a constant ambient temperature difference of 13-17°C did not affect the louse populations in the expected manner. Whether this indicates that ambient temperature has no significant effect on the population dynamics of *Bovicola* spp on goats, or that it was over-ridden by other host-related factors, is unclear. Obviously the

effect of ambient temperature is modulated by the pelage of the host as is the rate of heat loss from the skin and the associated temperature gradients. In this connection, it is notable that there was no effect of experimental temperatures on internal temperatures of the goats. There was no evidence that ambient temperatures *per se* led to higher skin temperatures. The two warm-room goats and one cool-room goat with lice all had slightly higher skin temperatures than the goats with few or no lice, and the correlation between skin temperature and louse numbers was significant. However, with such small numbers of goats, this must be treated cautiously.

Under field conditions, the distinction must also be drawn between ambient temperature effects and the effect of direct insolation which can raise the skin and pelage temperatures to levels lethal to lice. In cattle, it appears that louse numbers increase in winter in association with the growth of the winter coat, and decrease when the coat is shed in spring due to the decrease in stability of the louse's microclimate, loss of lice and eggs, and increases in grooming efficiency (Murray, 1987). In direct sunlight, skin temperatures on cattle can reach very high levels (Matthysse, 1946) and it is interesting that Chalmers & Charleston (1980b) noted a preference by *L. vituli* for white rather than dark areas in summer months, presumably because they are cooler. In sheep, a high skin or fleece temperature as a result of solar radiation was found to reduce the amount of egg-laying, and increase egg mortality, in *B. ovis* populations (Murray, 1968). In the same study, sheep kept in the shade under high ambient temperatures developed relatively heavier infestations of lice. Sheep with fleeces soaked by rain were found to have fewer *B. ovis* than dry sheep, due to the high mortality of nymphs, adults, and hatching eggs (Murray, 1963a). A density of 2 lice per square inch was necessary in autumn for an increase in *B. ovis* populations to occur over winter (Murray, 1963a; Murray & Gordon, 1969). Murray

(1963a) therefore estimated that a population of about 4000 lice was necessary at the start of winter for a population increase to occur. On the horse, increases over winter in *B. equi* populations have been attributed to temperatures near the skin being continuously favourable for reproduction (Murray, 1957d, 1963a).

At an ambient temperature of 28°C, temperature near the skin on the sheep's body rose to about 39°C, and temperatures near the skin on the legs were also favourable for oviposition by *B. ovis* (Murray, 1960). When sheep were exposed to an ambient temperature of about 6°C, temperatures on the body near the skin were suitable, but temperatures on the extremities became too cold for oviposition and egg development.

It appears that ambient temperature within the range used in this study was not able to influence population dynamics or have adverse effects on the lice. Rather, synergistic effects of temperature, changing photoperiod, solar radiation or heavy rain may influence the microclimate to which lice are exposed, and hence louse populations. Overall, however, the over-riding factor affecting the louse populations on the six goats appears to be individual variation in host susceptibility.

4.3 Validation of sampling technique for determining the number of lice on live hosts

Since there was reasonable correlation between total live and post-mortem counts for the 20 feral×angora goats, the fleece parting technique can be used to provide an estimate of the abundance of lice on a goat. The better agreement between the two techniques for the counts from corresponding regions from the experimental goats probably results from my greater

experience in using the fleece-parting technique, and therefore larger numbers were represented more realistically in counts on these animals. This implies that the technique can also provide information on the distribution of lice over a goat's body.

An index similar to that used by Chalmers & Charleston (1980b) which scores the presence of lice so that 1 louse = 1, 2-10 lice = 2, and more than 10 lice = 3 in a 10 x 10 cm square on cattle, would also be a useful technique for assessing louse population levels. It would be easier and less influenced by sampling error between different examiners than the technique I used. The scoring system would need to be different according to the numbers of lice present, the objectives of the study and the levels of discrimination needed. Such an index should also be altered depending on the size of the host and the size of the examined area.

The presence or absence index used by Kettle & Pearce (1974) is another method for determining differences in louse numbers in regions and between hosts; however it is of limited use because many potentially useful data are lost. It may be applicable for hosts with a very low louse population level but would not help to determine the relative distribution over the host's body, nor to determine population build-up.

The three indices therefore have different uses; the actual count in fleece partings which I used is tedious and time-consuming but can provide excellent information including the relative proportions of males to females, or adults to juveniles. The index of Chalmers & Charleston (1980b) should be relatively easy to use, variation in counting between examiners would be reduced, and it provides a reasonable indication of the relative abundance of lice over the host's body. The index of Kettle & Pearce (1974) is simple and easy

to use, but provides very limited information.

There appears to be variation in the number of lice counted by different examiners, shown by the fluctuations in the number of lice over time during the population build-up experiment. This is probably partly sampling error inherent in the method. As lice are highly mobile, the live sampling technique is intrinsically variable, because it is possible to part the fleece in an area where lice are congregated, or move 2 cm to one side and miss the group completely. If one person counted the same goat 10 minutes after the first sampling, variation in the results would also be expected. Lice are negatively phototactic and move away from the parting once it is made. The adults could still be seen in the white fleeces of my goats, and were still available for counting. The nymphs burrowed into the fleece almost as soon as the parting was made and therefore could not be counted easily.

4.4 Directions for future work

This study indicates regional differences in the distribution of lice, but the reasons for it are only partially explained. There is a need for further investigation into physico-chemical properties of the pelage. Such investigations could include the determination of pH, relative humidity, and temperature differences between regions on a goat. The density of fibres in different regions could also be more directly assessed by histology on biopsies of skin.

The experiment under constant ambient temperature failed to show any effect on louse populations that could explain the seasonal trends in population dynamics. Other possible factors that need examining are the effect of photoperiod independently of temperature, the seasonal change in fibre

density and hence microhabitat stability, the loss of lice by the shedding of secondary fibres or shearing, and the effects of solar radiation or heavy rain on louse populations.

Of particular interest is the marked individual variation in susceptibility. The basis of this needs to be investigated, and if found to be genetic, might be exploitable in breeding programmes. If the mechanism of resistance is understood, it could lead to novel approaches to louse control.

5 SUMMARY

1) The louse populations of 20 feral$_x$angora goats were examined by fleece partings and post-mortem sampling in June 1986. *Bovicola caprae*, *Bovicola limbatus* and *Linognathus stenopsis* were present. The distributions of the two *Bovicola* spp were not treated separately, as *B. limbatus* was present in very low numbers.

2) The goats differed in their louse infestation levels.

3) An overall pattern of louse distribution was determined. The highest density of *Bovicola* spp was on the upper body regions, and the density was lowest on the abdomen, chest and throat. *Linognathus stenopsis* was most abundant on the shoulder regions, chest and throat, and rare on the abdomen and along the backline. The numbers of *L. stenopsis* on all the goats was low, probably caused by the dose of IVOMEC administered to the goats in April, 1986.

4) Grooming may have accounted for the observed distribution of *Bovicola* spp, but this did not appear to be the most important factor for *L. stenopsis*. There was no evidence for intra- or inter-specific competition.

5) Fibre density, and mean fibre diameter for the midside patch did not appear to influence the overall distribution of either genus. However, the distribution of female *Bovicola* spp was significantly correlated with fibre density. For *L. stenopsis* this was not the case.

6) The two genera had different preferences for egg-laying sites. Where *Bovicola* spp laid the most eggs, *L. stenopsis* eggs were few in number, and *vice versa*.

7) The mean fibre diameter of hairs used for oviposition

differed between the two genera. *Bovicola* spp used fibres of a significantly smaller diameter than *L. stenopsis*. Eggs were laid singly or on bundles of hairs. Fibre density was significantly correlated with the proportion of eggs laid in various regions by *Bovicola* spp, but not with the proportion of *L. stenopsis* eggs.

8) An experiment was conducted to examine the effect of temperature on louse population levels. Six saanen x angora goats were held in controlled temperature rooms under a 12:12 light regime. Three goats were held at 10°C and three at 25°C and all were infested with 200 female and 40 male *Bovicola* spp.

9) A greater build-up of lice under cool temperatures than warm temperatures was not demonstrated in this study.

10) Two goats, one from each treatment group, resisted their louse infestations on three occasions. Their rapid and consistent resistance to lice suggested that there was some fundamental difference between these two and the remaining four.

11) Counts of lice by fleece-parting techniques can provide good estimations of their population size. There was good correlation between the fleece-parting and post-mortem counts in this study.

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