AN INVESTIGATION INTO THE ECOLOGY, BIOLOGY, DISTRIBUTION AND CONTROL OF *HAEMAPHYSALIS LONGICORNIS* NEUMANN, 1901.

A thesis presented in partial fulfilment
of the requirements for the degree of
Master of Veterinary Science at
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1980

A B S T R A C T

In 1974, questionnaires were distributed to farmers in the East Coast and Hawke's Bay areas of the North Island of New Zealand. The tick Haemaphysalis longicornis Neumann 1901 was present on 59% of farms in the East Coast-Northern Hawke's Bay area and 7% of farms in the remainder of the Hawke's Bay area. In the former area the tick appeared to have spread rapidly between 1964 and 1974.

In the East Coast-Northern Hawke's Bay area, approximately one third of all farmers considered that the tick was a significant problem on their farm. In the Central and Southern Hawke's Bay area the tick was not considered a problem and conditions were probably marginal for tick survival.

The distribution of the tick was related to temperature, rainfall and altitude. Almost all farms where ticks were present were situated at less than 300 metres above sea level.

The distribution of tick counts of sheep were positively skewed and it was shown that the data should be normalized by transforming to logarithms or square roots. Square roots represent the easiest method of transformation.

A comparison between tick counts of the left ear, right ear, both ears and the body, showed that overall ear counts contribute to nearly 50% of the total tick count. However, the proportion of ticks on the ears compared with on the body varied over the counting period and ear counts were not highly correlated with body counts (highest correlation, r = 0.38).

The diamide, amitraz, showed a higher initial efficacy against H. longicornis compared with Chlorfenvinphos, but the latter appeared to have a longer period of residual activity.

In the Northern Hawke's Bay and East Coast area most (84%) sheep owners dip between January and March and over half (54%) dip in January or March and this period does not coincide with the adult and larval peaks.

Increasing sheep numbers from 3 per 1000 m^2 (equivalent to 30 per hectare) to 3 per 500 m^2 (equivalent to 60 per hectare) resulted in lower tick survival in the more heavily stocked areas.

An examination of the water balance of the unfed stages showed that larvae were very susceptible to desiccation at humidities below 80% R.H. Adults were more resistant to desiccation than nymphs. Larvae and nymphs regain water rapidly after desiccation. The critical equilibrium activities for the unfed stages was found to be approximately 0.8, 0.7 and 0.9 for larvae, nymphs and adults respectively.

Immersion of unfed and engorged stages in water indicated that the former survive immersion for $\geqslant$ 18 days while the latter showed lower survival.

Evidence is presented to suggest H. longicornis can cause deaths from anaemia in young Red Deer.

A C K N O W L E D G E M E N T S

The investigations reported in this thesis were carried out from 1974 - 1980 while the author was a veterinary officer with the Ministry of Agriculture and Fisheries. Some experimental work was carried out at Wallaceville Animal Research Centre and the remainder on farms in the East Coast and Hawke's Bay area.

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I am indebted to Dr W.A.G. Charleston and Dr A.C.G. Heath who supervised the research and provided valuable advice, criticism and encouragement throughout this study.

I wish to express my thanks to all past and present staff of the Animal Health Division, M.A.F. from Gisborne, Wairoa and Ruatoria who assisted with fencing and tick counting. To Messrs R. de Borst and M. Venning who also assisted with tick counting, my grateful thanks. Mr G.B. Davis collated the tick questionnaires from the central and southern Hawke's Bay area and I wish to acknowledge and thank him for this assistance.

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F.J.A. NEILSON

December, 1980

PREFACE

Between 1970 and 1974 the range and prevalence of *Haemaphysalis longicornis* appeared to be increasing on farms in the East Coast and Northern Hawke's Bay area. Because of this apparent increase in tick numbers a census was posted to farmers in the area with the aim of mapping tick distribution. Then by a process of inductive reasoning it was hoped to examine various factors that might influence this distribution. The Central Hawke's Bay area was included in the census as only a few ticks had been reported from this area.

Some farmers in the East Coast and Northern H.B. area considered that the tick was economically important so selected farm practices (e.g. stocking rate, time of dipping or showering, choice of insecticide) were investigated as it was hoped this might provide information on which recommendations for the control of the tick could be based.

Water balance is essential for the survival of all animal species but it is crucial to the existence of ticks because of their surface to volume ratio. As the water relations of eggs and engorged stages of H. longicornis have been thoroughly investigated (Heath, 1974) so it was decided to investigate this relationship in the unfed stages. It was hoped that this might lead to a better understanding of the survival and hence the distribution of the tick.

"The tick is generated from couch grass."
Aristotle in Historia Animalium, circa 300 B.C.

"After treatment there will be no sores and the wool will be more plentiful and in better condition and the ricini (ticks) will not be troublesome".
M. Porcius Cata 200 B.C.

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REVIEW OF THE LITERATURE

1.1 General introduction

Ticks are obligate, temporarily ectoparasitic, acarines. They parasitise terrestrial vertebrates i.e. mammals, reptiles and birds. Exceptions to this are the tick Aponomma ecinctum which parasitises a beetle, and two species of Amblyomma which infest marine snakes and lizards on land, and are carried to sea by their hosts (Hoogstraal, 1973; Krantz, 1975; Savory, 1977). Ixodid ticks feed almost exclusively on blood. Occasionally light coloured ticks are seen that have fed on extravascular fluid and lysed host cells (Arthur, 1965). The world tick fauna is known to comprise more than 800 species (Hoogstraal, 1973).

1.2 Taxonomy of ticks (Table 1.1)

Ticks are arthropod members of the class Arachnida and the order Acarina whose members differ from members of the other arthropod orders in that there is no recognisable constriction between the gnathosoma (region of oral opening and mouth parts) and the idiosoma (the remaining parts of the body) (Baker and Wharton, 1958; Noble and Noble, 1976). Ticks and mites are differentiated according to the absence, or presence and location of spiracles, in the older instars. Ticks also differ from other blood-sucking acarina in their possession of a well developed hypostome and with a few exceptions are of larger size than the mites.

The superfamily Ixodoidea consists of three families. There is only one species in the family Nuttalielidae. There are important differences between the Argasidae and Ixodidae but these will not be discussed in this review (see Lees, 1947; Campbell, 1966; Roberts, 1970; Hoogstraal, 1973, 1978; Savory, 1977). There are between 650 (Hoogstraal, 1973, 1978) and 700 (Krantz, 1975; Savory, 1977) species of ixodid tick.

Table 1.1

Taxonomic relationships of ticks.

Phylum Arthropoda	Classes Insecta, Crustacea, Myriapoda, Onychophora Pauropoda, Diplopoda, Chilopoda, Symphyla.
Class Arachnida	Orders, Scorpioniones, Pseudoscorpions, Opiliones, Palpigradi, Uropygi, Schizomida, Amblypygi, Araneae, Solpugida, Ricinulei.
Order Acarina (Acari) (ticks and mites)	Sub-orders, Astigmata, Cryptostigmata, Notostigmata, Mesostigmata, Prostigmata, Tetrastigmata.
Sub-order Metastigmata	
Superfamily Ixodoidea (ticks)	Families Argasidae, Nuttalielidae.
Family Ixodidae	Genera Amblyomma, Aponomma, Boophilus, Dermacentor, Hyalomma, Ixodes, Rhipicephalus, et al.
Genus Haemaphysalis	

1.3 The genus Haemaphysalis

There are approximately 150 species in this genus (Hoogstraal, 1973, 1978). Members of the genus are eyeless, inornate and relatively small. Despite the lack of fossil records of ticks (Savory, 1977), Hoogstraal (1978) suggests that the genus reflects a strong evolutionary trend towards reduction in body size. Most unfed female Haemaphysalis species are 2 - 4 mm in length, with a few species 5 - 6 mm long. More than 100 Haemaphysalis species infest mammals. However, domestic cattle, sheep and goats have been recorded as hosts of adults of only a few species. The smallest (2 mm long) parasitise rodents and birds while the small to medium size range (2.5 - 4.5 mm) feed on larger species such as deer, antelopes, wild goats, sheep and carnivores (Hoogstraal, 1973, 1978).

1.4 Taxonomy and distribution of Haemaphysalis longicornis

Haemaphysalis bispinosa is a bisexual tick found only in tropical countries (see Figure 1.1 and Table 1.2) for distribution. It is smaller than H. longicornis and there are other structural differences such as the shape of the coxal spurs and the dental formula (see Table 1.3). Despite this, until 1968, the parthenogenetic species of Haemaphysalis in Australia, New Zealand, some South Pacific Islands, Japan, North East China, and the Primorye area of U.S.S.R. was referred to as H. bispinosa. Specimens from these areas were found to be structurally and morphologically identical to H. longicornis Neumann, 1901, originally described from Australia (Hoogstraal, Roberts, Kohls and Tipton, 1968). It was found that the parthenogenetic species occurring in northeastern U.S.S.R. and northern Japan and previously referred to as H. neumanni was also structurally and biologically identical to H. longicornis (Hoogstraal, et al, 1968). Thus the parthenogenetic strain of either H. bispinosa or H. neumanni in the areas referred to above is in fact a single biological identity for which H. longicornis is the correct name (Hoogstraal, et al, 1968).

In 1961 it was established that there was a parthenogenetic and bisexual race of H. longicornis in Japan (Kitaoka, 1961d) the former occurring north of 36°N and the latter south of this line. However, Oliver, Tanaka and Sawada (1973) provide a modified map from Kitaoka (1971) to show that the parthenogenetic strain occurs south of 36°N to the extent that it is sympatric with the bisexual strain on southern Honshu and Kyushu Islands and even occurs on the Island of Yakushima, south of Kyushu.

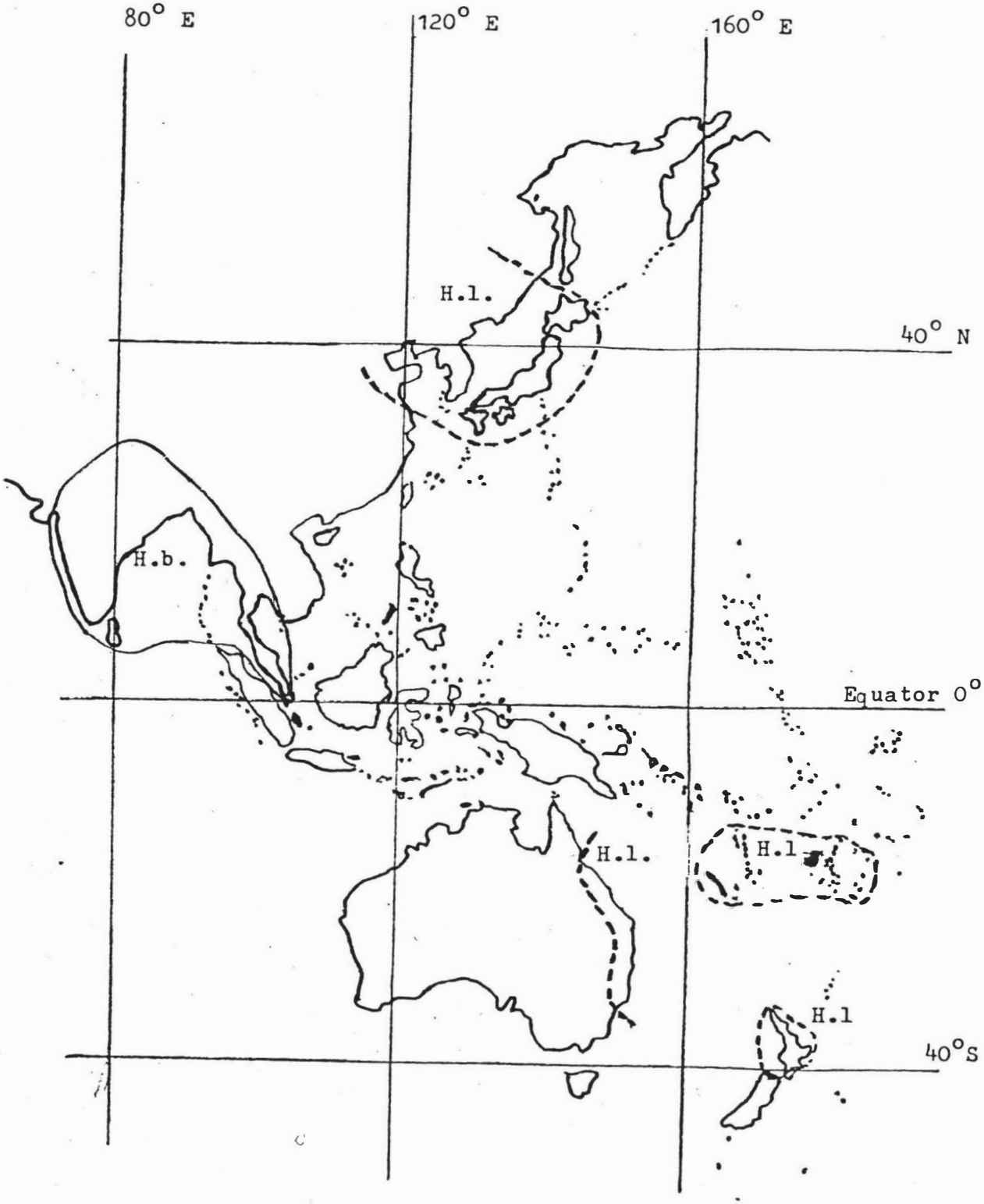
The bisexual race of H. longicornis as well as occurring in southern Japan, is present in the extreme south of the Primorye, U.S.S.R. and in Korea. The average size of this bisexual race is smaller than the parthenogenetic race (Kitaoka, 1961d; Hoogstraal, et al, 1968). This has been further confirmed by Oliver and Herrin (1976).

Despite differences in the biology of the bisexual and parthenogenetic races (Hoogstraal, *et al*, 1968), size differences already referred to, and differences in karyotype (Oliver, *et al*, 1973) the bisexual race has been tentatively referred to the taxon *longicornis* (Hoogstraal, *et al*, 1968) rather than *bispinosa*.

Both bisexual and parthenogenetic races are said to be present in north-eastern China (Teng, 1955). Female specimens from Australia, New Zealand, New Caledonia, Fiji and Tonga were examined, Hoogstraal, *et al*, (1968). They matched the description of parthenogenetic *H. longicornis*. Thus it appears *H. longicornis* is solely parthenogenetic in the South Pacific.

A race also exists on the Cheju Island off the southern tip of Korea which can reproduce either bisexually or parthenogenetically (Oliver, *et al*, 1973) (see section 1.6 for genetics of *H. longicornis*).

Figure 1.1 World distributions of H. longicornis and H. bispinosa.



Key to Figure 1.1

H.l = *Haemaphysalis longicornis*

H.b = *Haemaphysalis bispinosa*

Based on information from -

1. Hoogstraal, Roberts, Kohls and Tipton (1968)
2. Oliver, Tanaka, and Sawada (1973)
3. Heath (1974, 1977)
4. Muir (pers. comm.)

Table 1.2

World distributions of H. longicornis and H. bispinosa

H. bispinosa	Parthenogenetic H. longicornis	Bisexual H. longicornis	Bisexual and Parthenogenetic H. longicornis
Burma	Australia	China (North East)	Korea (at Sogwan) (on Cheju-Do-Is.)
Ceylon	China (North East)	Korea	
India	Fiji	Japan	
Malaya	Japan	Honshu Is.	
Nepal	Hokkaido Is.	Kyushu Is.	
Pakistan	Kyushu Is.	Shikoku Is.	
Thailand	Honshu Is.	+ 2 other islands adjacent to Japan.	
	Yakushima Is.	U.S.S.R. (South Primorye adjacent to Korea.)	
	+ 4 other islands adjacent to Japan.		
	New Caledonia		
	New Hebrides (Efate Islands)		
	New Zealand		
	Tonga		
	U.S.S.R. (most of Primorye area)		

Table based on information from:

Teng (1955)
Kitaoka (1961d)
Hoogstraal, Roberts, Kohls and Tipton (1968)
Oliver, Tanaka, and Sawada (1973)
Herrin and Oliver (1974)
Oliver and Herrin (1976)

One specimen of H. longicornis has been collected from Hawaii. This was recovered from a dog which was exported from New South Wales, Australia, to Hawaii, thence to Texas, U.S.A.

Table 1.3

Comparison of *H. longicornis* and *H. bispinosa*

	H. longicornis	*H. bispinosa*
Reproduction	(1) Bisexual (obligatory) race (2) Parthenogenetic (obligatory) race (3) Race reproducing either (1) or (2)	Bisexual only
Approximate size (in mm)		
Unengorged male	2.46 - 2.96	2.0
Unengorged female	2.56 - 3.25	2.2
Dental formula		
Female	5/5	4/4
Nymph	3/3	2/2
Coxal spurs	Short and triangular	Long and pointed
Palpal segment (nymph)	No bulge on postero-dorsal margin	Bulge on postero-dorsal margin
Spiracular plates (nymph)	Dorsal projection	No dorsal projection

Data from Hoogstraal *et al*, 1968
Roberts, 1963, 1970

1.5 Morphology of ticks

1.5.1 General

Ticks are the largest forms of the Acarina with engorged adults of some species of Amblyomma and Hyalomma measuring up to 30 mm in length (Balashov, 1972).

There is an unsegmented idiosoma and a gnathosoma. The idiosoma bears 4 pairs of legs in adult and nymphal ticks and three pairs in larval stages. The gnathosoma consists of a well developed capitulum which articulates with the idiosoma by the camerostomal fold. The aperture of Gene's organ is present in the dorsal part of the camerostomal fold. The hypostome is a heavily sclerotized anterior process of the basis capitulum, covered externally by longitudinal rows of retrograde teeth. Dorsal to the hypostome are paired chelicerae encased in sheaths. Each chelicera terminates in a movable and a fixed digit. On the lateral sides of the capitulum are two palps which function as sensory organs.

A prominent feature of ixodid ticks is the dorsal shield (scutum) which covers $\frac{1}{3}$ of the dorsal surface of unfed females, nymphs and larvae. In males, the scutum covers the entire dorsal surface of the body. Apart from their smaller size and absence of a ventral genital aperture, the larvae and nymphs resemble the female in external appearance.

In nymphal and adult ixodids the tracheal system opens at a pair of large spiracular plates behind the coxae of the fourth pair of legs. Ixodid larvae however, do not possess a tracheal system and this has important biological implications (see Section 1.12).

Apart from the palps there are two other sensory structures.

Haller's organ is an indented structure located on the tarsus of the first pair of legs and it probably has olfactory and humidity receptors (Lees, 1969). The forelegs have bristles (sensillae) which are thought to act as temperature receptors and tactile mechanoreceptors (Lees, 1969).

As the integument of arthropods is the main barrier reducing water loss by transpiration it has been the subject of considerable study. The integument of ticks has been described by Lees (1947, 1952). The internal anatomy of ticks has been reviewed in detail by Balashov (1972).

1.5.2 Morphology of H. longicornis

The morphology of the male, female, nymph, and larva are shown in Figures 1.2, 1.3, 1.4, and 1.5. The dimensions of the various instars are shown in Table 1.4. From this Table it can be seen that the engorged nymph is of similar size to unengorged female so that the engorged nymph could be misidentified as an unengorged adult. However, the legs of the adult are considerably longer than those of the nymph and this provides a quick means of identification.

Table 1.4 represents approximate values only. There is a variation between authors in sizes quoted, either expressed as one figure, as ranges and as means. The sizes mentioned by Wagland, et al,(1979) do not agree with that of Namba (1958). The latter author worked with H. longicornis on Hokkaido where only the parthenogenetic strain occurs.

Variations may be related to the area measured. In Roberts' original paper (1963) the lengths quoted are exlusive of the capitulum. Some of these figures are present in Hoogstraal et al (1968) without reference to the area measured. For this reason the values in Table 1.3 for the unengorged stages are from Roberts' (1963, 1970) who does not mention means or standard deviations.

Figure 1.2

Haemaphysalis longicornis from cattle (Queensland specimen)

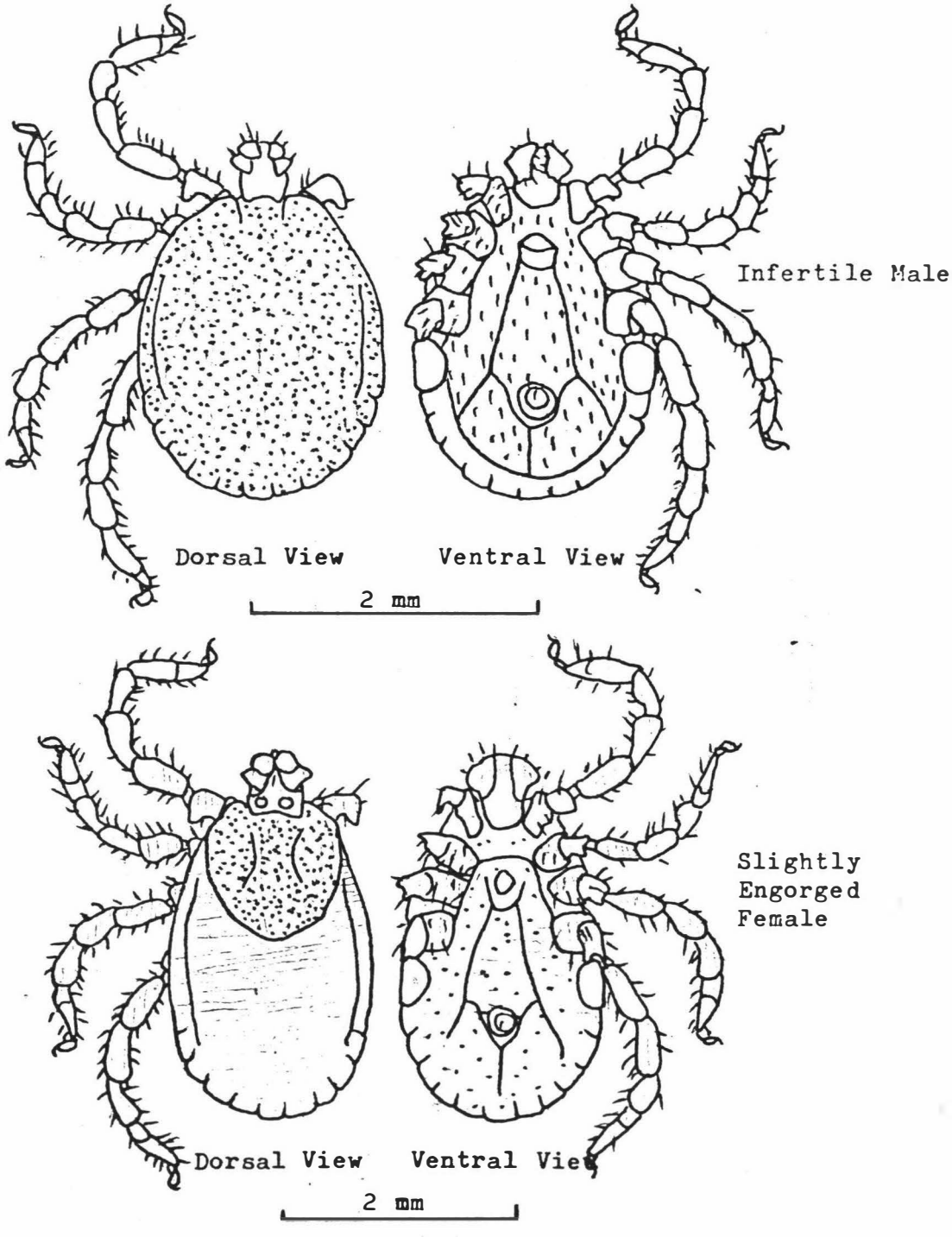


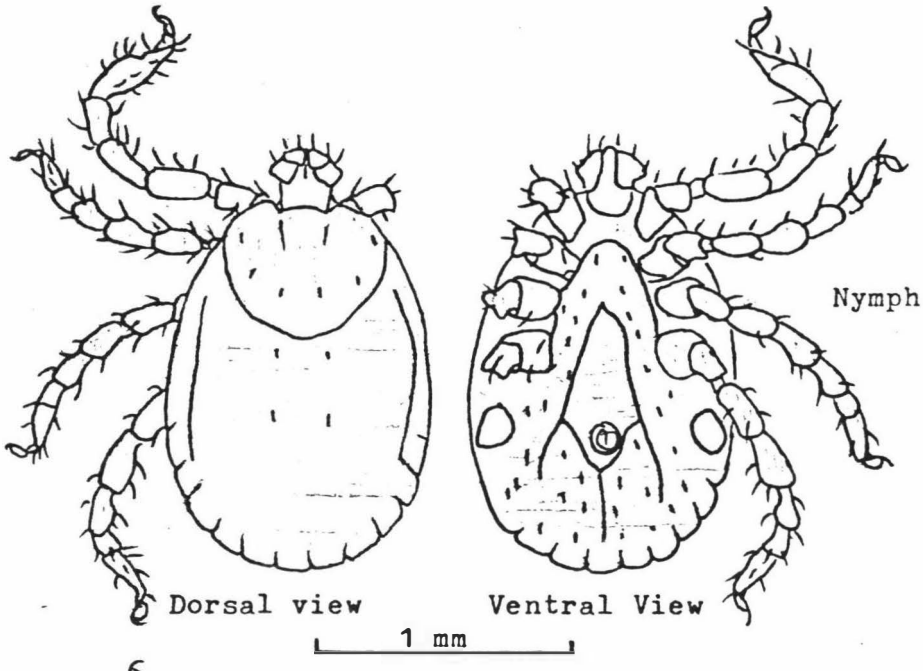
Figure 1.3

Haemaphysalis longicornis from cattle (Queensland specimen)

From Hoogstraal, Roberts, Kohls, and Tipton, 1968.

Figure 1.4

Haemaphysalis longicornis parent female from cattle
(Queensland specimen)



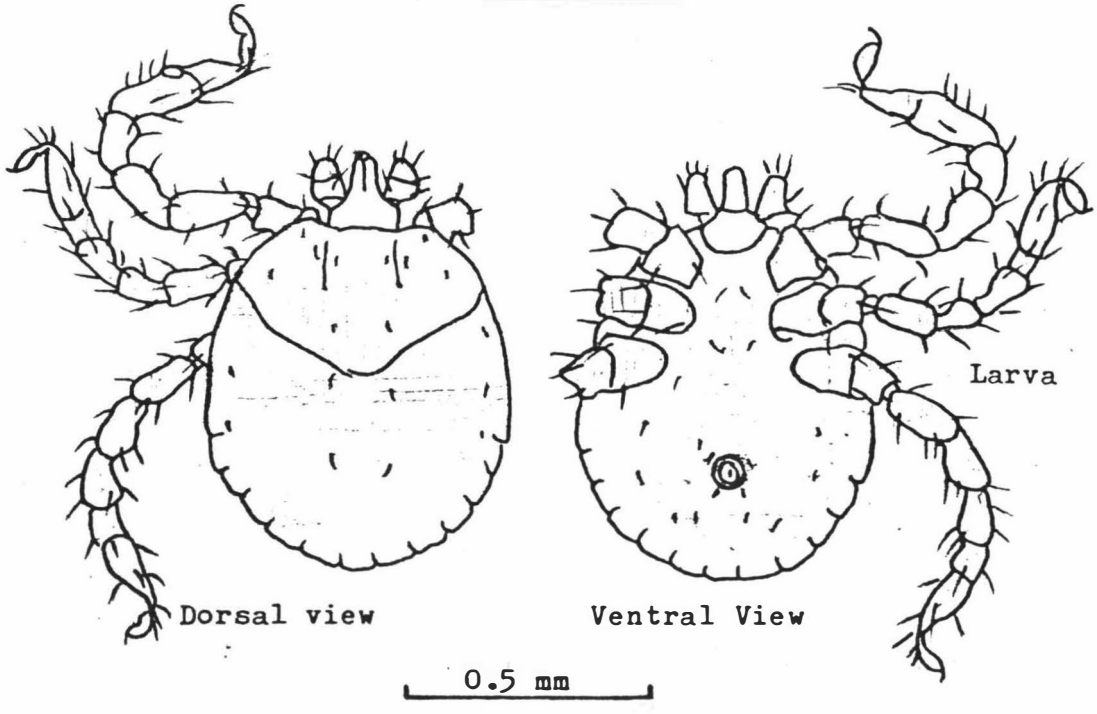


Figure 1.5

Haemaphysalis longicornis parent female from cattle
(Queensland specimen)

From Hoogstraal, Roberts, Kohls, and Tipton, 1968.

Table 1.4

Approximate size ranges of H. longicornis in mm.

		Male	Unengorged Female	Unengorged Nymph	Unengorged Larvae
1.	Length	2.46-2.96	2.56-3.25	Approx. 1.81	Approx. 0.73
	Breadth	1.50-1.70	1.5 -1.8	Approx. 1.03	Approx. 0.47
			Engorged Female	Engorged Nymph	Engorged Larva
2.	Mean length -		8.91 ±0.66	3.03 ±0.27	1.60 ±0.06
3.	Approx. Length x breadth -		9.8 x 8.2	2.9 x 1.9	1.5 x 1.0

1. From Roberts, 1963, 1970 - Unengorged stages.
2. From Wagland, Sutherst and Roberts, 1979 - Engorged stages.
3. From Roberts, 1963, 1970 - Engorged stages.

Although the first arachnids appeared in the Upper Silurian period about 400 million years ago (Southcott, 1978), there are inadequate palaentological records of ticks (Savory, 1977) so that their phylogeny is obscure. Notwithstanding this, Hoogstraal (1978), considers members of the genera Haemaphysalis and Ixodes structurally primitive ixodids.

All species of Haemaphysalis, Boophilus, Dermacentor and Rhipicephalus have short mouthparts and are brevirostrate because of the relatively small hypostome ("rostrum") (Balashov, 1972). Although the mouthparts of species of the latter 3 genera do not penetrate the dermis, they are inserted more deeply into the epidermis than are those of species of Haemaphysalis (Arthur, 1973). Some ticks such as species of Amblyomma, Hyalomma and Aponomma penetrate into the dermal tissue with their mouthparts (Arthur, 1973) (for further discussion, see Section 1.11.1).

1.6 Genetics of H. longicornis

A study of karyotypes and sex-determining mechanisms in ticks may clarify or confirm phylogenetic and taxonomic relationships (Oliver, 1964). The mode of reproduction is also important in terms of dispersal of ticks. As there are three races tentatively included in the taxon longicornis all with different karyotypes, they have been studied in more detail than have most other ticks.

The chromosome number and sex determining mechanism are variable in ticks (Oliver and Bremner, 1968). Most ticks have relatively few chromosomes (Oliver, 1964). The most prevalent karyotype in ixodid ticks is 20 autosomes and 2 sex chromosomes in the female and 20 autosomes and 1 sex chromosome in the male i.e. the male is the heterogametic sex. This is said to represent the primitive condition in ixodids (Oliver and Bremner, 1968).

The females of the bisexual race of H. longicornis possess 22 chromosomes, the males 21, and they are diploid. Species of the parthenogenetic race contain 30-35 chromosomes. Usually the females have 32 or 33 chromosomes and the rare males 31 so that they are triploid and polyploid. Specimens of the race from Cheju Island contain 22-28 chromosomes. Although many of these possess the diploid number (female, 2n = 22), others have more than an integral multiple of the haploid number and are, therefore, aneuploid (Oliver, Tanaka, and Sawada, 1973).

Polyploidy occurs in a number of species whose reproduction is parthenogenetic as it is in one race of H. longicornis (White, 1973a). There are 3 forms of parthenogenesis:

(a) cyclical parthenogenesis as occurs in aphids;
(b) arrhentoky - where males arise from unfertilised eggs and females from fertilised eggs.
(c) thelytoky - where males are rare or absent (White, 1973b).

H. longicornis clearly falls into this latter (c) category.

Arrhentoky has not been reported in ticks, although it occurs in many families of mites (Oliver and Herrin, 1974). Although thelytoky occurs in 5 of the 7 orders of Acarina, it is rare in ticks (Oliver, 1971). Two forms of thelytoky can occur; automictic thelytoky where meiosis still occurs in the egg and apomictic thelytoky where no meiosis occurs (White, 1973b).

The claim of Takenouchi, Shiitsu, and Toshioku (1970), that parthenogenetic H. longicornis reproduce by apomictic thelytoky, has been criticised by Oliver and Herrin (1976) who regard their evidence as unconvincing. They (Oliver and Herrin, 1976) suggest that the aneuploid thelytokous individuals from Cheju Island are probably automictic. The type of thelytoky occurring in triploid parthenogenetic H. longicornis remains uncertain.

According to White (1973b) most even-numbered polyploids reproduce sexually and the odd-numbered (anisopolyploid) e.g. 3n, 5n etc. individuals are apomicts. Regardless of whether thelytokous H. longicornis are apomictic or automictic, thelytoky itself differs radically from all other genetic systems (White, 1970). If a single thelytokous individual is transported by accident to a new locality it can give rise to a new colony of ticks providing conditions are suitable (White, 1973a). Circumstantial evidence for this can be seen in the wide dispersal of the thelytokous H. longicornis in the South Pacific.

If thelytokous H. longicornis reproduces apomictically, recombination of genes does not occur, i.e. no synapses or bivalents are formed (White, 1973a), there is only a single maturation division in the oocyte. Thus a single combination of genes is fixed and perpetuated ad infinitum. However, in spite of the fact that genetic recombination cannot occur, any successful mutations are immediately incorporated into the genome.

It has been suggested that the inherent genetic limitations of all thelytokous systems have prevented them from being a long-term success in any group of animals (White, 1973b). However, some triploid thelytokous forms of Chironomidae and Simuliidae survive successfully in the extreme environment of the subarctic or arctic. It should not be assumed therefore that if thelytokous H. longicornis is apomictic its genetic system is inferior or unsuccessful.

1.7 Introduction of H. longicornis into New Zealand and Australia.

The precise date of the introduction of H. longicornis into Australia and New Zealand is uncertain. The first recorded specimens in New Zealand were collected near Kaitaia in January 1911 (Myers, 1924). However, Reakes (1918) considered that there was an authentic report of the tick near Whangarei in 1904 and that it may have been present at the most northerly portion of the North Island of New Zealand (Mangonui County) in 1893. Six years after the tick's appearance near Kaitaia the tick was said to be plentiful in the Tauranga area (Myers, 1924). A report by Thomson (1922) refers to a hedgehog found near Tauranga and infested with ticks which was reported as having been observed "many years" prior to 1913. Ticks on a hedgehog are unlikely to be any species other than H. longicornis (see Section 1.9).

It is possible that following the introduction of the tick, low numbers may have been present and not noticed for several years. With reference to Ixodes ricinus, Milne (1950b) has suggested that ticks do not become numerous for 15 - 20 years after their introduction to a new location. This is less likely to apply to H. longicornis which has 1 generation per year compared to the $1\frac{1}{2}$ - $4\frac{1}{2}$ years needed for I. ricinus to complete its life cycle (Milne, 1943). The rate of increase in numbers would depend very much on host-availability and the suitability of environmental conditions. Considering the limited evidence available, it is therefore likely that H. longicornis was introduced into the Northland region between 1890 - 1900.

H. longicornis was first recorded in Australia by Neuman (1901) (cited by Hoogstraal, et al, 1968; Roberts, 1963). The specimens collected by Neumann were from cattle located at Kempsey on the northern coast of New South Wales. It is possible that the species was present in Australia several years prior to this.

Therefore, the date of introduction into Australia of *H. longicornis* is probably similar to, or perhaps earlier, that relating to the New Zealand introduction viz. 1870 - 1900.

The origins of the endemic tick fauna of New Zealand (see Section 1.9) have been reviewed by Heath (1977). These ticks appear to have been introduced from several areas remote from New Zealand. It is generally accepted that *H. longicornis* was introduced on cattle from Japan to Australia and thence to New Zealand (Roberts, 1963; Hoogstraal, *et al*, 1968; Heath, 1977). Thus it may appear fruitless to speculate on other modes of introduction. The subject is of some importance, however because of the possibilities of other tick species being introduced and becoming established in New Zealand. Unidentified ixodid ticks have been intercepted by the New Zealand Port Agricultural Service on plant material from Australia (Hellstrom, 1978). Both *Ixodes holocyclus* (Anon, 1973a) and *Rhipicephalus sanguineus* (Anon, 1980) have also been accidentally introduced into New Zealand. It is obvious that detailed information on the biology, and temperature and humidity preferendies of a tick species need to be known before one can speculate as to whether a tick species would establish if introduced into New Zealand. Lower temperatures in New Zealand would not prevent the establishment of some species of *Ixodes*, *Haemaphysalis* and *Argas*. Some members of these genera exist in cold northern and southern latitudes because of their ability to undergo diapause. Thus some other ticks, if introduced, could establish in New Zealand. Accordingly the likely methods of introduction of *H. longicornis* will be examined.

The establishment of quarantine for cattle began in Australia in 1871. This was extended to include sheep, goats, swine and dogs in 1884. Under the Customs Act of 1879, the importation of cattle and sheep was banned from all countries except Great Britain and Ireland (Pierce, 1975), where *H. longicornis* does not occur. Thus, if *H. longicornis* was introduced into Australia with cattle from Japan, it must have been introduced before 1879, 22 years prior to the Neumann's first record.

The early New Zealand Department of Agriculture, Annual Reports (first produced in 1893), contain general references to stock importations and quarantine, but little information on the countries of origin. The same can be said for the New Zealand Official Year Book.

In 1893 quarantine stations were established in New Zealand on Somes Island, Wellington and Quail Island at Lyttleton (Holmden, pers. comm.). Following an outbreak of pleuropneumonia in cattle in the Waikato in 1880, importation of cattle from Australia to New Zealand was stopped (Holmden, pers. comm.). As with Australia it appears that the connection between the introduction of H. longicornis with cattle is not supported with any factual evidence.

Acclimatization societies introduced a variety of exotic species into Australia (Pierce, 1975) and New Zealand (Thomson, 1922; Wodzicki, 1950) in the 19th century. The activities of these societies were short in Australia lasting from 1860 to 1870 (Pierce, 1975). These societies were very active until 1880 in New Zealand and it was not till 1895 that written consent from the New Zealand Department of Agriculture was required, to introduce any animal or bird into New Zealand.

Approximately 53 different species of mammals were introduced into New Zealand (Wodzicki, 1950). However, the countries of origin, dates of importation, or areas of introduction in New Zealand, eliminate these mammals as a possible means of introduction of the tick H. longicornis.

About 130 species of birds were introduced into New Zealand in the 19th century (Thomson, 1922). Again, many of these can be discounted as a method of introduction of H. longicornis for reasons similar to those relating to mammals. Chinese and Korean birds were imported into New Zealand (Thomson, 1922) but there are no records of them being introduced into Northland. It is unlikely that H. longicornis would still be on the host after a long sea voyage from China or Korea.

Australian quail were introduced by the Auckland Acclimatization Society in 1867 and 1871 and apparently flourished in the Auckland and Northland districts (Thomson, 1922) and are a possible means of introduction from Australia.

H. longicornis was first recorded from coastal areas of Australia and New Zealand. This could suggest that migratory birds may have introduced the tick and that it only established in 1890 - 1900 as vertebrate hosts increased in these areas.

The moulting of larvae and nymphs and the incubation of eggs of ticks are retarded by low temperatures and humidities, and Heath (1977) has suggested therefore that eggs or active stages of ticks could be transported over long distances adhering to birds' feathers or feet. Migratory birds do transfer ticks from one area to another (Dumbleton, 1953; Yamaguti, Tipton, Keegan, and Toshioka, 1971; Saito and Hoogstraal, 1972). Accordingly migratory birds cannot be discounted as a possible means of introduction of H. longicornis.

Finally, the survival and development of engorged nymphs held for 11 days at humidities below 5% R.H. (Heath, 1974) indicates that the introduction of the tick on inamimate objects also cannot be discounted.

1.8 The establishment, spread and present distribution of H. longicornis in New Zealand.

A generalised map of the distribution of H. longicornis in New Zealand is shown in Figure 1.6 (from Heath, 1977). This map does not show variations in densities or discontinuities in distribution of ticks. There are areas within the general endemic area where ticks are absent. On the edges of the endemic area, conditions for survival and development will be marginal so that the distribution will be irregular and, usually, ticks fewer in number.

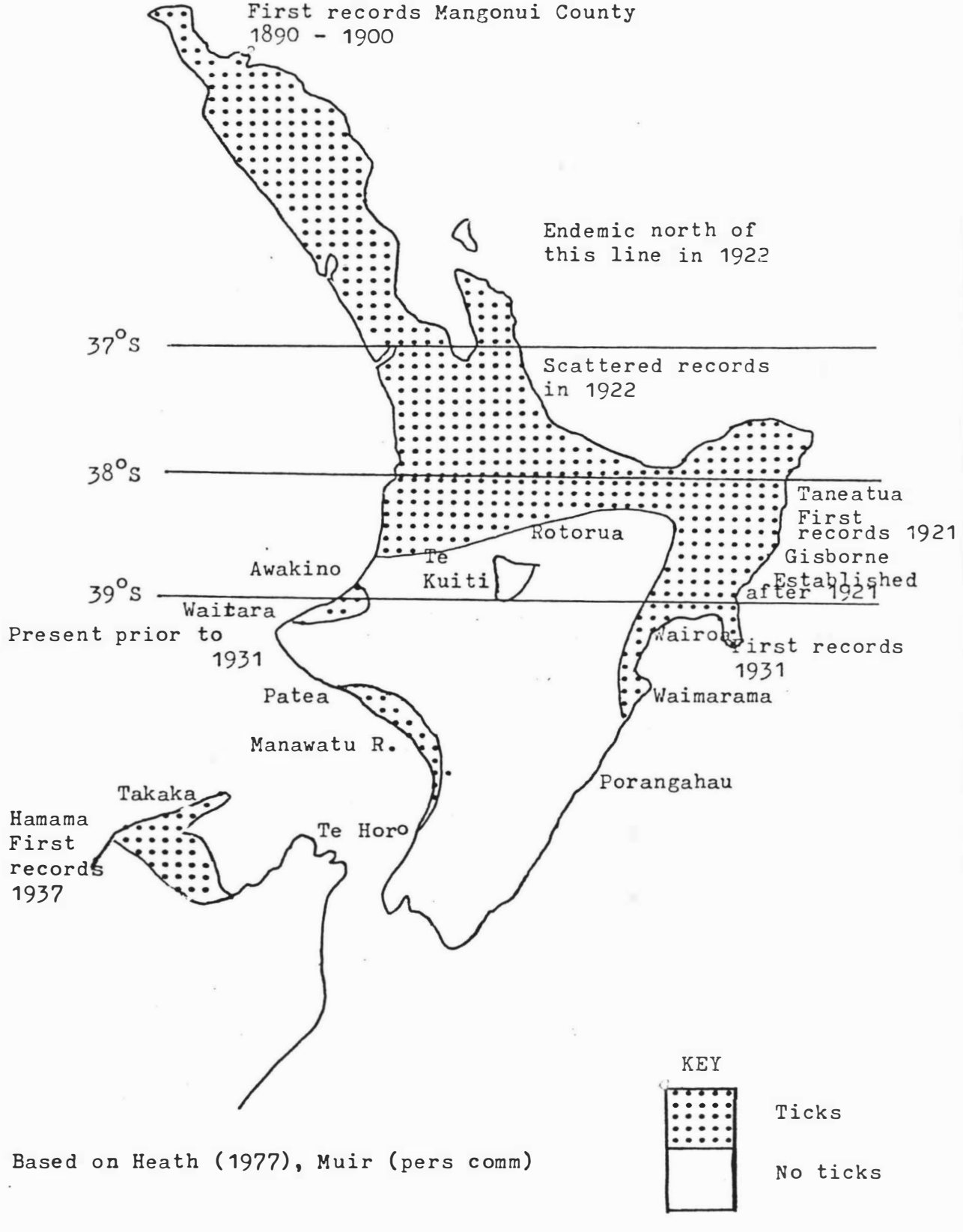
Having established first in Northland, the tick quickly spread southward over the next 20 years or so. Ticks were rare in the Bay of Islands in 1912, but increased rapidly from 1914 to 1918 (Reid, 1923). By 1922 the tick was established in the Auckland Province and most of the Coromandel Peninsula. It was recorded further south in scattered localities in the Waikato and Bay of Plenty areas (Miller, 1922).

On the East Coast of the North Island the tick was recorded south of Opotiki at Taneatua by 1921. Dips were erected on the northern highways leading into Poverty Bay (Mackay, 1949). These dips failed to check the spread of the tick. It is believed that not all access routes were covered and only cattle were dipped, not sheep or horses. H. longicornis subsequently established itself in the Poverty Bay area.

In 1931 the tick was first recorded in the northern Hawke's Bay area. One tick was found on each of three farms and 4 ticks on another in the Awamate area a few kilometres from Wairoa (Wairoa, M.A.F. office files). On the West Coast of the North Island H. longicornis had spread to almost the same latitude (39^{o} South) being present at Waitara in Taranaki by 1931 (Wairoa, M.A.F. office files). Within 30 or 40 years of its introduction the tick had spread to most of its endemic area of the North Island.

Figure 1.6

Distribution of H. longicornis within New Zealand



Based on Heath (1977), Muir (pers comm)

By 1928 H. longicornis had not yet been reported from the South Island. On that date the Cattle Tick Regulations were amended to require cattle and sheep to be inspected prior to shipment to the South Island. Sheep were only required to be inspected if they came from tick-infested areas. Horses or goats were not required to be examined. Nine years later, in 1937, H. longicornis was first recorded from the South Island. Ticks were present, "clustered around the heads" of dairy cattle, at Hanama, near Takaka, in Golden Bay. The tick was recorded from several farms in 1937 and an officer of the M.A.F. was stationed at Takaka to control the infestation by spraying the animals with an arsenical dip (Muir pers. comm.). Subsequent to 1937 ticks either disappeared or were reduced to such low numbers that they were not reported (Muir pers. comm.).

In January 1974, one adult tick was recovered from Romney lambs on a coastal property near the mouth of the Patarau River in western Golden Bay. This was identified as H. longicornis by G.W. Ramsey (Muir pers. comm.).

In December 1974, 30 ticks were recovered from 400 lambs from the same property (Muir pers. comm.). These ticks were also identified as H. longicornis.

Further east of Golden Bay, in the Tasman Bay area, there have been rare sightings of ticks, of which only one was identified as H. longicornis (Muir pers. comm.). Although ticks were first recorded in the area in 1937 it is clear that the area is marginal for tick survival and development. Based on this inference, the requirement that cattle and sheep be inspected for ticks prior to shipment to the South Island was abolished in 1977.

1.9 Tick fauna of the New Zealand sub region.

This has been described in several papers by Dumbleton (1943, 1953, 1958, 1961, 1963, 1973). There are 9 named species of which 8 are ixodids and one is an argasid. Apart from *H. longicornis* which has a wide host range, and *Aponomma sphenodonti* which parasitises the tuatara (*Sphenodon punctatus*), the remaining 7 species all parasitise birds. Recently an argasid tick, yet to be named, was collected from a native bat (Heath, 1977, citing a pers. comm. from G.W. Ramsay).

1.10 The significance and economic importance of ticks.

Ticks are generally regarded as the ectoparasites that cause the greatest economic loss in the world today (Snelson, 1975, cited by Bram and Gray, 1979). Ticks are reported to affect 80% of the world cattle population causing estimated losses of $400 million annually (Beesley, 1973). Ticks are considered a serious problem in Argentina, Australia, Colombia, Mexico, Uruguay and south and central Africa (Beesley, 1973). Theiler (1964) suggests that the economic loss caused by ticks in Africa is increasing. The breakdown of tick control in Zimbabwe during the war between 1973 and 1979 exemplifies the economic importance of ticks in this area. It has been estimated that of the 3 million cattle present on tribal trust lands in 1973, one third of these died of tick-borne diseases between 1974 to 1979 (Lawrence, Foggin and Norval, 1980).

Ticks are reservoirs and vectors of many pathogens which when transmitted to livestock, cause diseases of considerable importance. However, they are also capable of directly affecting the health and productivity of animals by the removal of blood, injection of toxins and predisposing animals to skin diseases: they can also affect the quality of hides and skins. Ticks which are known to cause disease in animals independent of their roles as vectors of pathogenic organism include members of the genera Amblyomma, Boophilus and Hyalomma (Callow, 1978).

A number of recent experiments have shown that at least some tick species can significantly affect cattle production. For example, even low (30 ticks) or moderate (80 ticks) burdens of adult Amblyomma maculatum significantly depressed growth and haematological parameters under both feedlot and pasture conditions (Williams, Hair and Buckner, 1977; Williams, Hair and McNew, 1978). It was thought that the tick either directly affected the host's metabolism and/or depressed appetite.

Boophilus microplus has long been known to decrease growth rates and cause anaemia in cattle (Riek, 1957; Francis, 1960; Little, 1963) and some experiments suggested that a toxin secreted by the tick might contribute to these effects (O'Kelly and Seifert, 1969, 1970). Further investigations indicated that a large proportion ($\frac{2}{3}$) of the decrease in growth rate was caused by decreased appetite and that animals did not readily make up the growth deficiency after the ticks were removed (Seebeck, Springell and O'Kelly, 1971). Major changes in erythroid values and plasma protein levels also occurred in these animals (O'Kelly, Seebeck and Springell, 1971) but these were found to be due directly to the feeding of the ticks rather than secondary to the anorexia (Springell, O'Kelly and Seebeck, 1971). Similar results were found by Vercoe and O'Kelly (1972) who found that the effects persisted for at least 4 weeks after removal of the ticks.

It appears reasonable to assume that much of the effects seen with infestations of B. microplus result from a toxin secreted by the ticks (Seebeck, et al, 1971; O'Kelly, et al, 1971; Springell, et al, 1971). Confirmation of this hypothesis can only be decided when the toxic principle is isolated and when injected into hosts which have been subjected to regular phlebotomy causes similar changes to that seen in tick-infested animals. Other species of ticks, such as Dermacentor andersoni, D. variabilis, Amblyomma maculatum, Ixodes rubicundus and I. holocyclus, inject a toxin into the host which may cause paralysis (Balashov, 1972).

An important component of the economic cost of ticks is the monetary value of labour and insecticides expended in attempting to control ticks. For example, in Australia, it was estimated that $\frac{1}{3}$ of annual cost of tick control was directly accounted for by labour and insecticides (Anon, 1975a).

In summary, to be of economic importance, ticks must either transmit diseases to domestic animals or increase to such numbers that the health and productivity of the animals are adversely affected.

For a species to build up to high levels on domestic animals on farmed land, the tick species must be able to exploit or survive the ecological changes caused by the agricultural practices of man (Norval, 1979).

Finally, the host-tick relationship may not always be significantly harmful to the host. Where both have had an intimate association for a long period the host may have developed a strong resistance. An example of this is the resistance of Zebu cattle to B. microplus (reviewed by Seifert, 1971). Domestic mammals and birds often carry heavier tick burdens than healthy wild mammals and birds living in the same environment. For example, African antelope carry fewer Boophilus decoloratus than cattle introduced into the same area (Hoogstraal, 1978).

There are, then, host factors that affect the numbers of ticks either gaining entry on, attaching or engorging on the animal. It has been shown that stress reduces the resistance of the host to some ticks. Cattle carry heavier burdens of B. microplus when under nutritional stress (O'Kelly and Seifert, 1969). European cattle (Bos taurus), when lactating, are more heavily infested with B. microplus than non-lactating cattle (Seifert, 1971). More Rhipicephalus sanguineus larvae imbibe from Vitamin A deficient rats than from normal controls and more larvae imbibe from cortisone treated mice than control mice (Sweatman and Ali, 1966).

Some of these host factors have recently been elucidated in Australia. Cattle highly resistant to B. microplus develop a skin reaction to larval B. microplus with histamine release and eosinophils and mast cells concentrated around the mouth-parts of the larvae (Durie, 1977). This skin hypersensitivity is apparently correlated with the resistance level of the host. Larvae apparently wander considerably on resistant hosts and an interesting finding is that the hypersensitivity sets up a grooming response; in highly resistant cattle, grooming removed 30 - 50% of the larvae that did not attach compared with only 2 - 6% in low resistance hosts (Durie, 1977).

It is logical that the more resistant the host is and the higher the parasitic challenge, then the greater the proportion of ticks that are killed (Anderson, 1976). This is why Randolph (1979) suggests that the natural regulation of tick populations is only brought about by density-dependent mortality factors.

1.10.1 The significance of H. longicornis.

Larval, nymphal and adult H. longicornis can become infected with Coxiella burnetti if they feed on a host infected with Q-fever (Smith, 1942). The tick is also a probable vector of Theileria mutans in Australia (Seddon, 1951; Riek, 1966), Japan (Namba, 1958, 1963) Korea (Han, 1978) and U.S.S.R. (Hoogstraal et al, 1968). The British strain of T. mutans appears to be identical to the Japanese and Korean of T. sergenti. The Australian strain of T. mutans is serological similar to the British strain (Joyner, Payne, Takahash, Brocklesby and Irwin, 1974). It is probable they are all the same species. H. longicornis is also a vector of Russian spring-summer encephalitis (Hoogstraal, et al, 1968), and has been found to transmit Babesia gibsoni to dogs in Western Japan (Otsuku, 1974).

H. longicornis is not capable of transmitting Babesia bigemina (Legg, 1926). Recently it has been shown that the tick does not transmit Anaplasma marginale in Australia (Connell, 1978).

It seems odd that Theileria mutans is yet to be recorded from New Zealand despite its presence in other countries where H. longicornis occurs. T. mutans causes a mild transient reduction in haematocrit (Kuttler and Craig, 1975). Pooled cattle bloods were collected from two known tick infested properties in the Wairoa County (the same area as the experiment of Heath, et al, 1976). The blood samples were injected into splenectomised calves and no blood parasites were found in smears from the calves up to 40 days later (Charleston and Collins, unpublished.)

The effects of H. longicornis on the host have been investigated under controlled conditions only on one occasion in New Zealand (Heath, Pearce, Tenquist, and Cole, 1977). Sixteen days after peak adult tick numbers, 100 sheep that had been dipped at approximately 14 day intervals were significantly ($P < 0.01$) heavier than 100 undipped controls. The depression in body weight of the undipped sheep was only transient.

The dipped and undipped sheep from this experiment were shorn 48 days after the peak of adult ticks. There was no significant difference between the mean greasy fleece weights of the two groups but the mean fleece weight, of scoured wool, from the dipped group was significantly ($P < 0.005$) heavier than the undipped group.

The haemoglobin and haematocrit values of undipped sheep were also significantly lower than the dipped sheep for up to 35 days after the peak in tick numbers.

It is generally assumed that ticks affect young animals more seriously. For this reason Heath, et al, (1977) concluded that their results suggest H. longicornis may cause considerable losses in lambs.

Cattle with heavy infestations of H. longicornis have been reported by Roberts (1963, 1970) and Newton (1973) in Australia and heavy infestations are said to cause "tick-worry" in dairy cattle (Seddon, 1951). According to Emmerson (1972) heavy infestations of H. longicornis cause anaemia and production loss in cattle although Roberts (1970), considers that the anaemia associated with heavy and continuous infestations of H. longicornis is less severe than the anaemia associated with B. microplus.

Mortalities have been observed in beef cattle and calves in Australia associated with H. longicornis (Campbell, pers. comm.) Tick counts on the hide of one necropsied animal suggested the animal was carrying about 21,000 ticks.

Haemoglobin levels in five surviving animals ranged from 2.0 - 6.4 g/d l. I have observed deaths and similar low haemoglobin levels in heavily infested beef cattle in the Waiapu County. Anaemia and deaths in sheep attributed to H. longicornis have been reported by Tenquist, Wright and Skyrme (1973) and Neilson (1976).

Single H. longicornis and B. microplus adults ingest 0.6 - 0.7 ml and 0.7 - 0.8 ml of blood respectively (see Section 1.11.1). In cattle infested with B. microplus these losses of erythrocytes and haemoglobin are not immediately replaced and it has been suggested that this may be from the inference of metabolism by a toxin from the tick (Springell, et al, 1971) Similar experimental evidence is not available for H. longicornis. However, where animals are infested with very high numbers of this tick, as reported by Campbell, blood loss is most likely to exceed the rate of replacement irrespective of whether H. longicornis secretes a toxin or not.

It is obvious that in any clinical observation, a causal association between anaemia and H. longicornis can only be assumed when other likely causes of anaemia are eliminated. These observations can only be regarded as circumstantial evidence of economic loss attributable to the tick.

Enlarged lymph nodes in lambs (Anon, 1973b; Roach, pers. comm; Anon, 1975b) and cattle (Crawford pers. comm.) at slaughter have been reported to be possibly associated with infestations of H. longicornis.

Whilst there is a lack of experimental evidence of the adverse effects of H. longicornis on cattle and lambs the known facts suggest it is of some economic importance in Australia and New Zealand.

1.11 Biology of ticks

In this section, although there are occasional references to argasid ticks, the biology of only ixodids ticks is discussed fully.

The eggs of ixodid ticks are never laid on the host (Campbell, 1966). Thus when the female tick is fully engorged, she detaches and falls to the ground. Detachment at specific times of the day has been reported for some species of ticks. For example, almost all (90%) of larvae, nymphs and adults of Haemaphysalis leporispalustris detach from the cottontail rabbit during daylight hours (George, 1964). This detachment occurs in a 6 hour interval, up to 2 hours before darkness (George, 1971). Haemaphysalis spinigera also shows a clear periodicity of detachment during daylight hours (Bhat, 1974). In Japan, Kitaoka (1962) has found that H. longicornis detaches in the early morning so that if stock such as dairy cattle infested with ticks are moved into different paddocks twice daily, ticks will be concentrated in the paddocks where they spend the early mornings.

After detaching, ticks are negatively phototropic (Myers, 1924; Dethier, 1957); the blood meal is digested in a moist microhabitat in vegetation or in the lair of the host, during the preoviposition phase. Metabolic activity is at a maximum in the period between detaching and prior to egg laying (Kitaoka and Yajima, 1958; Kitaoka, 1961c; Hefnawy, 1970). Marked increases in the rates of gaseous exchange at the end of feeding have been reported in ixodid (Belozerov, 1964) and argasid (Gabbay and Warburg, 1978) ticks.

After a variable preoviposition period, eggs are laid in successive daily batches. In most ticks, after the eggs are laid, a waxy secretion produced by Gene's organ, is applied to the eggs. This assists in waterproofing the eggs (Cherry, 1969).

Egg production in ixodids ranges from 1000 to 20,000 per female. During the subsequent incubation period, providing conditions are favourable, the larvae develop. Eventually the larvae emerge from the egg shell. After a period of inactivity, larvae then seek a host either from the ground or on the vegetation.

Ticks, (especially 3-host ticks), spend almost all their life cycle off the host. Accordingly, they are exposed to a vast range of conditions in the environment. Their sensory physiology is well developed to respond to various environmental signals (Camin, 1963). Unlike some other acarines, such as mites which live continuously on the host, ticks have elaborate behavioural mechanisms and sensory physiology required for host location (Camin, 1963).

Ticks that infest the larger domestic mammals generally climb vegetation to seek a host. The directional stimulus is said to be in response to gravity or light with Ixodes ricinus (Lees, 1948). Light appears to be the principal stimulus causing climbing in B. microplus larvae (Wilkinson, 1953). Vertical movement of H. leporispalustris larvae is controlled by humidity and light. If ticks are fully saturated they are photopositive but when desiccated they become insensitive to light and respond positively to moisture (Camin and Drenner, 1978). I. ricinus returns to the moist vegetation mat to rehydrate (Milne, 1950a) but some ticks e.g. Rhipicephalus evertsi larvae are capable of remaining at the tips of the vegetation for up to 175 days (Gray, 1961); this may be a reflection of differences in resistance to desiccation. Even at the tips of vegetation the humidity would most likely increase above the C.E.A. (see Section 1.12.3) of the tick during night-time.

When ticks climb vegetation they appear to possess a mechanism which registers the height climbed and hence station themselves at a suitable level to locate the host (Wilkinson, 1953; Lees, 1969).

In Norway it has been shown that different stages of I. ricinus are present at different levels in vegetation: larvae lowest, nymphs next and adults highest in the vegetation (Tambs-Lyche, 1943, cited by Lees, 1969). This is compatible with the fact that immature stages of some tick species e.g. Dermacentor andersoni, Amblyomma variegatum, Hyalomma dromedarii, occur more frequently on small hosts (rodents and birds), while the adults utilise larger hosts (cattle and horses) (Campbell, 1966).

At the tips of vegetation, ticks extend or wave their forelegs. Presumably, this assists in receiving various stimuli. Ticks quest very strongly in response to odours (Wilkinson, 1953) and several ticks are known to be attracted to CO_2 (Garcia and Furman, 1966). This fact has been utilised to collect ticks in the field with the use of dry ice cubes (Nosek, 1978).

When it gains access to a suitable host, each unfed stage attaches, usually at a preferred feeding site such as the inner surface of the ears, axilla, mane, tail, perineum etc. (MacLeod, 1939; Balashov, 1972; Heath, 1973; Hoogstraal, 1978). According to Arthur (1973) no information is available to explain why ticks have preferred sites of attachment on the same or different hosts. However, Balashov (1972) suggests that irregular distribution on the host is associated with capitulum length, host skin thickness, air-layer microclimate next to the skin, and the hosts grooming ability. Protection from the sun and areas safe from being dislodged are suggested as reasons for preferred areas by Hoogstraal (1978). The skin of cattle is thinner in the axilla and groin (Arthur, 1965) and there is an inverse relationship between skin thickness and hairiness (Arthur, 1976). Cattle skin temperature varies from 35 - 40.5°C (Arthur, 1976) and it is likely the ears of most hosts have a lower temperature than other parts of the body. One or more of the factors suggested by Balashov (1972) may influence tick distribution on the host.

According to Campbell (1966) most ticks have a wide host range, a few species have a narrow host range but virtually no ticks are absolutely host specific. However, there is often evidence of a narrow range of preferred hosts. Ecological and behavioural associations between the parasite and the host may determine why certain ticks infest only a few host species but Arthur (1976) considers that the main reason may be because of a real restrictive specificity.

Ticks may wander over the host for several hours before attaching (Balashov, 1972). The attachment and feeding of ticks has been filmed by Gregson (1967) and the reviews of Balashov (1972) and Arthur (1973) restate the findings of Gregson. Having selected a feeding site, the tick bends the capitulum towards the host and splays the palps. The cheliceral digits sweep and cut outwards from the midline and there are alternate thrusting movements of the chelicerae. Once the stratum corneum is penetrated, a cement-like substance is released from the salivary glands and flows around the mouth-parts hardening into a sheath around them. The hypostome is gradually pushed into the wound and its retrograde teeth and the cement-like substance anchor the tick firmly to the host.

Ticks are ectoparasitic for several days on the host from attachment until engorgement. Ixodid larvae feed for 3 - 5 days, nymphs 3 - 8 days and females 6 - 12 days (males do not feed) (Balashov, 1972). The only exception to this is the rapid feeding (1 - 2 hours) of larvae and nymphs of Haemaphysalis inermis.

During feeding, periods of sucking alternate with periods of salivary ejaculation (Gregson,,1967) and by this means 70% of excess water is returned to the host (Tatchell, 1967).

Ixodid ticks differ from blood-sucking insects in the amount and rapidity of ingestion of blood and Lees (1952) has shown the physiological reason for this.

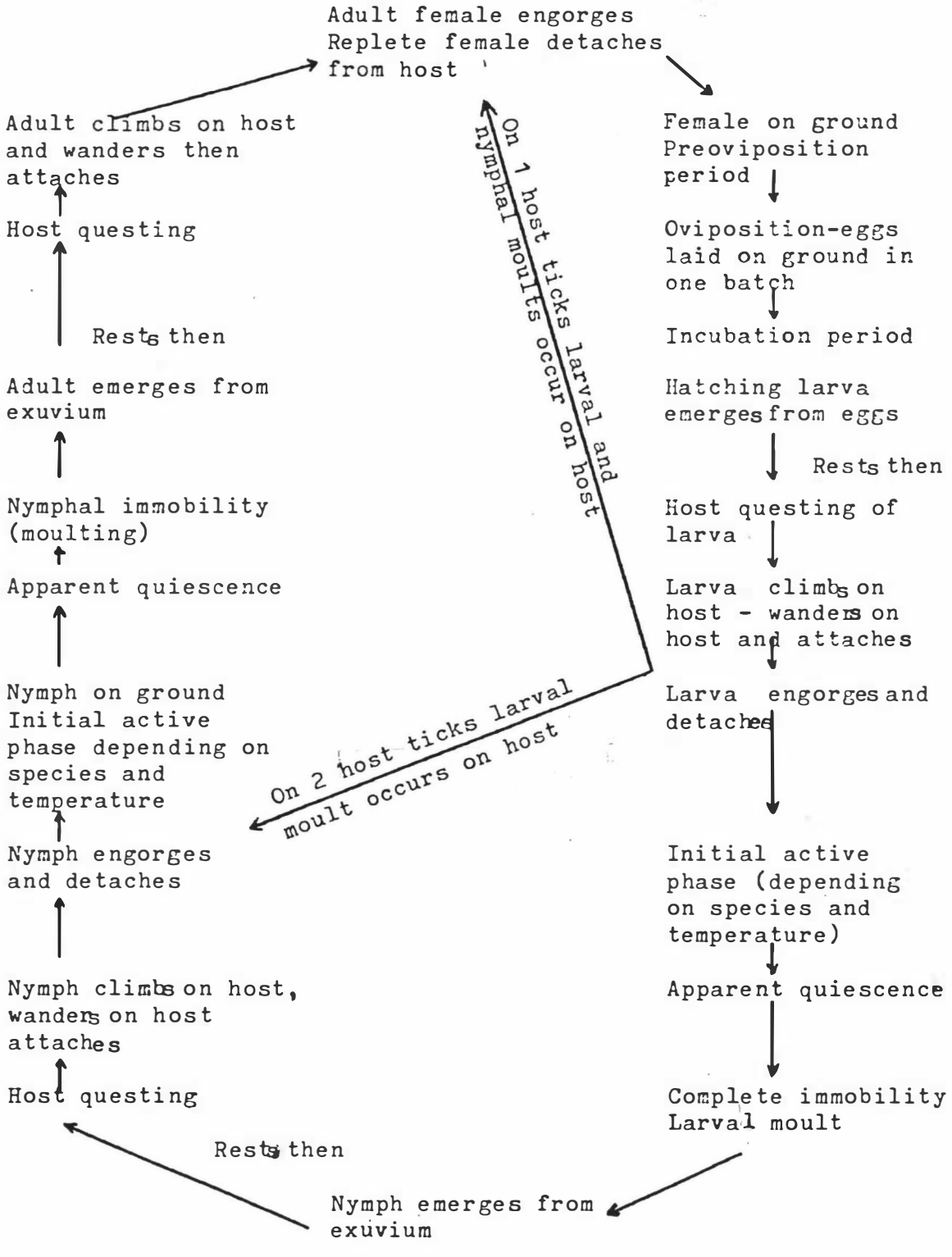
Blood sucking insects can ingest over 10 times their body weight by distension of the cuticle. However, ticks can ingest over 100 times their own weight of blood, and this is accomplished by distension and growth of the cuticle. In blood-sucking insects the endocuticle is usually secreted immediately after moulting whereas in ixodid ticks the endocuticle is secreted by the epidermis during engorgement.

Growth of the cuticle and engorgement appear to occur in 3 distinct phases as indicated by weight changes (Kitaoka and Yajima, 1958; Kitaoka, 1961a). In fact, in the first phase, some ticks lose weight (Balashov, 1972). Engorgement is most rapid in the third phase (Myers, 1924; Kitaoka, 1961a; Wharton and Utech, 1970).

When engorged, larvae of 3-host ticks detach and drop to the ground, and if conditions are suitable they eventually moult to nymphs. In 2-host ticks, the larval moult occurs on the host. In 1-host ticks both the larval and nymphal moults occur on the host. Most ixodid ticks undergo a 3-host cycle and as might be expected, those 3-host species that quest from vegetation have a wide natural host range (Balashov, 1972). A few species of Hyalomma and Rhipicephalus are 2-host ticks. All 6 species of Boophilus and some of Margaropus and Dermacentor are 1-host ticks (Hoogstraal, 1978). These differences are very important in relation to disease transmission, the development of insecticidal resistance and in relation to controlling ticks. The life cycles are represented diagrammatically in Figure 1.7.

It should be noted that as shown in Table 1.7 that each instar is immobile for a period after moulting. During this post-moulting development period many physiological changes occur (Balashov, 1972). The cuticle continues to harden. Hypertrophied cells in the gut from the previous engorged stage are replaced by flat epidermal cells. The salivary gland alveoli are increasing in size; they are not, at this stage at the final size typical of unfed ticks. Food reserves are still available in the gut and the malpighian tubules discharge large amounts of guanine.

Figure 1.7 Life Cycle of Ixodid Ticks



Based on information from Campbell (1966), Lees (1969), Heath (1974)

1.11.1 Biology of H. longicornis

This has been discussed in a number of papers including Myers, 1924; Legg, 1926; Namba, 1953, 1954, 1958, 1963; Teng, 1956; Bremner, 1959; Kitaoka, 1961d; Saito, Kubota, Yajima, Watanabe and Kamino, 1965; Hoogstraal, et al, 1968; Sutherst and Moorhouse, 1972; Tenquist, 1973; Heath, 1973, 1974; Heath, Bishop and Tenquist, 1977; and Heath, Tenquist and Bishop, 1978. Data from some of these authors is included in Table 1.5.

H. longicornis is a three host tick. Following engorgement, detachment and the preoviposition period, the female lays between 1 - 2,000 brownish, ovoid eggs (Myers, 1924; Hoogstraal, et al, 1968; Heath, 1973). The eggs are approximately 0.58 - 0.62 mm long by 0.40 - 0.43 mm wide (Namba, 1958; Myers, 1924). It has been observed by Heath (1974) that H. longicornis may oviposit in conditions where the humidity is so low that the eggs may not survive. Although low humidities do not affect oviposition of H. longicornis (Heath, 1974) it seems that oviposition is mainly controlled by temperature. Oviposition at low humidities has also been observed with Rhipicephalus sanguineus (Sweatman, 1967) and Amblyomma americanum (Sauer and Hair, 1971). This seems surprising since it is obvious as reported by Labeyrie (1978) that the way a female arthropod distributes its eggs is an essential element in the survival of the species. In most insects studied, low humidities reduce the rate of oviposition (Bursell, 1974). A reduction in water content can reduce the rate of metabolism (Wigglesworth, 1966). However, following the peak of metabolism soon after detachment of females, the metabolic rate declines (Balashov, 1972). If the metabolic rate is low during egg-laying, reduction in water content would only marginally affect the rate of metabolism.

Table 1.5 Field and laboratory data on the biology of H. longicornis (duration shown in days).

	Myers (1924)	Nelson (1974)	Legg (1926)	Namba (1958, 1963)	Bremner (1959)	Kitaoka (1961d)	Hoogstraal et al (1968)	Heath (1973) Heath et al (1977, 1978)
Pre-oviposition	7-60	14	-	7-12(9.9)	5-6	-	3-7(5)	-
Oviposition	23-28	21	-	11-32	11-13	-	11-27	(89-165)
Incubation	37-90	10-60	-	24	18-21	12-25 (19.0)	24-31 (27.5)	48-116
Resting larvae	-	-	-	4	-	-	3-5	-
Feeding larvae	7	4-7	>4	3-12 (5.8)	6-8	-	4-7	4-7
Premoult larvae	21	21	10	12-25 (19.5 summer) (19.1 winter)	9-11	10-19 (130)	14-17 (15.5)	21-98
Resting nymphs	-	-	-	5	-	-	2-3	-
Feeding nymphs	7	4-7	>4	4-8 (6.8)	4-7	-	5-7	4-7
Premoult nymphs	23-95	21	10	14-198 (23.7)	11-13	10-22 (129)	12-16	35-150
Resting adults	-	-	-	5	-	-	4-6	-
Feeding adults	7	4-7	>4	7-11 (10.3)	9-15		11-19	4-7
Total time	132-315	99-158	-	96-154	73-94	-	93-145	-
Temperature	All seasons	-	High	16-24°C	30°C	30°C	26-28°C	-
Humidity	-		-	80-95%	90%	Saturation	20-30%	-
Host	Cattle	-	-	Cattle	Rabbit	-	Rabbit	Sheep Cattle
No. eggs laid	1,000	1,200		1110-1120	-	-	2,024	2000
No eggs hatching	-	-	-	54-67% (-5°C-3°C)	-	-	94%	-
Optimum temperature	-	-	-	25-30	-	-	-	-
Optimum humidity	High	-	-	65-75%	-	-	-	-
Longevity	263	-	-	560	-	-	-	150-259

NOTE (with reference to Table 1.5)

1. All stages in days.

2. Means where quoted shown in brackets.

3. Helson's data probably from Myers (1924).

4. Helson suggests time from egg to adult 80 - 225 days (mean 100).

5. Data from Campbell (pers. comm.) not included as it is directly from Myers (1924).

It was found by Heath (1974) that under very dry conditions (saturation deficit of 20 mm of Hg) at 25°C H. longicornis did not oviposit but it did oviposit at the same saturation deficit at 28 - 32°C. This implies an effect on metabolic rate.

Being a 3-host tick, each stage (larvae, nymph and adult) returns to the pasture following engorgement and detachment. It follows that H. longicornis spends more than 90% of its life cycle in pasture (see Section 1.12.6).

The mouthparts of the larvae, nymph and adult of H. longicornis do not penetrate deeply into the host. Each instar inserts its mouthparts to the same depth in the epidermis (upper ⅓ of the Malpighian layer) and not into the dermis (Moorhouse, 1969). There appears to be a correlation between the depth of insertion of the mouthparts and the final engorged weight of the tick species. Species of Hyalomma and Amblyomma penetrate into the vascular layers of the dermis and reach engorged weights of 600 - 1200 mg (Balashov, 1972). Weight increases recorded by Myers (1924) were 0.25 mg to 4 mg for nymphs and 1 mg to 154 mg for adults. Kitaoka (1961a) also observed weight increases in parthenogenetic adult H. longicornis from 1.5 mg to 300 mg. The increase in weight of ticks during engorgement is only an approximate guide to the amount of blood ingested because of assimilation, digestion and excretion (Kitaoka and Fujisaki, 1976). For example, the amount of blood (0.7 - 0.8 ml) ingested by adult B. microplus was estimated to be about 3 times the final engorged body weight. The amount of blood (0.6 - 0.7 ml) ingested by H. longicornis was estimated to be 3 - 5 times the final engorged body weight.(Kitaoka, 1961b).

Although the apex of the rostrum of H. longicornis is in line with the Malpighian layer haemorrhages beneath this in the dermis and subcutis have been observed by Saito and O'Hara (1961). These authors also observed that lesions produced by nymphal H. longicornis were less severe in winter than summer and concluded, like Wagland, Roberts and Sutherst (1979), that temperature affects the duration of parasitism on the host and this may result in different lesions.

1.11.2 Seasonality of H. longicornis.

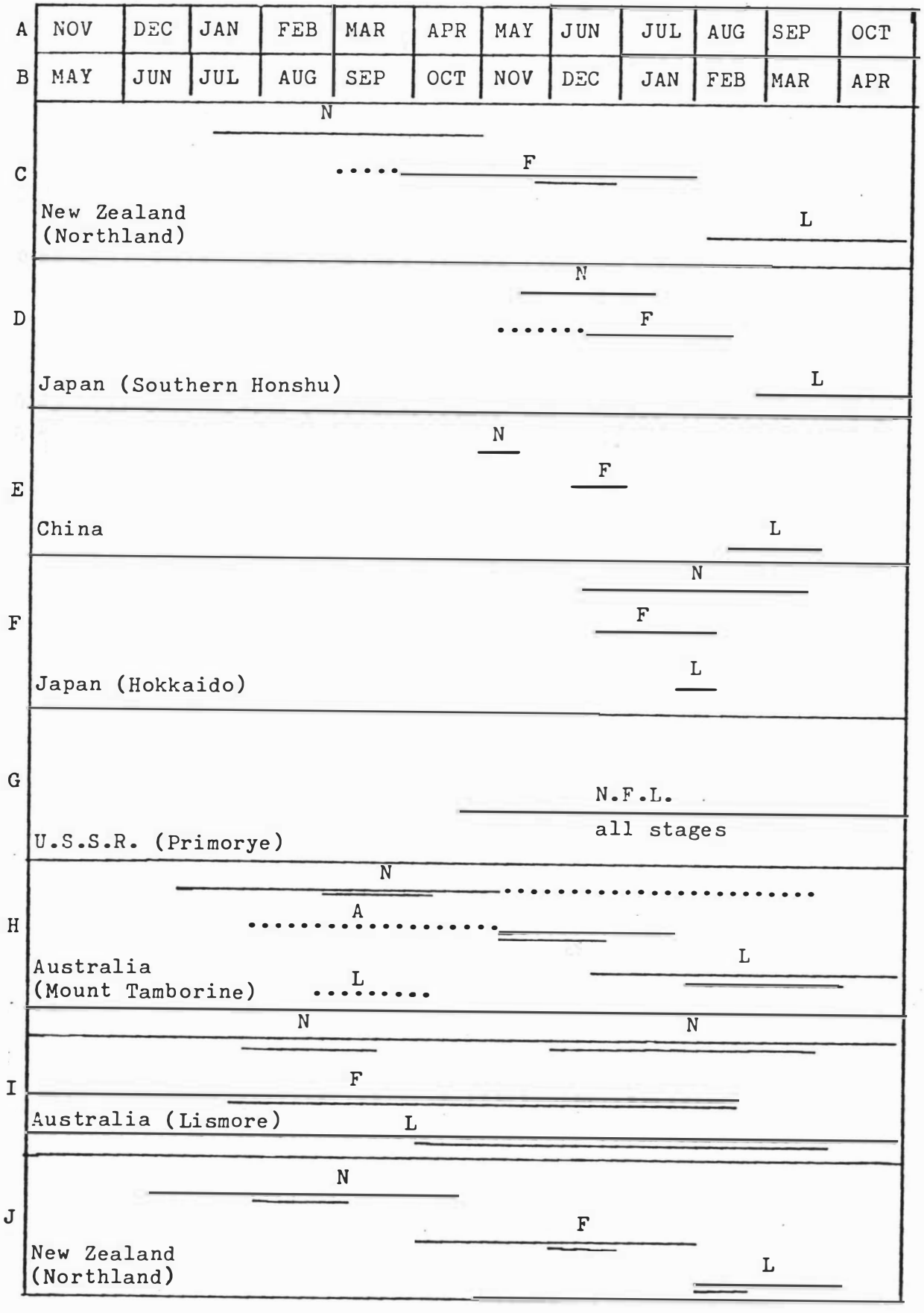
This has been described for Australia, China, Japan, New Zealand and U.S.S.R. and is shown diagrammatically in Figure 1.8. In the areas where H. longicornis occurs, the climate is of a humid subtropical or a mid-latitude, humid summer, category (Anon, 1966a), except for a small area of northern Japan and part of New Zealand (see Figure 1.9). In areas where the tick is present in the Northern Hemisphere, in September, the monsoon blows from the north-west spreading cold air over the area. In northern Japan (Hokkaido and north-west Honshu) snow is present from December to March. In April the wind changes and blows from the South bringing warm air (Anon, 1964). The colder autumn and winter temperatures explain the shorter periods of activity of H. longicornis in the northern hemisphere (see Figure 1.8, D, E, F, G.).

The periods of abundance of the various instars at the elevated area, Mount Tamborine, in Australia and Northland in New Zealand are similar (H, C and J in Figure 1.8). However, Sutherst and Moorhouse (1972) noted that other patterns of activity occur at lower altitudes. Further evidence of this is shown by Tenquist (1973), where at Lismore in Australia, (which is less than one degree of latitude further South than Mount Tamborine, but 600 metres lower in altitude) the periods of activity and abundance of each instar are considerably lengthened. It has been suggested by Campbell (pers. comm.) that South of Grafton in New South Wales, the seasonality of H. longicornis is similar to that reported for Northland in New Zealand.

In New Zealand the unfed nymph is the primary overwintering stage (Heath, 1973) (see Figure 1.8). However, unfed larvae have been observed to overwinter at Wairoa (northern Hawke's Bay) and Awakino (northern Taranaki) (Heath, Bishop and Tenquist, 1977) and these have been observed on the underside of the leaves of the sedge, Mariscus ustulatus (Neilson unpublished). At Awakino and Te Horo (near Levin) unfed adults also overwinter (Heath, et al, 1977).

Figure 1.8

Diagrammatical representation of the seasonality of H. longicornis.



Key to Figure 1.8

A = Northern Hemisphere

B = Southern Hemisphere

C = Northland New Zealand - Myers (1924)

D = Southern Honshu, Japan - Chitake and Otake (1956)

E = China - Teng (1956)

F = Hokkaido, Japan - Namba (1958)

G = Primorye, U.S.S.R. - Hoogstraal et al (1968)

H = Mount Tamborine, northeastern border New South Wales, Australia - Sutherst and Moorhouse (1972)

I = Woolongbar, Lismore, New South Wales, Australia - Tenquist (1973)

J = Northland, New Zealand - Heath (1973)

N = nymph

F = female

L = larvae

_____ period of activity on host

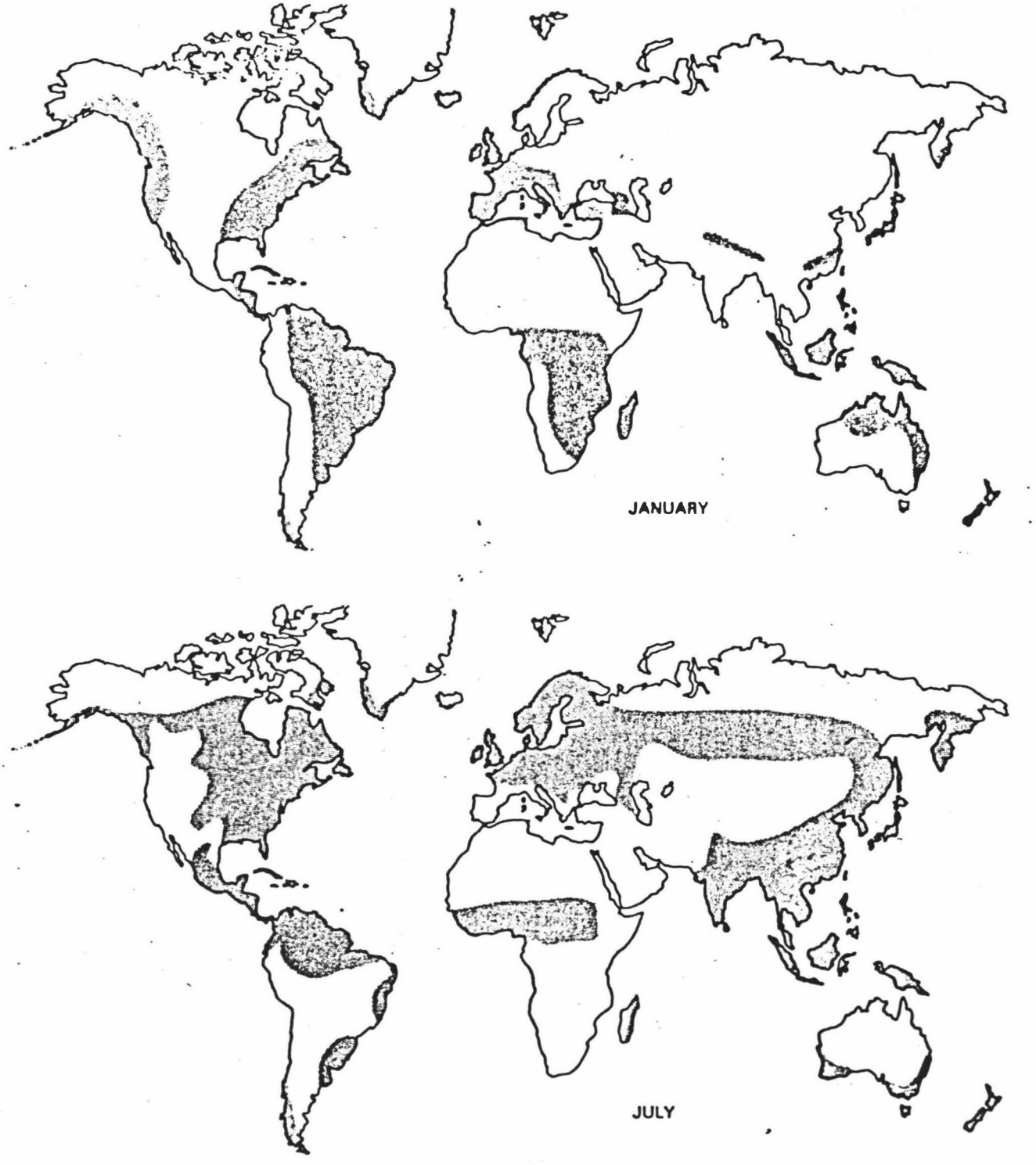
═══ period of maximum abundance on host

..... low numbers only

NOTE - Data from Saito, Kubota, Yajima, Watanabe, and Kamino (1965) ~~is~~ are not included because the information is vague.

Figure 1.9

Seasonal distribution of precipitation exceeding 50 mm per month (shaded areas). (From Winter, 1974).



It has been demonstrated that nymphs may have a long premoult period of 14 - 198 days in Japan (Namba, 1958) and 138 - 150 days in the winter in New Zealand (Heath, and Bishop, 1978). Because of this long premoult period it has been suggested (Heath, et al, 1978) that nymphs may overwinter in the engorged state. If this is so then adults seen on stock in New Zealand in the Spring may arise from recently moulted overwintered nymphs or unfed overwintered adults.

1.12 Ecology of ticks.

Ecology is the relationship between an organism and all the features of its environment. The influence on ticks of physical factors (autecology) and biotic factors (synecology) of the environment as outlined by Savory, (1977), will be considered separately. Obviously many of these factors are interelated since a change in one factor may produce a change in another so that a single change can produce a chain of events in the whole ecosystem. An example which illustrates this is the mechanical analog drawn by Arthur (1966) to illustrate the ecology of Ixodes ricinus and Ixodes persulcatus.

1.12.1 The temperature relations of ticks.

All organisms have a preferred temperature range in which to survive and reproduce (Andrewartha and Birch, 1954). This range of favourable temperatures has been referred to as the "thermopreferendum" (Wigglesworth, 1966); the "temperature preferendum" (Andrewartha and Birch, 1954); and the "viable range" (Bursell, 1964). In the higher part of this preferred range is a point where development proceeds at the fastest average rate and this has been referred to as the "peak temperature" (Davidson, 1944) or the "optimum temperature" (Wigglesworth, 1966).

There are also upper and lower limits for the survival and development of arthropods. The lower limits are referred to as "developmental zero" (Davidson, 1942) or "developmental threshold" (Bursell, 1964). The upper limits are referred to as the "thermal death point" (MacLeod, 1935; Wigglesworth, 1966) or "upper lethal limit" (Bursell, 1964).

As environmental temperatures increase, in live and dead insects (Beament, 1945; Wigglesworth, 1945) and in live and dead ticks (Lees, 1947) and in tick eggs (Lees and Beament, 1948) the rate of evaporation increases suddenly at a "critical" or transition temperature.

It has recently been suggested by Davis (1974b) that the reason for this phenomenon is a change in epicuticular lipids from the crystal to the liquid crystal phase with an increase in space between the hydrocarbon chains of the lipids. As a result of this there is a sudden escape of water.

It is generally assumed from the work of Lees (1947) that in comparing various species of ticks, critical temperatures are inversely related to transpiration rates at normal temperatures i.e. there is a positive correlation between critical temperatures and resistance to desiccation.

A similar association occurs in insects (reviewed by Ebeling, (1974). This relationship between critical temperatures and resistance to desiccation is not however consistent when comparing different developmental stages within one species. Engorged females of Haemaphysalis leporispalustris have a lower critical temperature than unfed females, yet at 25°C the rate of water loss is also lower in engorged females (Davis, 1974a). Critical temperatures alter with the developmental stage and the nutritional state in H. leporispalustris (Davis, 1974a). It has been shown that changes in critical temperature in the one developmental stage are associated with changes in the composition of cuticular lipids (Davis, 1974b).

Critical temperatures are normally well above those of the ticks environment so most authors (e.g. Stobbart and Shaw, 1974) have considered that they are of limited ecological significance. An interesting hypothesis has been proposed by Davis (1974a). The critical temperatures of adults of H. leporispalustris are higher than host body temperature during feeding. Just prior to the rapid engorgement phase the critical temperature falls to within the range of the host body temperature. The accompanying rapid loss of water may initiate the rapid engorgement phase.

Critical temperatures of ixodid ticks (Lees, 1947) and tick eggs (Lees and Beament, 1948) are in the range of 32 - 45°C.

Those of the eggs of Ixodidae are probably the same as that of the cuticle of the various instars of the particular species (Lees and Beament, 1948).

The critical temperature of a hygrophilic ixodid species such as Ixodes ricinus is lower than the upper lethal limit, whereas in a xerophilic ixodid species such as Hyalomma dromedarii critical temperatures are above the upper lethal limit (Hafez, El-Ziady and Hefnawy, 1970a). This is advantageous for the ecology of xerophilic species.

In summary, temperature has a profound effect on the entire life history of ticks. The rate of ixodid feeding, growth and development depend largely on environmental temperature (Balashov, 1972). Temperature also affects the activity, dispersal, behaviour and distribution on ticks (Nosek, 1978).

1.12.2 Temperature relations of H. longicornis

A great deal of information on the relationship between temperature and the biology of H. longicornis is available from Heath's (1974) study. As expected, developmental rates of the various instars increase with increasing temperatures (Myers, 1924; Namba, 1953; Heath, 1974).

A proposed relationship between temperature and biology for H. longicornis is shown in Table 1.6. A combination of temperature and saturation deficit favourable for the survival and development of H. longicornis is shown in Figure 1.10. This Figure is derived from extrapolations (not all the combinations of temperature and saturation deficit were examined) so that it does not represent the exact levels of tolerance of the non-parasitic stages to temperature and humidity.

Of the eggs and engorged stages, females require the highest temperatures during preoviposition (Table 1.6). This would be related to the high rate of metabolism reported during this period.

Table 1.6

Possible relationship between temperature and biology of *H. longicornis* (values are all °C).

	Eggs	Larvae	Nymphs	Females
Developmental zero	9°	11°	9°	16°
Peak temperature	32°	38°	38°	32°
Upper lethal temperature	41°	near 41°	near 41°	41°
Critical temperature			Between 35-38°	

NOTE (1) Data from Heath (1974)

(2) Critical temperature not established accurately.

(3) Proposed values taken from temperature - development velocity curves.

(4) Developmental zero may be lower than the theoretical limit of 9°C.

(5) Critical temperatures suggested are from experiments with eggs.

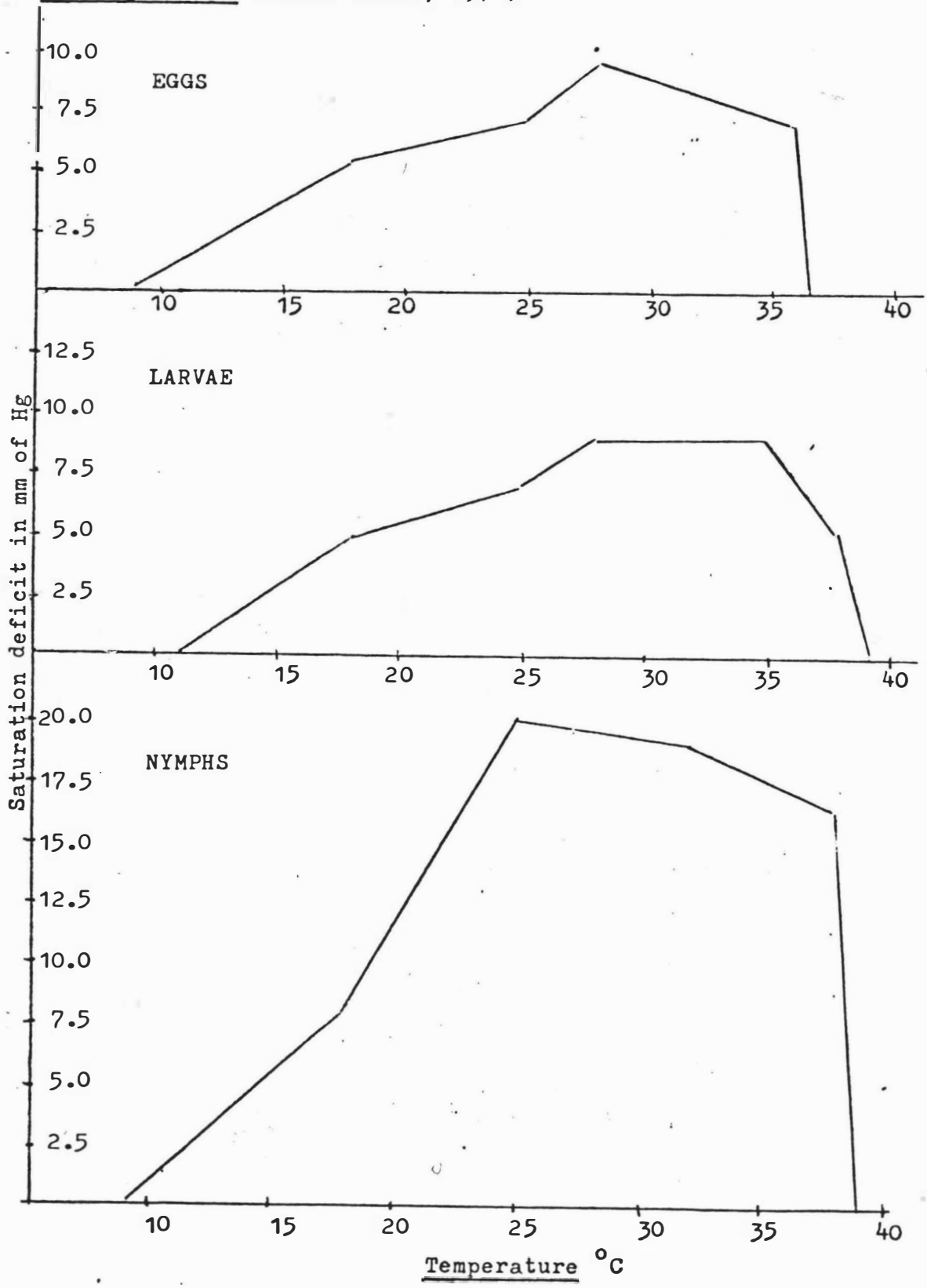
(6) Values for upper lethal temperatures refer to eggs and engorged stages.

(7) Developmental zero and peak temperatures apply to the
(a) Incubation period of eggs;
(b) Premoult period of larvae and nymphs;
(c) Preoviposition period of females.

(8) All values were obtained at one high humidity (2 mm Hg saturation defit) as low humidities can increase the time of development for all stages.

Figure 1.10

The range of temperatures and saturation deficits favourable for survival and development of non-parasitic stages of H. longicornis (after Heath, 1974)



The influence of low temperatures on H. longicornis in Australia and New Zealand have not been adequately studied. Short periods (14 days) of exposure of engorged adults to low temperatures (2 - 3°C) did not affect oviposition and survival. However, most engorged adults died after exposure to 2 - 3°C for 49 days (Heath, 1974).

In the U.S.S.R. unfed nymphs of H. longicornis are said to undergo behavioural diapause in the winter, although this may be regulated photoperiodically (Belozerov, 1973). No evidence of any diapause has been found in nymphs in New Zealand (Heath pers. comm.). Nymphs of parthenogenetic strains of H. longicornis have been observed to be inactive at room temperature in mid-autumn and winter in northern Japan (Saito, et al, 1965). Difficulty was experienced in getting these nymphs to attach and/or engorge on rabbits during these months. This was not observed with larvae. In Japan, milder lesions are produced by nymphs in the winter compared with those seen in summer (Saito and O'Hara, 1961).

Eggs of the Australian and Japanese (Hokkaido Island) strain differ in their response to temperature. Eggs from the parthenogenetic strain of females from Hokkaido Island were held at -5°C and 3°C for 30 days then transferred to a higher temperature (28°C) and 54% and 67% respectively of these eggs hatched (Namba, 1953). Whereas eggs of the Australian strain held at 12°C at close to 100% R.H. failed to hatch (Heath, 1979). For this reason, Heath (1974) has suggested that the Japanese strain has probably undergone an adaption to cold conditions. Any favourable adaptive combination of genes is fixed and perpetuated ad infinitum (Section 1.6) in this tick so it seems strange that, if H. longicornis was introduced to Australia and New Zealand from Japan, this adaption was not already present in the exported strain.

By a process of induction, various climatic indices have been compared with the Australian and New Zealand distribution of H. longicornis. Those that best fit the distribution are shown in Table 1.7. These relationships between distribution and climatic indices need to be supported by laboratory studies to establish their biological significance.

Table 1.7

Distribution of H. longicornis in New Zealand and Australia in relation to climatic indices.

NEW ZEALAND	AUSTRALIA
1. Present where mean annual air temperature is greater than 12°C.	January 32.2°C isotherm (daily maximum temperature) limits western extension from N.S.W. and Queensland.
2. Present where July minimum air temperature is > 2°C. Present where July maximum > 12°C.	Present where July minimum > 1.7°C. More common where July minimum 4.5 - 10.2°C.
3. Areas likely to be free of ticks where > 50 frosts/ annum.	Areas likely to be free of ticks where > 65 frosts/ annum.
4. Areas > 1 day snow/annum likely to be free of ticks.	-
5. Absent or uncommon where rainfall is 1000 mm or less.	Distribution limits follow closely the 1000 mm isohyet.

Data from Heath, 1974, 1975; Heath, Pearce and Tenquist, 1976.

1.12.3 The water relations of ticks.

The water content of terrestrial arthropods varies between and within an individual species but is generally high representing 45 - 95% of body weight (Rapoport and Tschapek, 1967; cited by Wharton and Arlian, 1972). The water content of fully hydrated ixodid ticks at high humidities is between 50 - 57% of the total body weight, e.g. I. ricinus 53.2%, Dermacentor marginatus 55.7%, (Belezerov, 1967); Amblyomma americanum 50 - 56% (Sauer and Hair, 1971); Dermacentor variabilis 57% (Knulle and Devine, 1972). Even the cuticle of arthropods contains 15 - 70% (mean 43%) water (Richards, 1951).

In living arthropods more than 99% of all molecules are water (Edney, 1977). As most other molecules in arthropods have a high molecular weight, when the water content is expressed as a percentage of total weight (as above), this is much less than its mole fraction (Edney, 1977).

Many authors (e.g. Wigglesworth, 1966; Bursell, 1974; Ebeling, 1974) have remarked on the fact that as the size of an arthropod decreases, the surface area through which water is lost increases in relation to the quantity of water at its disposal. Water content is a function of volume and evaporation is a function of surface area so that small arthropods are at a disadvantage with respect to water conservation.

In the small developmental stages of ticks, such as eggs and larvae, the oxygen demands can be satisfied by transcuticular diffusion. In the larger developmental stages there is insufficient haemolymph movement to transport respiratory gases so that oxygen requirements are provided by tracheal ventilation (Edney, 1977). In ixodid eggs and larvae, movement of respiratory gases occur through the cuticle and where carbon dioxide and oxygen pass freely so also must water molecules (Waggoner, 1967). Transcuticular respiration is an active process and it requires the expenditure of more energy than tracheal respiration so that larval survival is particularly precarious in marginal environments (Hoogstraal, 1978).

Consequently, rainfall, evaporation, and environmental humidity can be important factors in tick distribution and larval survival can be a major determining factor in the overall distribution of ticks.

Although the amount of water that can be lost before biological processes are affected, or death occurs, is very variable (Edney, 1977), arthropods must maintain their water contents within certain limits in order to survive (Bursell, 1974). Some authors talk of water loss as a percentage of body weight. For instance, man can only tolerate a 10-12% water loss while some arthropods can withstand a 30% water loss as a percentage of body weight (Edney, 1977). Others talk of "water reserve" which is the amount of water itself which can be lost before death supervenes, e.g. when 50% of water is lost death usually occurs (Bursell, 1974). To evaluate the effects of humidity on ticks the amount of water reserve, the rate of loss of water and the mechanisms by which depletion is regulated and water is replenished, must be known (Bursell, 1974).

Water is lost from ticks by active and passive transpiration and water is gained by active and passive sorption. Transpiration is the movement of water-vapour from the tick into the surrounding air. Sorption is the movement of water-vapour from the air into the tick. When ticks are exposed to an environment where the air is not saturated with water-vapour, there will be a net water loss through the cuticle or from respiratory surfaces by evaporation (Edney, 1977). A gradient of vapour pressure or of "activity" is set up between the insect's surface (at which water is present in liquid form) and the ambient air (Bursell, 1974). As has already been stated, the integument is not completely impermeable, so water will evaporate from the liquid surface and diffuse into the air along this gradient (Bursell, 1974). The movement of water will depend on the vapour pressure (P) of the surrounding air (Edney, 1977).

The rate of evaporation depends on;

(1) the permeability to water vapour of the transpiring membrane:

(2) the temperature of the transpiring surface which affects the rate of diffusion of molecules of water:

(3) the activity gradient between the cuticular surface and the surrounding air (Bursell, 1974).

Water tends to move from regions of high concentration, or "activity", or high partial pressure (P) to regions of lower concentration, or lower "activity", or lower partial pressure (P).(Wharton and Arlian, 1972; Bursell, 1974; Edney, 1977; Wharton and Richards, 1978).

Thus it is clear that units are required to measure each end of the gradient. The only easily determined measurement is the vapour pressure of the atmosphere. Since air is rarely saturated with water vapour, the term relative humidity (R.H.), which is the amount of water vapour in the air as a percentage of the saturation water vapour pressure at that temperature, expresses the relationship. Relative humidity gives a good indication of the gradient of activity which promotes diffusion of water across a transpiring surface but only relative to a single temperature (Bursell, 1974). As an alternative, Wharton and Devine (1968) suggest that the unit "activity" can be used for both vapour and liquid phases in the air. The activity of water vapour (a_v) is related to relative humidity as follows -

$$a_v = \frac{R.H.}{100} = \frac{(P)}{(P^1)} \quad \frac{\text{actual partial pressure of water vapour}}{\text{potential saturation vapour pressure}}$$

The activity of water (a_w) is used to refer to the chemical potential of water in its liquid phase. This term can be used to describe the concentration of water in solution. It also takes into account the osmotic concentration in the liquid phase.

Under the same conditions of temperature and pressure in a closed water system, water molecules evaporate and others condense so that equilibrium is reached and the activity of water in its liquid phase (a_w) will be equal to the activity of water in its vapour phase (a_v) (Edney, 1977; Wharton and Richards, 1978).

$$a_v = \frac{RH}{100} = \frac{P}{P'} = a_w$$

The same concept is valid in relation to activity of water in the arthropods body (Vannier, 1976).

The a_w of body fluids of most arthropods is generally quoted at circa 0.995 (Edney, 1977) or 0.99 (Wharton and Richards, 1978). The one measurement in ticks (0.99) is from argasids (Hefnawy, 1972). For air to be in equilibrium with an arthropod whose a_w is equal to 0.99 the R.H. of the air would need to be 99% (a_v = 0.99). This is why a net loss of water occurs since the air usually has a lower R.H. than this.

It may be thought that if the a_w of body fluids is lowered that this would reduce the activity gradient. Since a_w is the ratio of the chemical potential of the body fluids divided by the chemical potential of pure water (at the same temperature and pressure) (Wharton and Richards, 1978), if solutes are present in the body water the a_w is reduced (Edney, 1977). However, the water concentration of body fluids must be maintained at an a_w = 0.99 or else metabolism will slow down and death usually occur (Wharton and Arlian, 1972). This is why it is essential that arthropods have access to relatively pure water.

Cuticular water loss can be expressed as a proportion of the total weight of ticks or as a rate of transpiration per unit area (Edney, 1977). There is wide range of cuticular transpiration rates (= cuticular permeability) in ticks and this is most likely related to the humidity of the environment in which they normally live.

A cuticular transpiration rate of 0.06 mg/cm^2/mm Hg/hour has been reported for Ixodes ricinus (Lees, 1947) whereas Hafez, et al, (1970a) reported only 0.012 mg/cm^2/mm Hg/hour, for H. dromedarii. Even lower values are reported for some argasids. There is general agreement that the epicuticular waxes (Lees, 1947; Lees and Beament, 1948; Beament, 1961, Hafez, et al, 1970a) and also the epidermis, Lees, 1947; Hafez, et al, 1970a; Wharton and Richards, 1978) are important in preventing water loss.

There are differences in the rates of transpiration amongst the various developmental stages of ticks. For instance, water loss in 6 ixodid species exposed to dry air at 25°C was 5 times greater per unit of surface area in engorged ticks compared with unengorged ticks of the same species (Lees, 1947). A similar finding has been described for engorged and unfed H. dromedarii (Hafez, et al, 1970a) and this was attributed to the need to remove excess water following engorgement. Similar results have also been reported for H. leporispalustris where permeability is greater in engorged nymphs and females than in unfed specimens (Davis, 1974a). Increased cuticular permeability shortly after moulting has also been found for this species. At humidities below those at which body water content can be maintained, a higher rate of evaporation is found in dead ticks than with live ones because the process of resisting desiccation is an active one (Lees, 1946).

Engorging ticks are able to obtain water from the host but unfed ticks must maintain their water balance by other means. Some ticks such as larval B. microplus imbibe water through their mouthparts (Wilkinson, 1953; Schunter and Tatchell, 1970) and Londt and Whitehead (1972) observed that 4 other species of ixodid larvae that imbibe water. However, some tick species do not, including nymphs and adults of I. ricinus (Lees, 1946) and larval Dermacentor variabilis and Amblyomma cajennse (Knulle, 1966).

Unfed ticks of some species obtain water by sorption of water vapour from subsaturated atmospheres (Lees, 1946, 1947, 1948; Browning, 1954; Knulle, 1966; Hafez, et al, 1970b). This also occurs in some species of insects (Noble-Nesbitt, 1969, 1970). This mechanism only operates down to a certain level of humidity.

This minimum R.H. at which a fasting tick can maintain its water balance with ambient air, was first called the critical equilibrium humidity (C.E.H.) (Knulle and Wharton, 1964). In terms of water activity this becomes critical equilibrium activity (C.E.A.).

The site of uptake of water in unfed ticks was first proposed by Lees (1946) to be the cuticle, but recent studies suggest this is incorrect. Blocking the mouthparts of unfed adult Amblyomma variegatum prevents water uptake (Rudolph and Knulle, 1974). These authors collected crystals of sodium and potassium salts that accumulated at the mouthparts of desiccated ticks and found that these crystals absorbed water from air if the R.H. was above 75%. By covering either the anus, dorsal surface or mouthparts of desiccated unfed A. americanum with paraffin and then placing them in a R.H. of 93%, McMullen, Sauer and Burton (1976), have confirmed that the oral region is the site of water uptake. These authors also injected Ringer-saline solution containing radioactive chloride ($Na^{36}Cl$) into ticks then observed the movement of ^{36}Cl following desiccation. The concentration of ^{36}Cl was higher in the mouthparts of desiccated ticks, and higher in the mouthparts of desiccated and rehydrated ticks compared with fully hydrated ticks. That the salivary glands are involved in this mechanism is evident from the fact that if the type alveoli in the glands are destroyed by infection, ticks are not able to sorb water vapour (Rudolph and Knulle, 1978, cited by Wharton and Richards, 1978).

This process if of major importance to the ixodid ticks as they lack a cement layer over the epicuticle (Lees, 1947; Balashov, 1972) unlike argasids and some insects.

An important aspect of the uptake of water vapour from sub-saturated air by unfed ticks is that the rate of uptake is less rapid at low temperatures. This was first observed in I. ricinus (Lees, 1946) where uptake was less rapid at 9°C than at 15 to 25°C. When predesiccated unfed adults of Amblyomma americanum are exposed to a range of temperatures at a single humidity level above their C.E.A. their resultant percentage weight change, when plotted against temperature, forms a parabolic curve (Sauer and Hair, 1971), i.e. minimum sorption at low (5°C) and high temperatures (45°C), with a peak at 25°C. This indicates that sorption is an "active process." This point will be returned to when discussing distribution of H. longicornis.

Throughout this review, the minimum requirements of water for ticks have been stressed since it is obvious that H. longicornis is a relatively hygrophilous species (see subsequent section). Upper tolerance limits of humidity can also influence the distribution of ticks such as with species of the xerophilic genus Hyalomma. In South Africa the upper limit of rainfall for survival of H. glabrum is 380 mm; for H. truncatum is 500 mm; for H. rufipes is 500-635 mm and rarely up to 760 mm (Theiler, 1964).

The reason why excess moisture affects survival of species of Hyalomma is not clear. The epicuticular lipids are clearly important in reducing water loss since removal increases transpiration (Lees, 1947). Furthermore, if no epicuticular lipids were present, ticks could be subjected to a lethal rate of excess water uptake by osmosis in environment with excess free water (Ebeling, 1974). Hyalomma species can be expected to have a low cuticular permeability as regards movement of water vapour outwards. Why can some species not tolerate higher rainfall? One possible explanation is that one or more of the development stages cannot withstand immersion in water.

Several species of ticks can withstand immersion in water (MacLeod, 1935; Gray, 1961; Honzakova, 1971; Sutherst, 1971; Smith, 1973). Theiler (1964) considers floods have very little effect on tick distribution. Others have suggested that flooding decreases tick survival (Rosicky, Cerny, Hejny, 1973; Akafe kwa, 1976; Osman, 1978). It seems this varies between species. It is possible also that unfed stages are more likely to survive flooding than the engorged nymph and adult which, because of their high rate of metabolism and consequent spiracular opening, are liable to water entry through these openings (Sutherst, 1971).

1.12.4 The water relations of H. longicornis.

No experimental evidence is available on the effects of humidity on the unfed stages of H. longicornis. But enough information is available to form the basis for some hypotheses. The critical temperature (C.T.) for this species is probably in the range of 35 - 38°C (Heath, 1974, 1979). According to Lees (1947) resistance to desiccation is correlated with the C.T. Since the C.T. of H. longicornis is at the lower end of the range of C.T.'s in Ixodidea, it is reasonable to expect cuticular permeability will be relatively high.

The distribution of H. longicornis in New Zealand and Australia suggests that it requires a relatively high amount of rainfall for its survival since it is not common in areas where the rainfall is less than 1000 mm per annum. This is a marked contrast to the distribution of 11 ixodid species in South Africa (Theiler, 1964). All are present in areas where rainfall is between 250 to 750 mm per annum.

The effects of humidity on the eggs and engorged stages of H. longicornis have been examined experimentally by Heath (1974, 1979).

The percentage of eggs hatching at humidities between 2 and 6 mm Hg S.D. (R.H. of 60 - 87% between 18 - 38°C - Buxton, 1931) does not vary significantly, although more eggs hatch at the higher humidities. At humidities of 8 mm Hg S.D. (R.H. of 48 - 85% between 18 - 38°C) egg hatching is markedly affected. Since the results were reported in terms of S.D.'s the effects of temperature and relative humidity cannot be separated.

The rate of development of many insect embryos is reduced by low humidities (Bursell, 1974). Eggs of H. longicornis kept at 72.5% R.H. at 28°C (S.D. 8 mm Hg) for 10 days, had a significantly longer ($P < 0.01$) incubation period than eggs kept for 5 days at 72.5% R.H. then transferred for 5 days to 89% R.H. at 28°C (S.D. 2 mm Hg) (Heath, 1979). Eggs can withstand moderate desiccation (8 mm of Hg S.D.) for up to 8 days providing they experience moist conditions immediately before or after this exposure to dryness (Heath, 1979). However, if they are not preconditioned by exposure to high humidities for 10 days, or continue to experience dry conditions (72.5% R.H. at 28°C) for 10 days or more, the percentage hatch is virtually nil (Heath, 1974, 1979). After 10 days at a R.H. of 72.5% at 28°C, the weight loss of eggs was approximately 22% and Heath (1974) has shown that a water loss of 40% of the total weight of the egg appears to be critical. This is possibly the extreme upper limit since the water content of eggs of H. longicornis is approximately 56%. If eggs lose 40% of their weight as water, then this represents a loss of over 70% of the original water i.e. higher than Bursell's (1974) suggestion that death occurs when 60% of water is lost.

The weight loss at 25°C at an approximate R.H. of 5% of eggs and engorged larvae and nymphs of H. longicornis are shown in Figure 1.11. It is obvious that permeability of the egg shell and cuticle of the larvae is high and that nymphs are much more resistant to desiccation. Females are probably similar to nymphs in their resistance to desiccation (Heath, 1974). Reference has already been made to the fact that females can survive and oviposit at low humidities.

Figure 1. 11

Cumulative weight loss of eggs and engorged stages of H. longicornis exposed to saturation deficit of 22 mm of Hg (dry air) (approximately 5% R.H.) at 25 C. Results are from eggs oviposited up to 24 hours and from engorged freshly detached larvae and nymphs (from Heath, 1974).

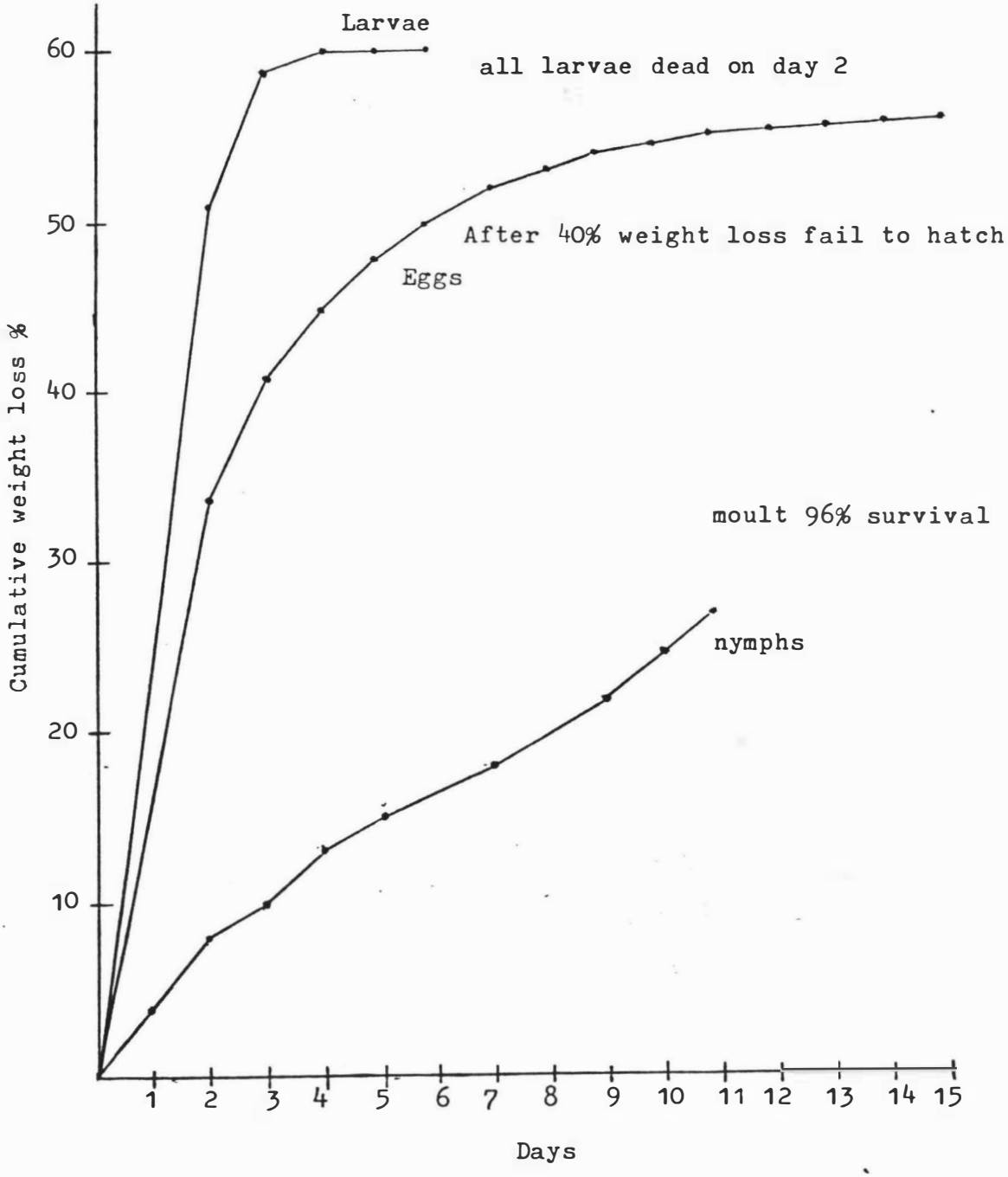
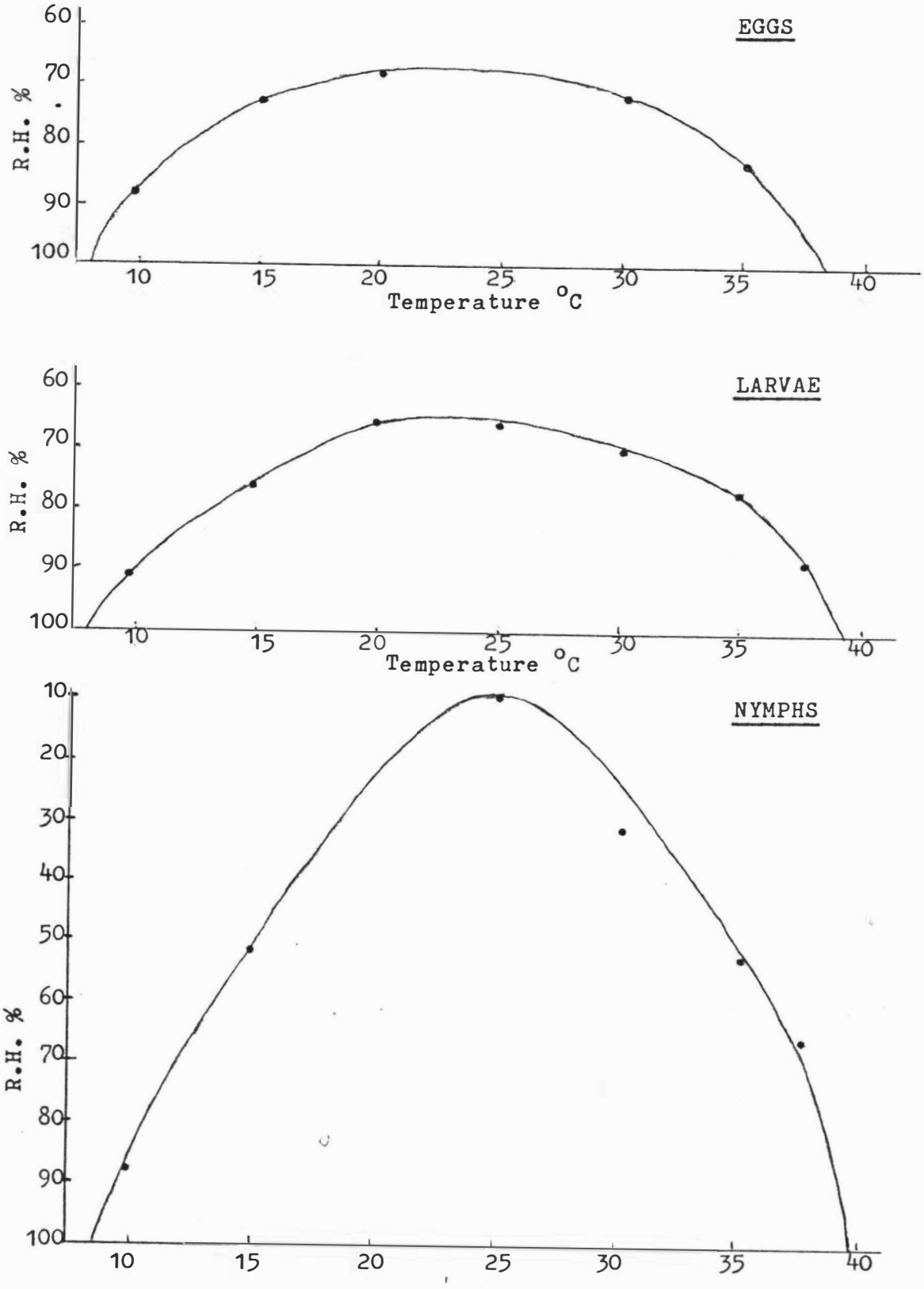


Figure 1.12

Range of temperature and relative humidity found to be favourable for the survival of eggs, engorged larvae and nymphs of H. longicornis (adapted from Heath, 1974).



At humidities below 85% R.H. the survival rate of engorged larvae is reduced (Heath, 1974). Following engorgement, larvae require 4 - 5 days at a favourable humidity in the premoult phase before they can resist desiccation (Heath, 1974). Neither engorged larvae or nymphs are able to take up water vapour from air following desiccation, but the nymphs are able to withstand desiccation for much longer than the larvae (Figure 1.11). Unfed stages can actively take up water vapour from the atmosphere (see Section 9).

The survival of H. longicornis following immersion in water has not been investigated under controlled conditions. Fewer overwintered nymphs were found in rush plants that had been subjected to winter flooding compared with non-inundated rush plants (Myers, 1924). Counts of nymphs prior to flooding were not performed so it is impossible to calculate the mortality under different conditions. Limited evidence on the effects of immersion in water of the various stages of H. longicornis is described in Section 10.

1.12.5 The influence of vegetation on the survival, activity, development and distribution of ticks.

It is clear that ticks require certain temperature and humidity conditions for their activity, behaviour, development and dispersal. These conditions of temperature and humidity will depend on the plant community since the microenvironment will be directly affected by the vegetation. The plant community also indirectly affects tick numbers since the plants species may be favoured foods for hosts.

In a survey of the distribution of ixodid ticks in South Africa, Theiler (1964) found that ticks were present only when rainfall exceeded a certain minimum figure (250 - 500 mm, depending on the species). She suggested that rainfall should however, be interpreted in terms of so much plant growth per unit area.

This is probably related to the fact that vegetation is likely to be sparse since $\frac{2}{3}$ of South Africa has an arid or semi-arid climate (Anon, 1964).

The association between I. ricinus and certain plant communities has been widely reported. By sampling various types of pasture Milne (1944, 1946) found that this tick was found in higher numbers in association with tall vegetation and where there was a thick mat at the base of the pasture and hence high humidities in this region. The R.H. varied from 40 - 100% at the grass tips (Milne, 1946) so that the tick periodically re-entered the vegetation mat to rehydrate.

There is diurnal variation in ambient R.H., it being low at mid afternoon and high at night with a peak early in the morning (Trewartha, 1968). It is a reasonably safe assumption that for at least part of the 24 hour period the R.H. will be above the C.E.A. of unfed ticks. For example, on the Kenyan coast, during the rainy season, the R.H. at ground level is above 90% during the hours of darkness. Even in the dry Kenyan season, R.H. is above 90% for up to 6 hours (Newsom, 1978). As larval uptake of water is rapid at humidities above their C.E.A.'s (see Section 9) they can obtain their water requirements at night. As well, some larvae are also able to imbibe free water.

Unfed larvae of 6 ixodid species were found by Londt and Whitehead (1972) to be associated with definite microclimate conditions; larvae were not present where the midday saturation deficit was in excess of 10 mm of Hg and were more predominant in shaded habits. Since air-current speeds were low in the area sampled, it was assumed that larval migration was minimal. Hence where larvae were found most likely represented an area favourable for egg development as conditions were not marginal for larval survival.

The numbers of Rhipicephalus appendiculatus collected in blanket drags (200 metres) from long pasture (40 cm) were 10 times greater than were collected from short pasture (6 cm) (Tukahirwa, 1976). The author related this to humidities and temperature but again the effect seen may have been on the egg stage with tick numbers reflecting higher survival of eggs.

Another important consideration in comparing the effects of pasture lengths is the suggestion of Londt and Whitehead (1972) that there is an optimum pasture length for ticks to be picked up by passing hosts.

The distribution of ticks in association with specific vegetation has been noted on a few occasions. In South Africa Stampa (1959) found that the density of larval Ixodes rubicundus was higher in pastures where the shrub Rhus erosa was present. This plant provides shade, protection from desiccating winds and decomposing plant litter. In dry conditions the most vulnerable stage of the life-cycle of I. rubicundus is the hatching of larvae. Rhus erosa provides sufficient moisture for this stage to complete its development.

In Canada, Wilkinson (1967) found a significant association between certain shrubs and density of Dermacentor andersoni. He suggested that these shrubs were indicators of suitable temperature and humidity conditions required for the ticks and that they may also provide food and shelter for small hosts of the tick.

In an unreplicated experiment, Thompson, Roa and Romero (1978) found after seeding B. microplus larvae on single species grass plots that recovery of larvae from 2 of the plots was higher (range 1.5 - 12%).

These findings indicate that certain plants provide more suitable microenvironmental conditions than others for the survival and development of ticks.

1.12.6 The influence of vegetation on the survival, development, activity, and distribution of H. longicornis.

Ticks distribution is never uniform over a land area and mosaic and the pattern seen probably reflects differences in ecoclimatic and trophic relationships in the area (Nosek, 1978).

It is often difficult to determine whether the non-uniform distribution is related to the individual variation amongst hosts which may graze preferential pasture species and may only graze in certain areas because of the social organisation within the herd or is related to the variation of micro-environment.

Namba (1958) has suggested that in Northern Japan all stages of H. longicornis are selectively associated with certain plants and are more commonly found questing on these plants. However, his conclusions are questionable as the statistical analysed used to analyse counts of ticks on plants rests on assumptions that are not necessarily valid.

When Myers (1924) investigated the distribution of H. longicornis in Northland, the tick was still in the process of establishing and spreading. From information of areas of reputed tick scarcity pasture flagging and examination of hosts, Myers (1924) concluded that the survival of the tick was related to the presence of Paspalum dilatatum and rushes (Juncus effusus).

He found ticks absent where pasture was very short or improved pasture containing English grasses, browntop (Agrostis tenuis) and danthonia (Danthonia pilosa) was present. The tick was said to be absent from areas with free draining soils formed from basalt.

In Australia, the distribution of H. longicornis is also closely coincident with the distribution of paspalum (Heath, 1974).

In New Zealand paspalum is present over the most of the North Island and the extreme north-west of the South Island (see Figure 1.13). Its greatest concentration is in Northland, Auckland, Waikato, Bay of Plenty and Poverty Bay (Percival, 1977). Thus there is an association between H. longicornis and paspalum in New Zealand. An important question, yet to be resolved, is whether the coincidence of distribution is causal or coincidental.

It is acknowledged that the distribution of H. longicornis in association with paspalum should be investigated carefully before any conclusions can be drawn. Nevertheless, some aspects of water and temperature requirements of paspalum need to be examined.

Although larval drinking has been observed in several species of ticks, free water as dew or surface water is not always available. Consequently, the main source of water is as water vapour. What is the source of this water vapour?

The major source of this water vapour is transpiration by plants. In a temperate climate, in general terms about 30% of the years precipitation is retained by the soil, 20% evaporates from the soil and 50% is transpired by plants (Winter, 1974). Evaporation from bare soils decreases rapidly 1-2 days after rain as the hydraulic conductivity falls rapidly as the moisture content decreases (Kerr, 1973; Winter, 1974). Only a small proportion of water is required for the plants own metabolism (Sturrock, 1973), i.e. less than 1% (Kerr, 1973). So those plants that absorb more water, also transpire more.

The rate of transpiration is governed by the temperature, humidity, and movement of air above the evaporating surface and the amount of energy available to change the water at the stomatal surfaces into water vapour.

Figure 1.13

Percentage of occupied improved land containing paspalum in the pasture (Figure 1.13a). The lower figure shows the proportionate change in paspalum content (Figure 1.13b).

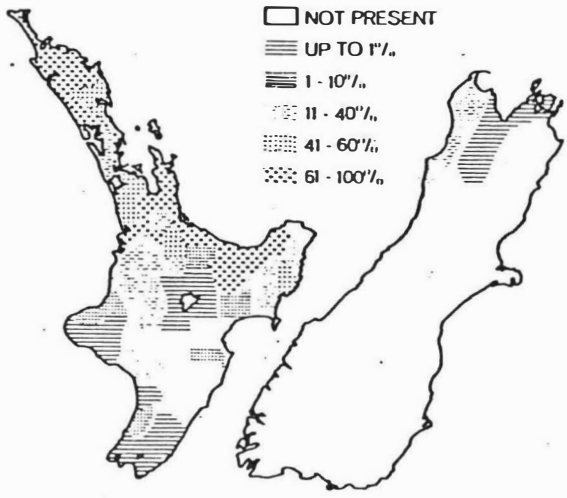


Figure 1.13a

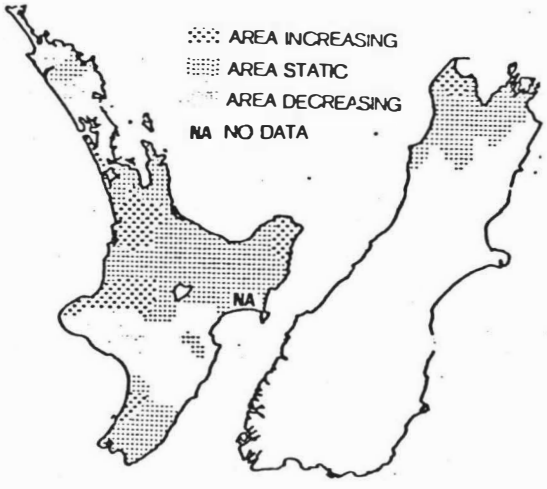


Figure 1.13b

From Percival (1977)

Most of the energy comes from short wave radiation; some is available from the change of temperature as air passes over the transpiring surface (advective energy). Thus the rate of transpiration is closely correlated with net radiation.

Transpiration rate is also dependent on soil moisture levels and the height of the pasture and leaf area (Winter, 1974).

The ration of the actual evapotranspiration to the net radiation is equal to 0.72 over long paspalum (30 cm) and falls to 0.38 over short paspalum (5-7 cm) (Kerr, 1973). Transpiration from paspalum is higher than from white clover/ryegrass pastures (Kerr, 1973). Transpiration produces a large amount of water for a small unit area i.e. in temperate summer conditions a square metre of vegetation can produce 2 litres of water/day.

Paspalum has many features that make it an ideal supplier water vapour to ticks. In summer conditions in Queensland in short paspalum pasture, the R.H. 2.5 cm above the pasture, remained above 90% during darkness, even though no rain had fallen for 4 weeks and only 92 mm of rain had fallen in the previous 8 months (Wilkinson and Wilson, 1959). Paspalum requires high air temperatures (Madden, 1940; Pearce, 1976; Percival, 1977) and thrives in warm, moist summers. Its optimum growth occurs at 30°C compared with 25°C for white clover and 20°C for ryegrass (Pearce, 1966).

As paspalum has well developed rhizomes, it is able to draw water from deeper in the soil profile and retain water more efficiently in dry periods than ryegrass. At Kaikohe in Northland, temperature and water measurements from these two plants show this clearly (Table 1.9).

Table 1.8

Soil temperature and water measurements in the environment of ryegrass and paspalum pastures (from Pearce, 1976).

	Ryegrass Pastures	Paspalum Pastures
Days at wilting point	90	36
Temperature at soil surface in °C	46	27
Temperature 2 cm above soil surface in °C	36	24
Soil water %		
0 - 7.5 cm	15	27
7.5 - 15 cm	20	25
15 - 22.5 cm	24	27
22.5 - 30 cm	26	25

These results were reported without any means, ranges, maxima or minima.

It is of interest to note the high soil temperatures recorded under ryegrass in Northland. These temperatures exceed the critical temperatures (35 - 38°C) and upper lethal temperatures (circa 41°C) of H. longicornis.

From what has been said, it is clear that plants such as paspalum must be important in the survival of those stages most susceptible to desiccation i.e. eggs and larvae. The immobile egg must lose water when the a_v of the air is less than its own a_w pf 0.99 (equivalent to 99% R.H.). Since the critical temperature of eggs is low, the permeability of the egg shell (relative to other ixodids) is also high.

I can only find one reference in the literature stressing the importance of plant transpiration in tick ecology. Branagan (1978) concluded that the survival of larval Rhipicephalus appendiculatus in East Africa depended on high transpiration rates from the underside of plant leaves.

1.13 Hosts of H. longicornis.

Most 3-host ticks have a wide natural host range which includes mammals and birds and occasionally reptiles (Balashov, 1972). H. longicornis is no exception. From the records of Myers (1924); Seddon (1951); Wilkinson and Utech (1962); Saito, et al, (1965); Hoogstraal, et al, (1968), it is clear that the tick shows a remarkably wide host range; it has been recorded from at least 30 species of mammals and 7 species of birds. On birds the immature stages are more prevalent (Myers, 1924; Wilkinson and Utech, 1962). A New Zealand host list is presented in Table 1.10.

Except for the addition of deer as hosts of H. longicornis (Newbold, 1963; Wilson) 1979, the list of hosts has changed very little since 1924. A notable absentee from the host list is the opossum (Trichosurus vulpecula). This animal spends some time on pasture, but no ticks were found when 2,000 opossums (collected from the Cook, Waikohu, Waiapu and Wairoa Counties of the East Coast) were necropsied (Neilson - unpublished). Opinion from the local opossum skin exporter suggests that ticks are not found on skins of this species.

Circumstantial evidence suggests there may be some host preferences amongst the various stages. For a 4 month period when ticks were most numerous, goats and sheep grazing together were examined for ticks. Larvae were seen on goats only. Nymphs were more numerous on goats than sheep which in turn carried higher numbers of adults than did goats (Heath, Bishop and Tenquist, 1977). Small mammals can support a large population of ticks since a maximum of 371 larvae from the ears of one hare has been recorded (Heath, Tenquist and Bishop, 1978).

Table 1.9

New Zealand hosts of *H. longicornis*.

Mammals

Ruminants	Non-ruminants
Cattle (*Bos taurus*)	Dog (*Canis familiaris*)
Goat (*Capra hircus*)	Horse (*Equus caballus*)
Red Deer (*Cervus elaphus*)	Hedgehog (*Erinaceus europaeus*)
Samba Deer (*C. unicolor*)	Cat (*Felis cati*)
Rusa Deer (*C. timoriensis*)	Man (*Homo sapiens*)
Fallow Deer (*Dama dama*)	Hare (*Lepus europaeus*)
Sheep (*Ovis aries*)	Rabbit (*Oryctolagus cunciculus*)
	Pig (*Sus scrota*)

Birds

Skylark (*Alanda arvensis*)
Duck (*Anas boseas*)
Domestic Fowl (*Gallus gallus*)
Turkey (*Meleigris gallapavo*)
Sparrow (*Passer domesticus*)
Pheasant (*Phasiamus colchicus*)
Thrush (*Turdus philomelas*)

This host list is from Myers (1924) except for:
Hedgehog - Thompson (1922);
Cervidae - Newbold (1963);
Fallow Deer - Wilson (1979).

1.14 The control of ticks.

The approach to tick control used will depend upon the production loss caused by the tick. Obviously where the tick and the host are well adjusted to each other and tick numbers are low and no disease transmission occurs, then no control is necessary. Such a situation exists with 3 species of *Boophilus* and indigenous *Bos indicus* cattle in Asia (Barnett, 1978).

If the tick significantly affects production there are 3 alternative approaches to control (Wharton and Norris, 1980):
(1) discretional suppression;
(2) strategic suppression;
(3) eradication.

Control is very important where the tick is a vector of a protozoal or rickettsial agent causing diseases as the high morbidity or mortality rates such as theileriosis, babesiosis, anaplasmosis, and heartwater. Whereas species of *Theileria* such as *T. parva*, *T. mutans*, and *T. sergenti* and *Cowdria ruminantium* are transmitted only trans-stadially, some viruses, and species of *Babesia* and *Anaplasma* are transmitted trans-ovarially. In this latter case even low numbers of ticks can represent a significant hazard. However, total tick control by strategic immersion dipping every 7 days is needed to control theileriosis (Baker, 1978).

Chemical treatment of the infested host still remains the main method of control. However, overseas it has become increasingly difficult to obtain satisfactory tick control because of the development of insecticidal resistance. A recent review of resistance of ticks to insecticides is given by Wharton and Roulston (1970).

As a consequence of this resistance it has been suggested that using resistant breeds of cattle may be the most effective long term method of tick control in Australia (Wharton, Utech and Sutherst, 1973).

Although low tick numbers on these resistant breeds may be associated with a lowered prevalence of tick-transmitted diseases as heartwater and theileriosis (Baker, 1978) there is still a need for effective immunisation and chemotherapy against these diseases especially in the highly productive breeds of Bos taurus (Barnett, 1978). As well, small numbers of ticks can transmit disease and if tick numbers are low, young animals may not be effectively preimmunised by infection against babesiosis and anaplasmosis.

Other methods of control such as alteration of the micro-environment by ploughing, cultivation, pasture spelling, burning, heavy grazing, removal of long, rank vegetation should be considered, providing they are economic and practical.

Chemical treatment of the environment is usually impractical because of high cost, residues in food producing animals, and possible deleterious effects on other pasture and soil mesofauna. However, it is likely to be economic and safe to treat animal houses. Ten million square metres of livestock premises in Iran are sprayed annually with insecticide (Arshadi, 1976).

1.14.1 The control of H. longicornis.

So far as is known, this tick does not act as a vector for any infectious agent in New Zealand. If control is needed, it is only to prevent the direct effects to the host usually caused by relatively high tick numbers.

Chemical treatment of the host when large numbers of ticks are seen (discretional suppression) is the main method of control in New Zealand. Logically, the efficiency and length of protection of available insecticides against H. longicornis on sheep and cattle should be known. A summary of experimental work with these insecticides is shown in Table 1.11.

Except for amitraz (which is unrelated to organophosphates and carbamates), commercially available insecticides give a very short period of control on cattle and pour-ons give inconsistent results (see Table 1.11 for references). The short persistence of insecticides in hair compared with fleece is well known and has been reviewed by Sinclair (1977). In cattle with a higher grease content of the hair coat such as in Herefords insecticides can last up for to 7 days but persistence is less than this in Brahmans which have a lower grease content of the hair.

It has been suggested that most of the insecticide loss from dipped cattle is the result of the abrasive action of the tail, contact with ground, rubbing, licking, grooming and the action of the rain (Roberts and Chamberlain, 1963). However, these authors suggest that other causes of insecticide loss include chemical interaction between the insecticide and skin secretions and solar radiation.

Insecticides combine with the yolk of sheep fleece to remain for a considerable period but persistence will be short in the hairy areas (Sinclair, 1977).

Since most ticks occur on the hairy areas of sheep (Heath, 1973) this presumably is the reason for the short period (1 - 3 weeks) of protection. The persistence of insecticides on goats will also be short as no yolk is present. Some insecticides e.g. chlorfenvinphos, phosalone shower a higher efficiency when applied to sheep as they give a higher initial reduction in tick numbers and longer protection than others (see Table 1.11).

The majority of the unfed nymphs, adults and larvae appear to be available for transfer to the host over relatively short periods (Heath, 1973). This will vary according to temperature and host availability but the nymphal and adult peaks on stock occur at reasonably defined periods. This means strategic dipping, if applied at times of expected peaks of tick numbers, could markedly reduce numbers the following season. For this reason, Heath (1973) has suggested that the "live baiting" or "vacuum cleaner" technique may be a useful method of reducing tick numbers. Under this system, undipped sheep are mob stocked onto areas of known high tick numbers at the start of the nymphal, adult or larval peaks. They are removed after 2 or 3 days, before the ticks can engorge, and dipped. Then another mob (or the same one) is introduced into the area after 1 week, then dipped after 2 or 3 days. Farm management practices must be considered before this procedure can be implemented. Lambs are normally weaned from ewes at the time of the adult peak and ewes are often mob-stocked over this period. However, many North Island ewes are shorn in December and farmers are reluctant to dip ewes if they are to be shorn soon afterwards. Ideally, ewes should be shorn in October and, after weaning, dipped and mob stocked on known tick-infested pastures in late November or early December. Ewes with at least 6 weeks wool are available at the larval peak in February. This is perhaps the ideal time to implement the "vacuum-cleaner" technique. The nymphal peak coincides with lambing and it is most unlikely that farmers would dip ewes at this time of the year.

Cattle require spraying or dipping if health or productivity is adversely affected by the tick.

Table 1.10

Summary of insecticidal trials against H. longicornis on cattle and sheep in New Zealand.

1. The following insecticides have been tested -

Cattle	Sheep
Amitraz	Carbophenothion
Chlorfenvinphos	Chlorfenvinphos
Chlorpyrifos	Chlorpyrifos
Clodrin	Coumaphos
Coumaphos	Diazinon
Dioxathion	Ethyl bromphos
Fenthionmethyl	Fenthionethyl
Phosalone	Phosalone
Rabond	Surecide
Famphur)	
Fenchlorphos)	
Fenthion) pour-ons	
Phosmet)	
Prolate)	
Temephos)	

2. In general, in cattle, not more than 1 full days protection and partial protection for 7 days (except for amitraz).

3. In sheep, 2 - 3 weeks protection.

4. Pour-ons not efficient in cattle.

5. On sheep the insecticides diazinon, coumaphos, phosalone and chlorfenvinphos are more efficient than other insecticides.

Data from - Tenquist, Wright, and Skyrme, (1973, 1975); Heath (1973); Tenquist and Wright (1974); Heath, Tenquist, Bishop and Cole (1978); Heath, Tenquist and Bishop (1980).

Because of the risk of residues, insecticides for use on dairy cattle in milk are restricted to ciodrin, and amitraz. The latter would be the treatment of choice because of the reported longer length of protection (Heath, Tenquist and Bishop, 1980).

If the microenvironment in the vegetation can be altered to create less favourable conditions, this will assist in reducing tick numbers. Well-grazed and/or ryegrass dominant pastures appear to be unsuitable for the survival and development of H. longicornis (Myers, 1924; Tenquist, Wright and Skyrme, 1973). The development of these pastures by oversowing, subdivision and rotational grazing may assist in reducing tick numbers. Tick survival may be higher in paspalum pastures. This grass only becomes dominant (more than 60% of the summer pasture) under low fertility conditions and poor grazing. Hard grazing after autumn rain helps suppress paspalum and encourages ryegrass tillering (Pearce, 1976). The control of rank pasture growth and the removal of plants that provide warmth in the winter and high humidities in the summer are thus important in controlling the tick (Myers, 1924; Mutch, 1966; Heath, 1973).

As H. longicornis exhibits a defined seasonal pattern of Mount Tamborine in Australia (and in New Zealand) it has been suggested by Sutherst and Moorhouse (1972) that pasture spelling for 3 - 9 months may put the life cycle out of phase and also reduce tick numbers by starvation at the longer period of pasture spelling. However, stages feeding on hosts outside their expected periods of abundance have been recorded by Heath, et al, (1977, 1978) which suggests relatively long survival "out of phase". Pasture spelling is generally uneconomic under the higher stocking rate practised in New Zealand and the technique appears more applicable in Australia where, with lower rainfall, the tick is more susceptible to desiccation over this spelling period.

The long winter premoult periods of engorged larvae (21 - 80 days) and engorged nymphs (138 days) with minimum mortality (0-34% and 0-20% respectively) at Wairoa (Heath and Bishop, 1978) suggested winter pasture spelling in the relatively warm areas of New Zealand may result in large numbers of unfed ticks per unit area all able to engorge simultaneously when stock are finally admitted. In fact these authors found that many larvae (resulting from egg laying females deposited in pasture at Wairoa 150 - 259 days previously) were able to engorge on suckling mice but there was no correlation between viability and length of starvation.

Recently, Wharton and Norris (1980) have suggested that biological control of ticks seems to have limited application. In this respect an encyrtid wasp (Hunterellus species) which parasitises other ticks in Queensland does not appear to parasitise H. longicornis (Doube and Heath, 1975).

EXPERIMENTAL SECTION

2. Tick questionnaire.

2.1 Introduction.

Between 1970 and 1974 farmers reported to the officers of the Ministry of Agriculture and Fisheries (M.A.F.) at Ruatoria, Gisborne, Wairoa and Hastings, that they were alarmed at the apparent increase in tick numbers on their farms in these areas. There were also reports of stock losses attributed to *H. longicornis* during this period (Tenquist, *et al*, 1973).

To define the distribution of, and attempt to assess the economic importance of *H. longicornis*, a postal questionnaire was sent from the Hastings and Gisborne offices of the M.A.F. to farmers in the East Coast and Hawke's Bay areas.

2.2 Materials and methods.

The area from which information was sought from farmers approximates to that of the East Coast and Hawke's Bay areas shown in Figure 2.1. From the Gisborne office of the M.A.F. questionnaires were sent to all farmers in the Cook, Waikohu, Waiapu and Wairoa Counties who were listed on the 1974 Sheep-owners list as having more than 100 sheep. This area includes the 3 Counties of the East Coast and one County in northern Hawkes Bay.

From the Hastings office of the M.A.F., questionnaires were sent to all farmers on the 1974 Sheep-owners List located in Counties of Hawke's Bay, Waipawa and Waipukurau and to farmers in the northern half of the Patangata County. A reply-paid envelope was enclosed with each questionnaire.

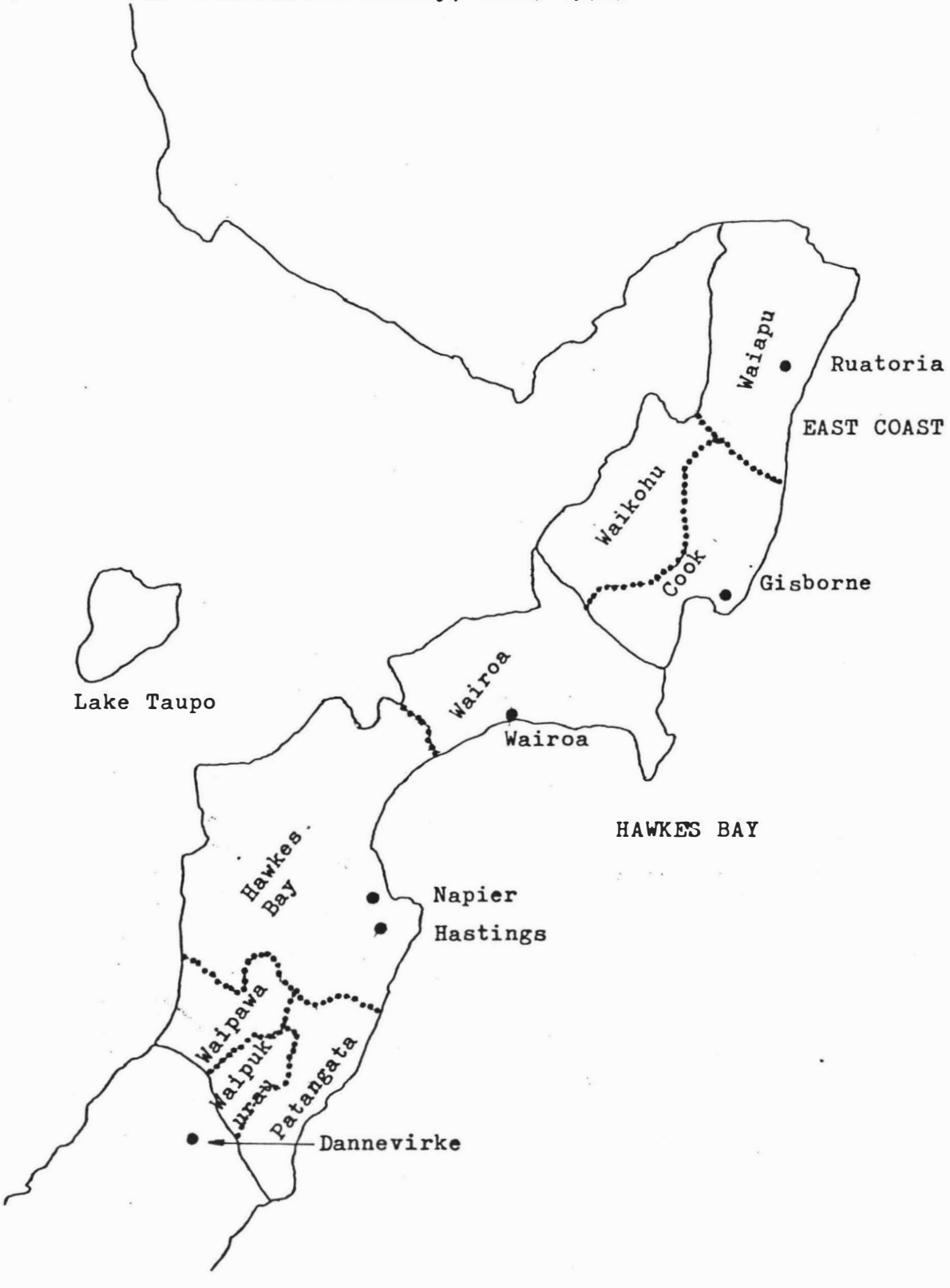
A copy of the questionnaire is shown in Appendix 1.

Figure 2.1

Approximate area of distribution of the questionnaire.
Regional Boundaries _____

County Boundaries .....

(from National Resources Survey, Anon, 1971)



2.3 Results.

The results are reported separately from two areas depending upon which office the questionnaires were returned to. Replies sent to the Gisborne office include the East Coast and Northern Hawke's Bay areas. Replies sent to the Hastings office were from Central Hawke's Bay.

Return rate

	Sent out	Returned	% returned
East Coast-Northern Hawke's Bay	1397	866	62%
Central Hawke's Bay	1440	823	57%

Presence or absence of ticks

Of the returns received, farms were recorded according to the presence or absence of ticks.

	Properties with ticks	Percent of farms
East Coast-Northern Hawke's Bay	512	59%
Central Hawke's Bay	58	7%

These results and a subsequent map of tick distribution (Figure 2.3) show that H. longicornis occurs only on a few properties in the Hawke's Bay County and conditions are therefore likely to be marginal for tick survival in that County.

Significance of H. longicornis

The returns from farmers in the central Hawke's Bay area indicated that ticks were not considered a significant problem. Only two properties dipped specifically to control ticks. The opinions of farmers in the East Coast-Northern Hawke's Bay area are shown in Figure 2.2.

Figure 2.2

Opinions of farmers in the East Coast and Northern Hawke's Bay (Cook, Waikohu, Waiapu and Wairoa Counties) as to the significance of H. longicornis on their properties.

TICKS	316 farms 36.5%	Ticks present and considered a significant problem.
	196 farms 22.6%	Ticks present and not considered a significant problem.
NO TICKS	354 farms 40.9%	No ticks present

Length of time ticks have been present on the farm

Of the 58 farms in the central Hawke's Bay area on which farmers reported ticks, the first recorded sighting was in approximately 1968. The tick has only increased in numbers since 1972 (G.B. Davis, pers. comm.). For the 512 farms reporting ticks from the northern Hawke's Bay and East Coast area, the replies are shown in Table 2.1.

Table 2.1

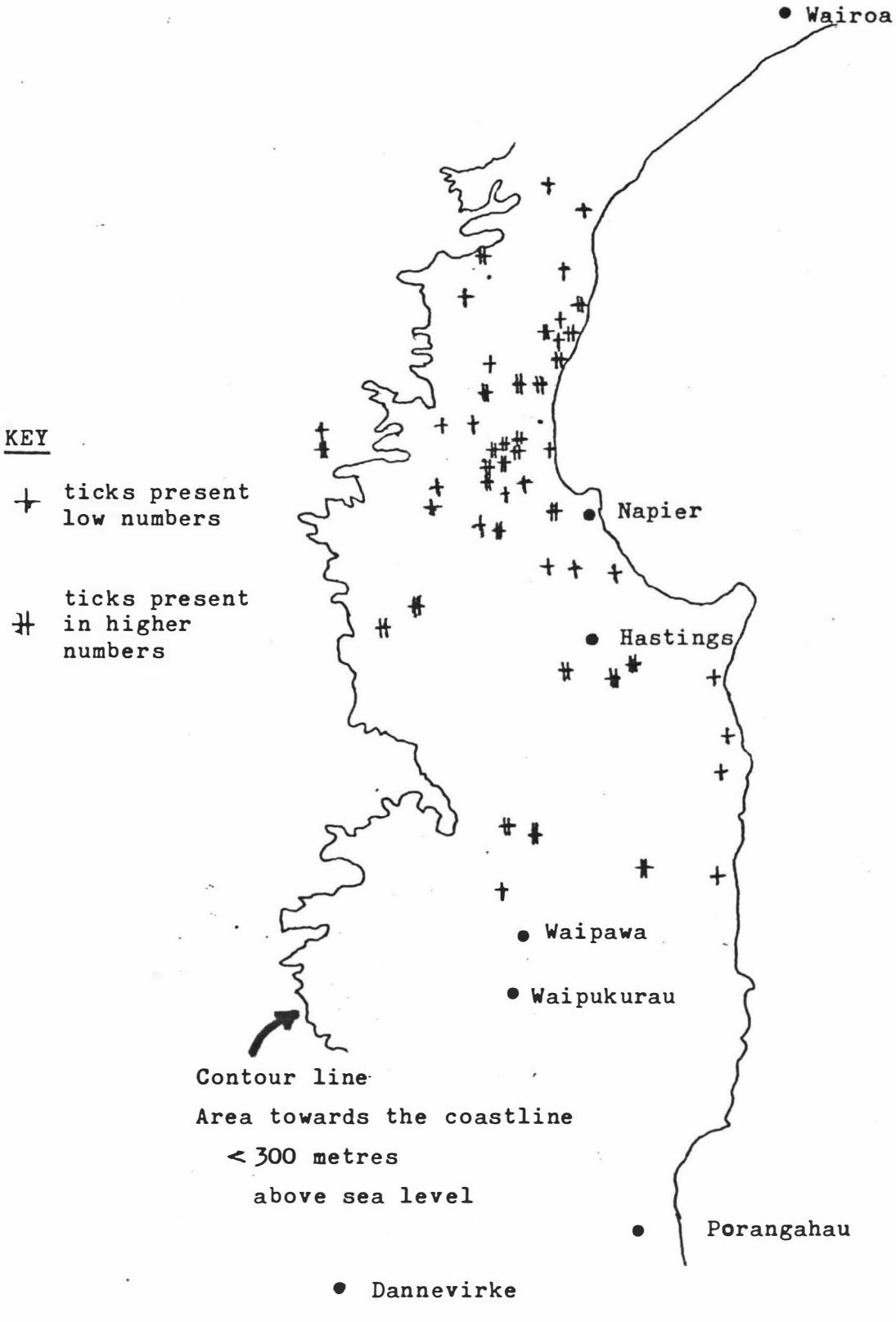
Length of time H. longicornis present on farms in the Northern Hawke's Bay and East Coast area.

County	Unknown	Present but disappeared	Present 1-10 years	Present more than 10 years
Wairoa	18	4	71	37
Cook	16	2	73	61
Waikohu	7	-	41	29
Waiapu	17	1	25	30
Unidentified	13	1	50	16
	71	8	260	173

Total 512

Figure 2.3

Distribution of farms in central Hawke's Bay area, on which owners or managers reported ticks (H. longicornis) on the property.



Distribution of H. longicornis in central Hawke's Bay area.

The distribution of farms whose owners or managers reported ticks is shown in Figure 2.3. Replies to the questionnaire were divided into properties where only an occasional tick was noticed, and properties where ticks were considered more numerous. Most of the farms where H. longicornis was reported to be present are located north of Napier in the warmer coastal areas of Eskdale and Tangoio.

Distribution of H. longicornis in northern Hawke's Bay and the East Coast area (Waiapu, Cook, Waikohu and Wairoa Counties.)

The area from which replies were received by the Gisborne office of the M.A.F. is shown in Figure 2.4.

From the replies to the questionnaire, properties were divided into:

1. no ticks present
2. ticks present but no problem
3. ticks present and a problem

The locations of these properties were then plotted on (scale 1 : 63,360) topographical maps. From this it was apparent that ticks were mainly present at altitudes below 300 metres.

The distribution of ticks in relation to the 300 m contour in the 3 categories mentioned above is shown in Figures 2.5, 2.6 and 2.7.

Figure 2.4

Area from which replies to the questionnaire were received by the Gisborne office of the M.A.F.

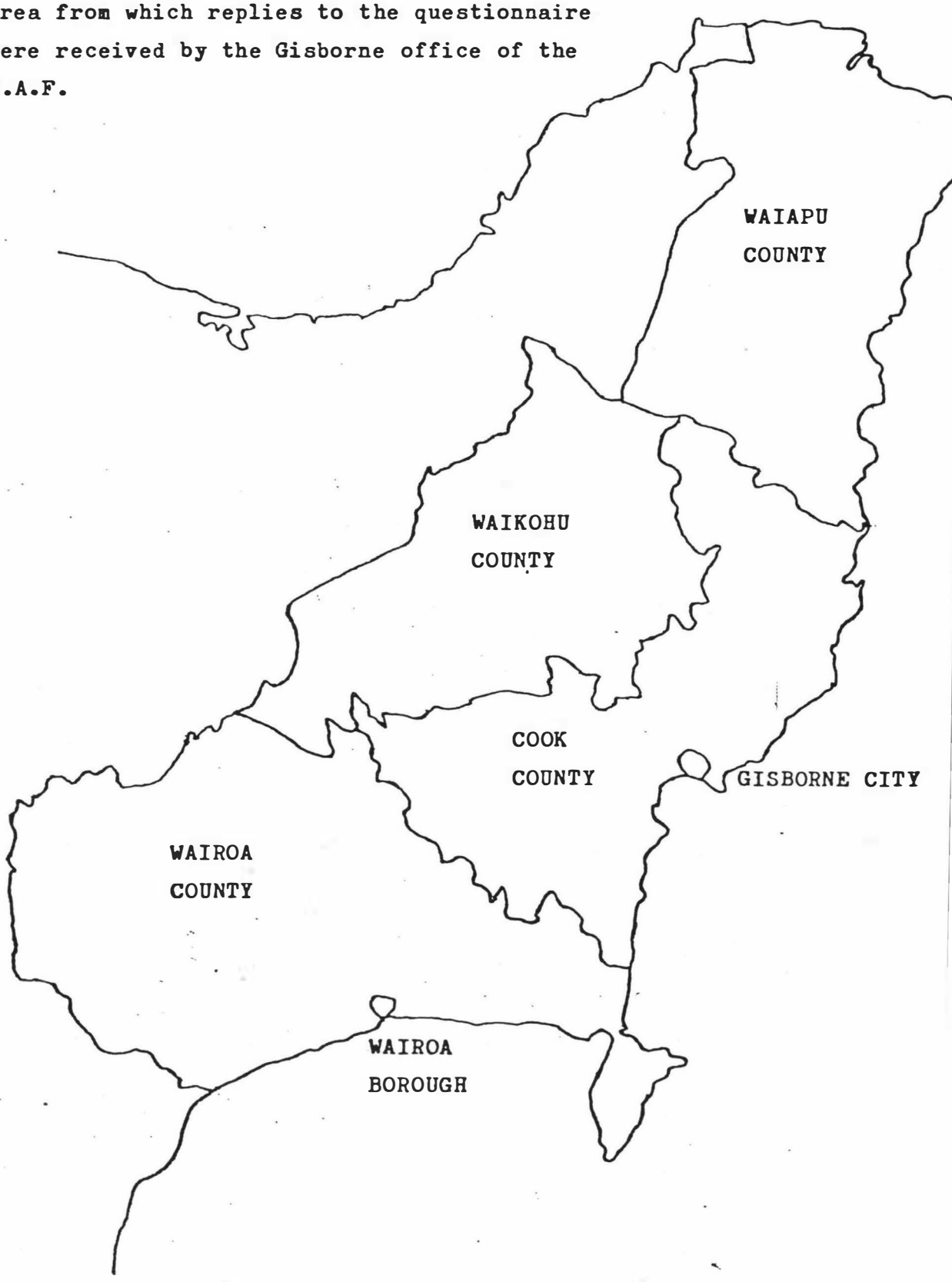


Figure 2.5

Distribution of properties which reported no ticks present. The shaded area represents an altitude of 300 metres or less above sea level.

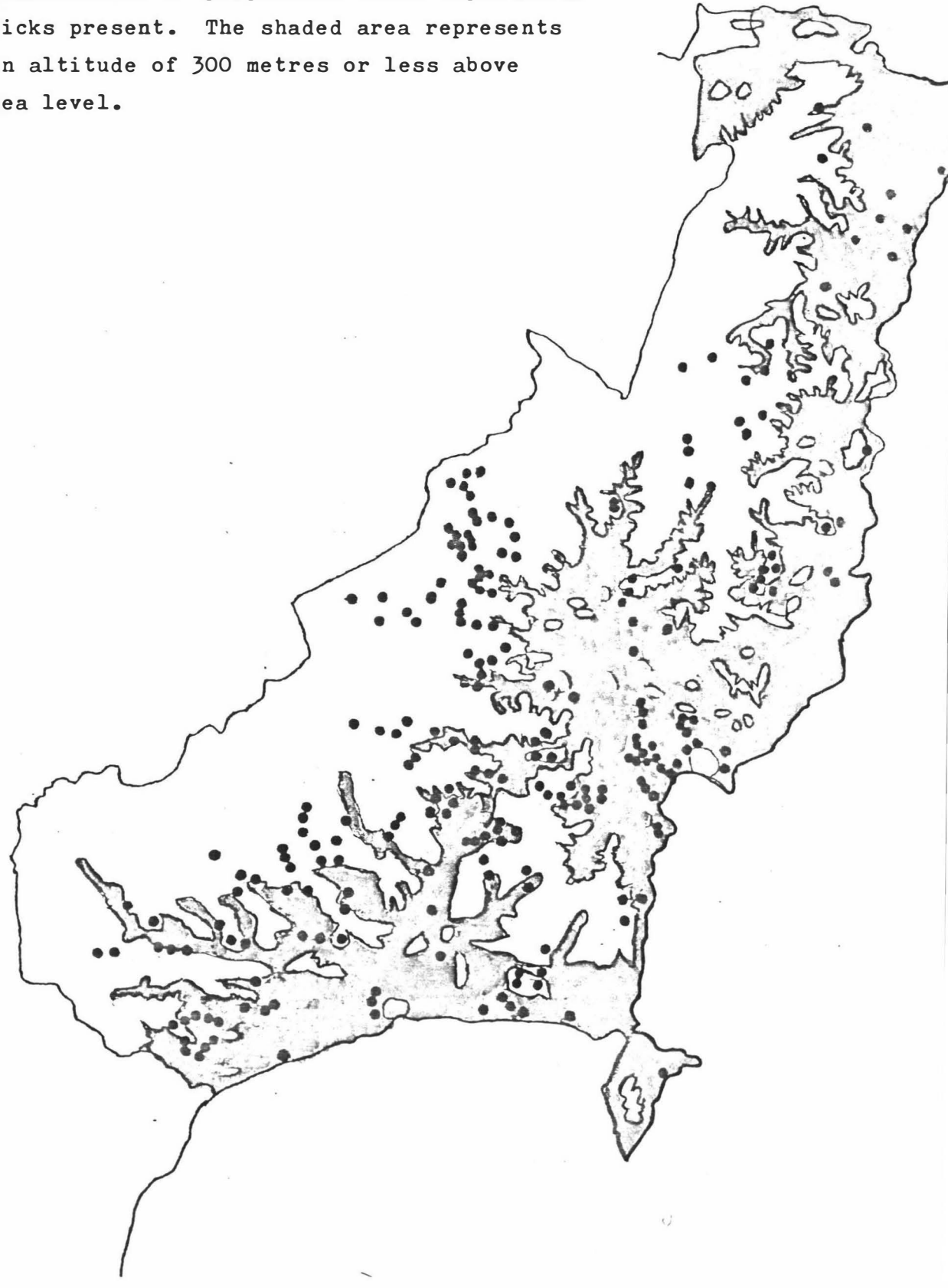
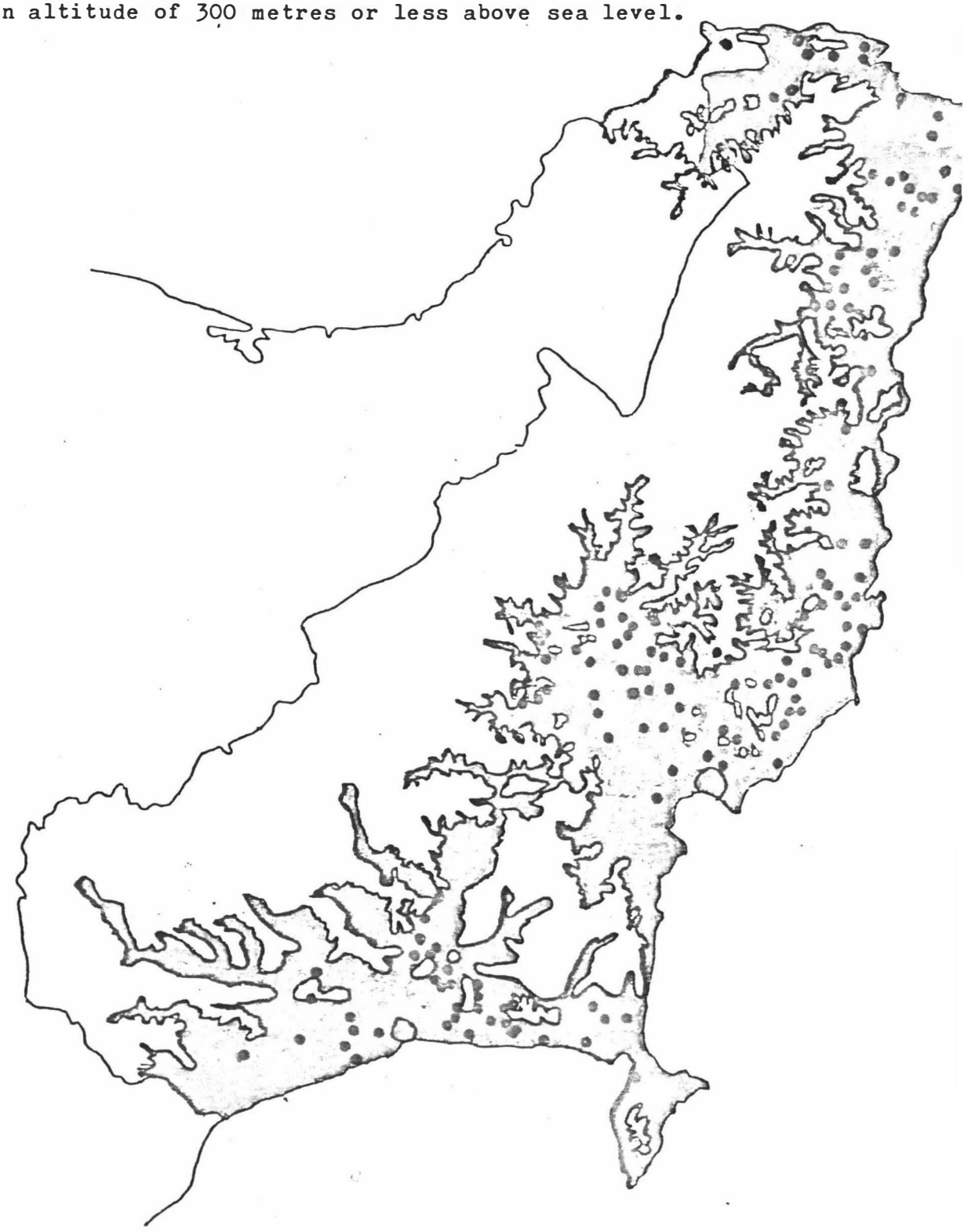


Figure 2.6

Distribution of properties which reported ticks present but were not considered a problem. Shaded area represents an altitude of 300 metres or less above sea level.

Figure 2.7

Distribution of properties which reported ticks present and considered a problem. The shaded area represents an altitude of 300 metres or less above sea level.



2.4 Discussion.

It has been stated that there is very little information about the effects of diseases or parasites on animal productivity and on general farming operations involving large populations of animals (Simpson, 1976). This is true in New Zealand for diseases or parasites that do not cause high mortalities or do not cause partial or complete rejection for export of animal products..

To obtain such information, a survey can be carried out on a district, region, or national probability sample. In this instance it was decided to carry out a census of farmers in the specified area so that tick distribution could be mapped more accurately. More accurate information can be obtained from personal interviews with livestock owners. However, a census was employed because the high operating cost precluded the use of personal interviews. Thus the results of the questionnaire represent the opinions of farmers only.

Some diseases including parasitic diseases, apart from their direct effects on productivity, may interfere with farming operations (Simpson, 1976) and this indirectly affects production. For example, farmers may be unable to graze heavily tick infested pastures and the time required for repeated dipping may prevent the farmer from attending to other aspects of stock management.

Moule (1965) has suggested that opinion surveys or censuses may indicate pointers to appropriate solutions and the results may be useful in formulating extension and research programs. Therefore, the author believes, like Simpson, that farmer opinions must be given credence alongside measurement data of incidence, prevalence, mortality, etc.

Design of the questionnaire.

This was not preaddressed or number coded so that no follow-up on the non-returns could be made: because of this, no information is available from approximately 40% of farms. However, the high return rate from farms where no ticks were present suggests that the results can be considered representative of all farms in the area.

Some questionnaires were returned completed except for a name and address so that these could not be mapped. Local gossip suggested that some farmers were concerned that the M.A.F. might introduce farm quarantine and compulsory dipping. This possibility was not considered when the questionnaire was distributed - may be one reason why some questionnaires were returned unnamed.

Economic importance of H. longicornis.

The tick is not an economically important parasite in the central Hawke's Bay area. In the northern Hawke's Bay and East Coast area a relatively large number of farmers (89/866 = 10%) suggested that ticks were responsible for causing stock deaths on their properties.

A larger number of farmers (316/866 = 36%) in the northern Hawke's Bay and East Coast area considered that ticks either caused deaths, were an increasing problem, or a problem in some seasons only (see Figure 2.2). Since the tick can cause a reduction in body weight and reduce scoured wool yield (Heath, et al, 1977), where tick numbers are sufficiently high to be considered a problem economic loss is likely. To these can be added the cost of labour and materials where farmers dip specifically for tick control. An investigation of anaemia and deaths in Red Deer (Cervus elaphus) associated with heavy infestations of H. longicornis is presented in Appendix 33. The financial loss from these deaths amounted to $28,000.

Length of time H. longicornis present on properties in the northern Hawke's Bay and East Coast areas.

Over a period of 10 years there are likely to have been many changes in farm owners and/or managers. This may account for the 71 farmers who had ticks on their property but did not know how long the tick had been present (Table 2.1).

Where ticks were present, a large proportion (260/512 = 50%) of farmers indicated ticks were a recent introduction to the property. This indicates a substantial increase in tick numbers prior to 1974. The reasons for this apparent increase in tick numbers suggested by Tenquist, et al (1973) were:

(a) withdrawal of D.D.T. for topdressing;
(b) wet summers of 1970-1972;
(c) mild winters of 1970-1972.

In 1974 a meeting was held in Gisborne with farmers from the area who were concerned at the increase in tick numbers. These farmers disagreed the claim that tick numbers had increased since withdrawal of D.D.T. as very little D.D.T. had ever been used in the Gisborne area. Whilst this represents opinion only, it does suggest other factors such as favourable climatic conditions were more important in contributing to the apparent increase.

There are 4 climatological stations in the northern Hawke's Bay and East Coast area located at Waerenga-O-Kuri, Manutuke, Gisborne Aerodrome and Wairoa (see Figure 2.10). Figure 2.8 shows the monthly rainfall at Manutuke Climatological Station for those months during which the eggs of H. longicornis are present. It can be seen that rainfall was unusually high for the 4 month periods in 1969-1970 and 1970-1971.

Temperatures for the four coldest months of the year (June to September) from 1969 to 1973 are shown in Figure 2.9. The mean temperature for the four-month period is shown within each histogram.

In the year 1970 and 1971, temperatures were above average for the four-month period. Higher temperatures would influence the activity of overwintering nymphs and could have initiated an earlier nymphal peak. The temperatures during August and September were above the theoretical development threshold moulting temperature for nymphs suggested by Heath (1974).

It seems likely that the higher than usual rainfall in 1969/70 and 1970/71, (during the period when eggs were on the ground) provided the initial impetus for the tick population increase.

Figure 2.8. Mean rainfall and rainfall for November, December, January and February at Manutuke Climatological Station.

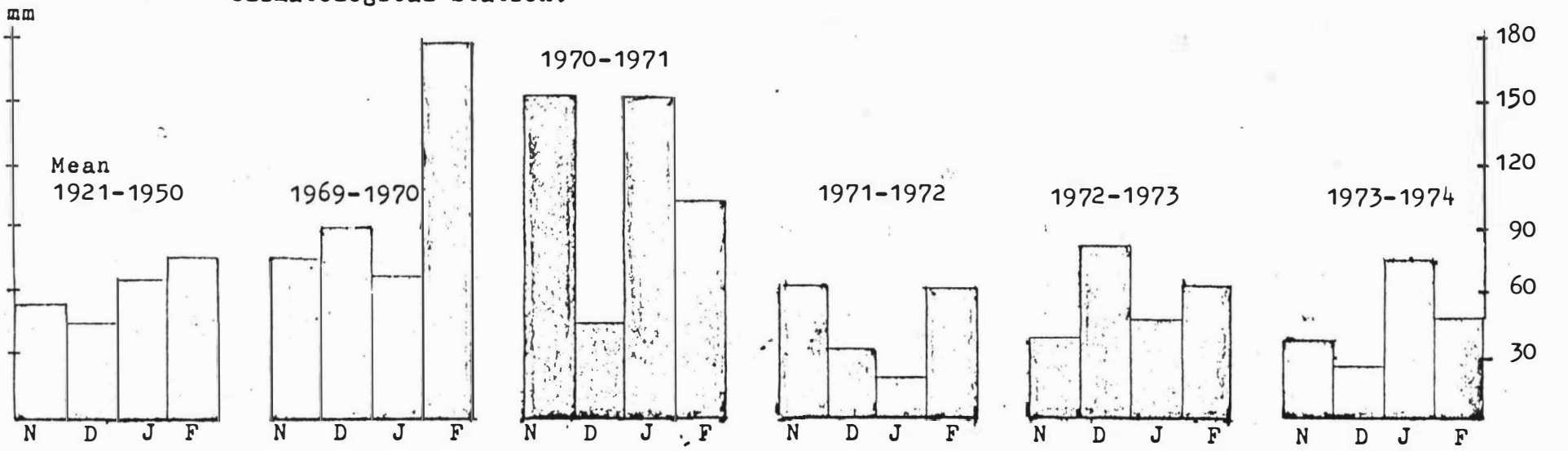


Figure 2.9. Mean temperature and temperature for June, July, August and September at Manutuke Climatological Station.

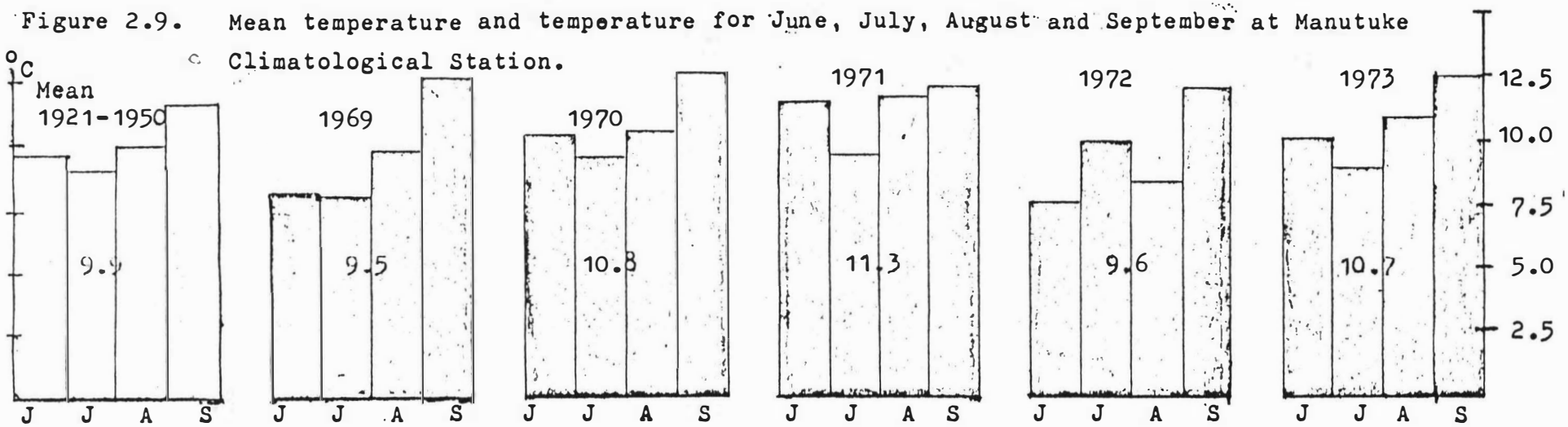
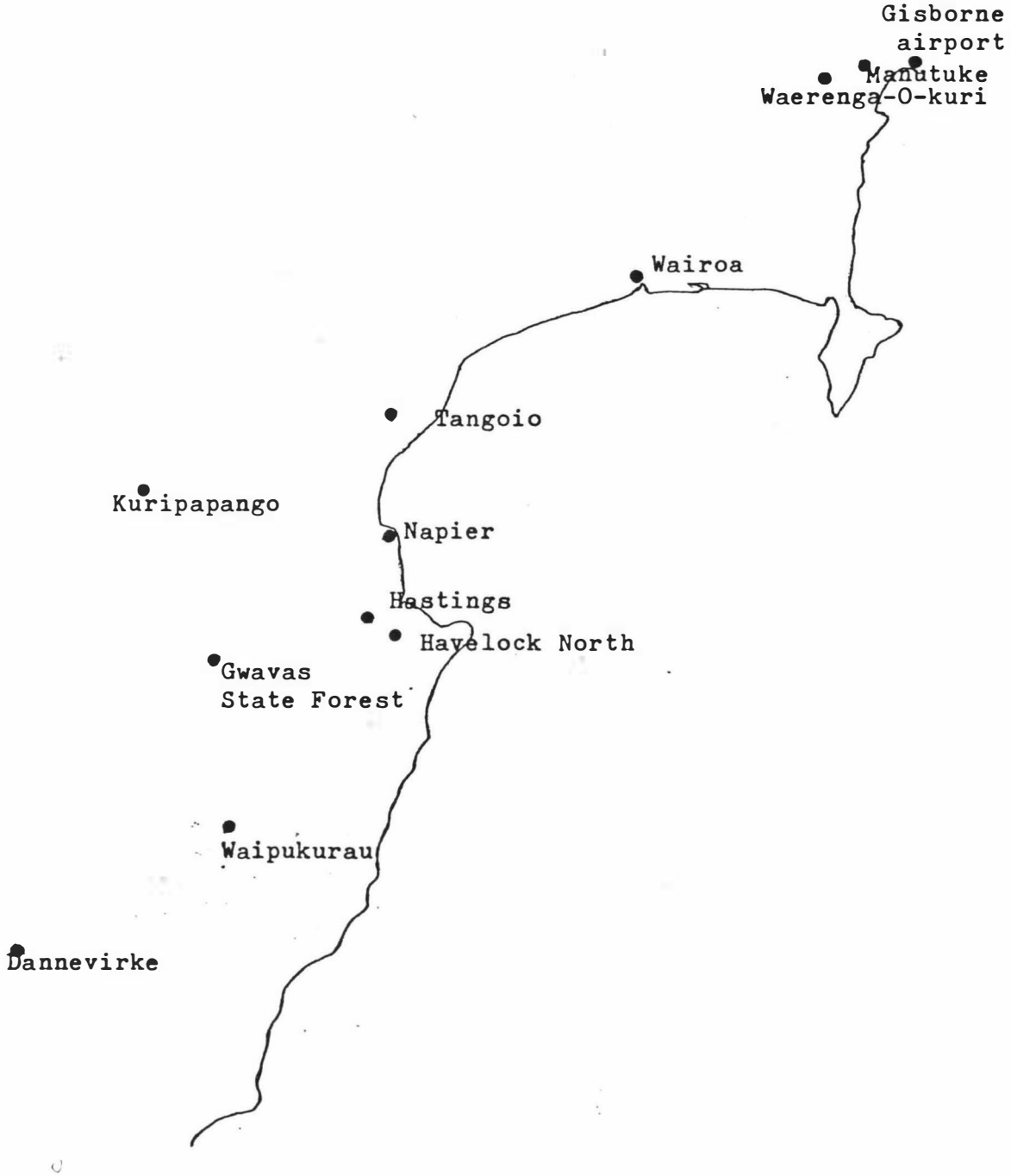


Figure 2.10

Climatological Stations in the area in which tick distribution was mapped.



From de Lisle and Patterson (1971).

Table 2.2

Altitude, rainfall and annual mean temperatures of the Climatological Stations in the area mapped for distribution of H. longicornis.

	Station	Annual mean temperature (°C)	Annual mean rainfall (mm)	Altitude (metres above sea level).
1.	Wairoa	14.5	1290	8
2.	Napier	13.9	780	2
3.	Gisborne aerodrome	13.8	1034	4
4.	Hastings	13.6	767	14
5.	Manutuke	13.5	998	30
6.	Tangoio	12.8	1432	299
7.	Havelock North	12.4	763	9
8.	Waerenga-O-Kuri	12.2	1343	314
9.	Waipukurau	12.1	824	137
10.	Dannevirke	12.1	1089	207
11.	Gwavas State Forest	11.1	1214	335
12.	Kuripapango	11.0	1625	488

Distribution of H. longicornis.

(i) Central Hawke's Bay

This is shown in Figure 2.3. Despite the introduction and establishment of ticks in the Wairoa area after 1930, ticks have not established on many farms in central Hawke's Bay. It is presumed that ticks have had the opportunity to spread by stock movement. Stock were, and still are, driven south from Wairoa on foot.

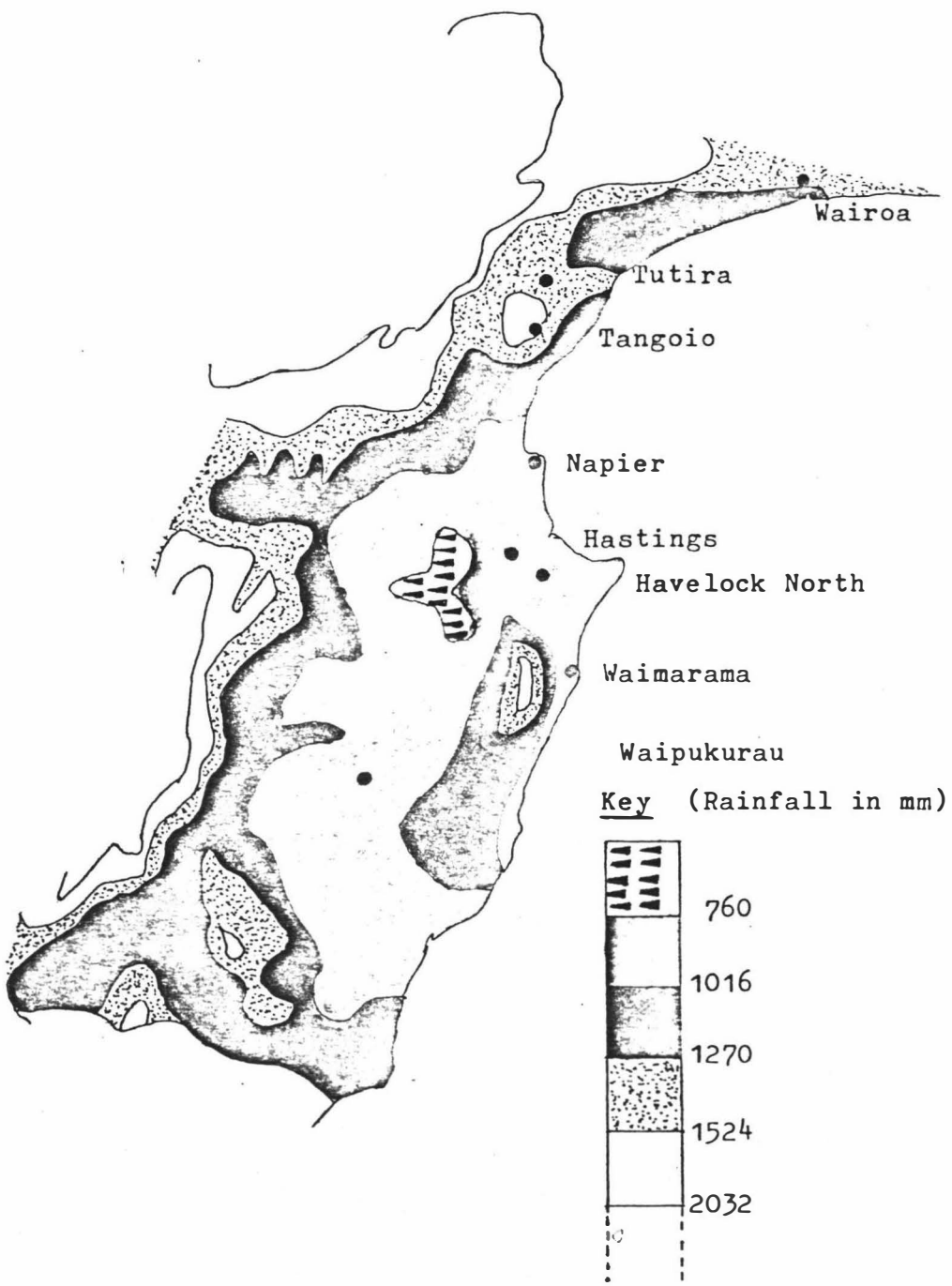
The locations of climatological stations for the area are shown in Figure 2.10 and summaries of records from these stations to 1960 or 1970 (Anon, 1966b, 1973c) are available. Tick infested properties are mainly concentrated north of Napier in the Eskdale, Tangoio area. In these areas the rainfall exceeds 1000 mm (see Figure 2.11). The annual mean temperatures, rainfall and altitude for the climatological stations are shown in Table 2.2.

Even though Napier and Hastings have high annual mean temperatures, the annual rainfall appears to be insufficient to maintain large tick populations. Where rainfall is above 1000 mm, temperatures are not sufficiently high to support large tick populations (see Figure 2.11) in much of central Hawke's Bay.

It seems likely that the distribution in central Hawke's Bay is influenced both by rainfall and temperature.

Figure 2.11

Mean annual rainfall (1921 - 1950) in central and southern Hawke's Bay region.



From de Lisle and Patterson (1971).

(ii) Northern-Hawke's Bay and East Coast

The distribution of properties on which the owners or managers reported ticks and considered them a problem is shown in Figure 2.7. With one exception all properties are situated less than 300 metres above sea level. It is assumed that this is an expression of the influence of temperature either directly on the life cycle of the tick or indirectly through effects on the botanical composition of the pastures. Even where ticks were present but not considered a problem, most farms are situated less than 300 metres above sea level. In this area temperatures conform to the general pattern of a decrease of 0.6°C for every 100 metres increase in altitude (Anon, 1979). A similar pattern is seen in central Hawke's Bay (de Lisle and Patterson, 1971).

Other authors have investigated and established some form of relationship between ecological factors and the distribution and abundance of ticks. These were reviewed earlier. As the replies to the questionnaire returned to the Gisborne office of the M.A.F. indicated a large number of properties with ticks as well as a large number without, the likely reasons for the distribution warrant a more detailed examination.

a) Distribution of ticks in northern Hawke's Bay and East Coast areas according to soil type.

The range of soil types in the four counties is narrow (about 40) and they can be subdivided into 3 basic soil types: alluvial, pumice and skeletal (includes mudstone and sandstone). The area has been subjected to 6 soil-forming deposits of pumice. This volcanic ash has been removed from most of the steeper land by erosion and consequently pumice soils are found on lower land and only at high altitudes where the contour is not steep (Anon, 1979).

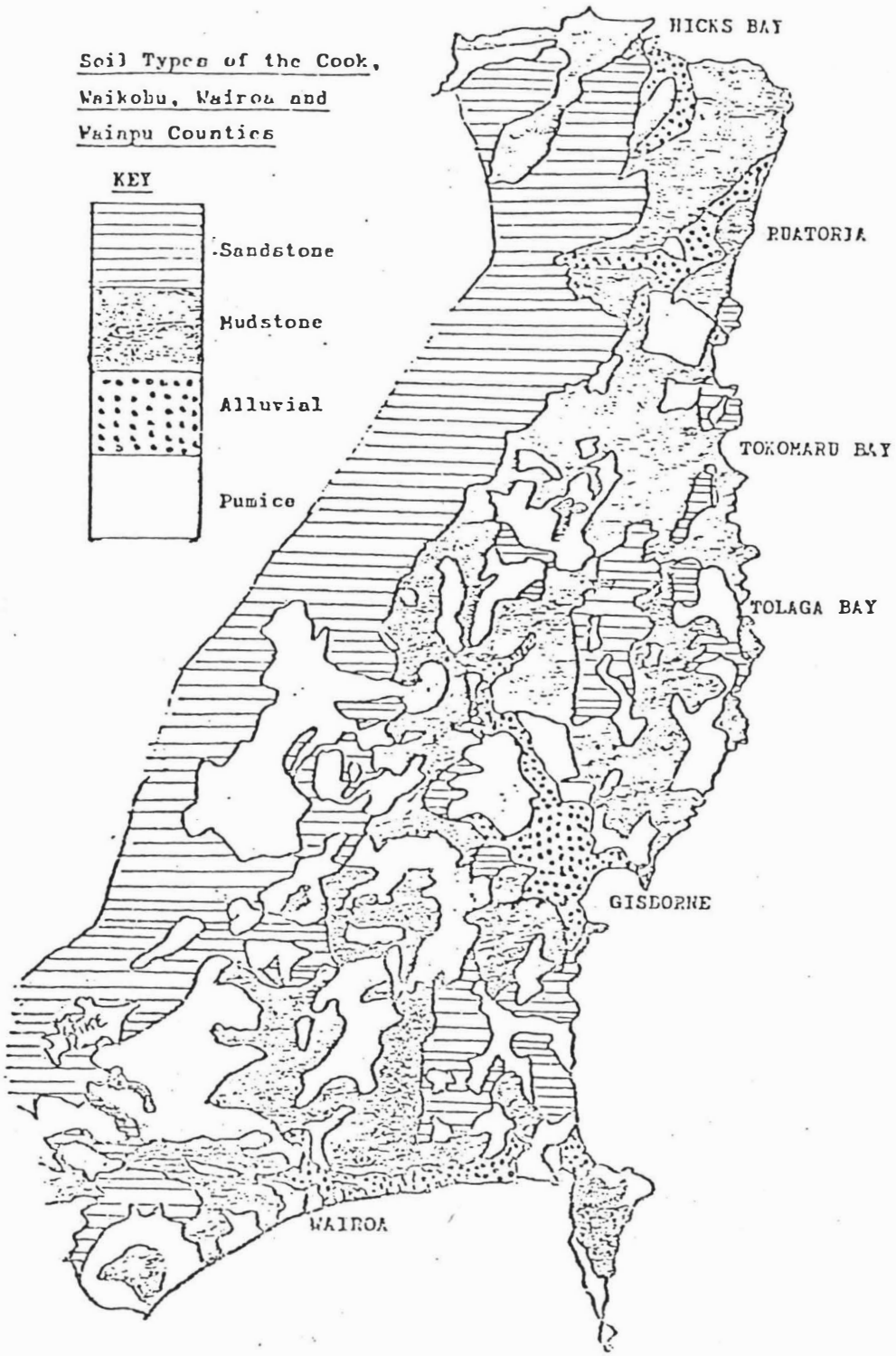
A map of the basic soil types is shown in Figure 2.12. Properties where ticks were present and a problem, tend to occur on pumice or alluvial soils although some are on mudstone. No tick problem areas are present on sandstone. This indicates the overriding effect of altitude. The properties from which no ticks were reported are mainly located on pumice and sandstone. Where ticks were reported not to occur and the soil type is pumice these are generally areas where the altitude is 300 metres or more above sea level.

(b) Distribution of H. longicornis in the East Coast and Northern Hawke's Bay area in relation to rainfall.

The rainfall for the area is shown in Figure 2.13. Ticks were generally recorded from areas where the rainfall is between 1000 - 1600 mm per annum. Ticks were absent in the higher rainfall areas but again this probably represented the influence of altitude on tick distribution. Because of the mountainous terrain, orographic influences on rainfall are marked. The rain-producing winds (northerlies and south-easterlies) both bring rain to the north-eastern part of the area and to the mountains. They bring less rain to the southern and western areas.

Figure 2.12

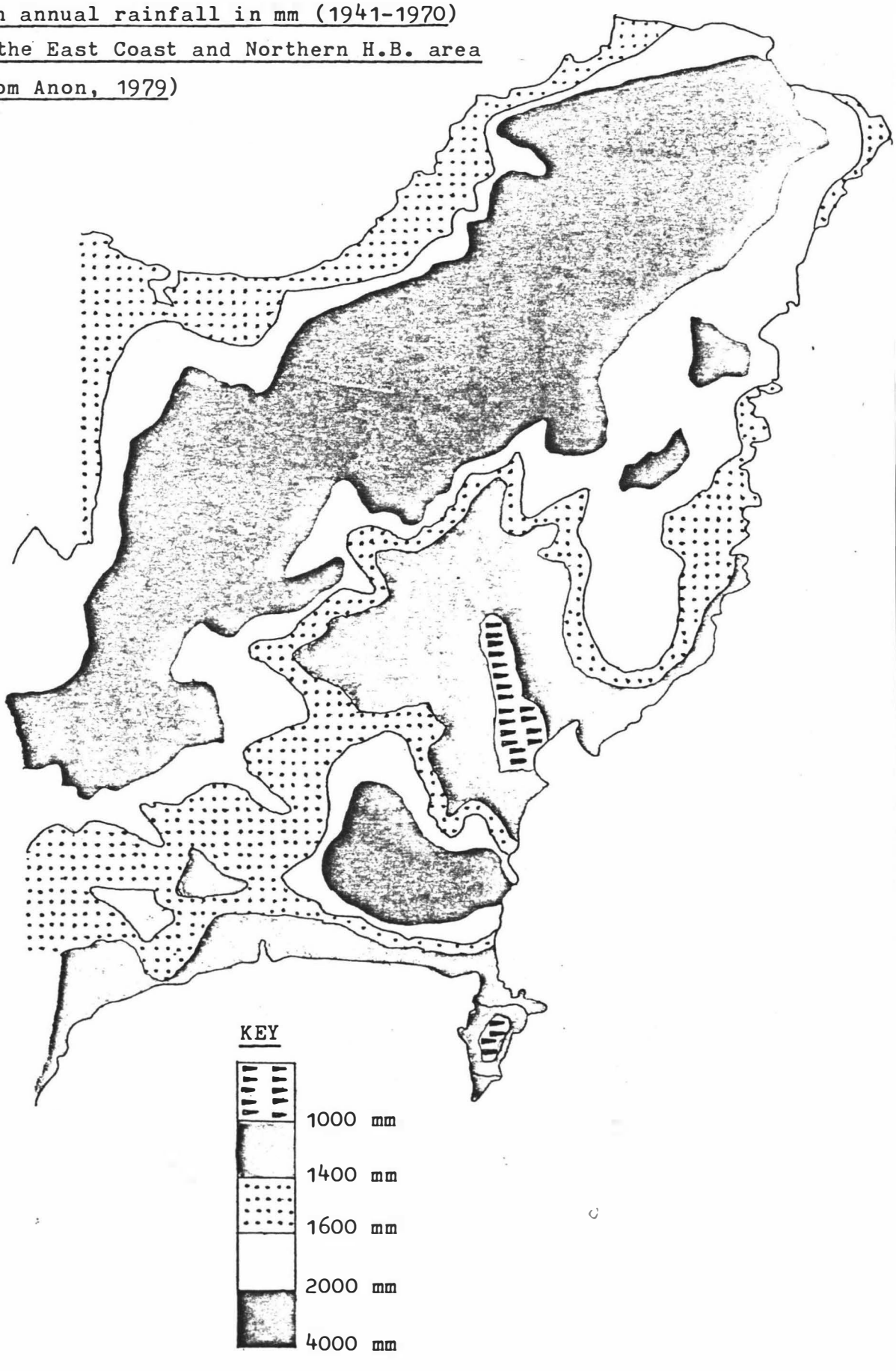
Soil Types of the Cook, Waikohu, Wairoa and Wainpu Counties



From unpublished map M.A.F. Gisborne.

Figure 2.13

Mean annual rainfall in mm (1941-1970)
In the East Coast and Northern H.B. area
(From Anon, 1979)



c) Distribution of H. longicornis in the northern Hawke's Bay and East Coast area in relation to temperature.

The distribution of ticks in the area is closely related to altitude and it is assumed that this represents the influence of temperature on the distribution of ticks. This relationship may be coincidental or may indicate the direct influence of temperature on some aspects of the life history of the tick. Precise information from laboratory experiments is not available to explain the reasons for this distribution.

Of the four climatological stations in the area (see Figure 2.10) one of these, Waerenga-O-Kuri, is situated at 314 metres above sea level and from the tick distribution maps the area adjacent to this station is known to be free of ticks. The mean annual temperature for this station is 12.2°C which is considerably lower than that from the other 3 stations (see Table 2.2).

With respect to the other climatic indices reported in Table 1.7, all four stations have a July minimum of 4°C or greater, i.e. above the July minimum air temperature of 2°C. The July maximum for 3 of the stations is between 13.5 - 13.7°C where this is only 11.1 for Waerenga-O-Kuri.

Consideration of the available evidence on the influence of temperature on the biology of H. longicornis, suggests that lower temperatures affect the survival and hence distribution of the tick as:

(a) Females require a minimum of 16°C for oviposition (see Table 1.6);

(b) Eggs require a temperature greater than 12°C for hatching (Heath, 1979);

(c) The water vapour pump of the unengorged stages is likely to be influenced by temperature as reported (Sauer and Hair, 1971) for other ticks;

(d) Temperature will influence the botanical composition of the pasture and hence transpiration rates and the amount of water vapour available for the susceptible stages such as eggs and larvae.

The way in which temperature influences the distribution (and numbers) of H. longicornis will only become clear when sufficient detailed experiments have been carried out.

d) Distribution of H. longicornis in East Coast and Northern Hawke's Bay in relation to evaporation.

The absence of ticks at altitudes above 300 metres at first suggests that this is related to temperature. This however may not be correct. In Canada it has been shown that mean daily evaporation (measured in unshielded Piche atmometers where the evaporating discs were suspended 30 cm above closely clipped grass) is positively and highly ($r = 0.95$) correlated with relative elevation. An inverse relationship was demonstrated between evaporation and maximum air temperature. Mean daily Piche evaporation is negatively correlated ($r = - 0.66$) with mean daily maximum air temperature (Machattie and McCormack, 1961). According to the authors the variation of evaporation with both temperature and elevation is related to ventilation. These results cannot be assumed to be correct for New Zealand. It does suggest however that tick distribution should be investigated in relation to evaporation.

3. Tick counting: distribution of tick counts of sheep.

3.1 Introduction.

A sampling technique is essential for the study of tick populations. Various methods have been described for collecting ticks on pasture to estimate the number of ticks present. To evaluate the efficacy of an insecticide, ticks must be counted on the host. This is more easily accomplished with 1-host ticks like B. microplus. Engorging females greater than a certain length can be counted on one side of the animal (Wharton and Utech, 1970). However, counts of B. microplus from cattle show a strongly skewed distribution and for statistical analysis counts have to be transformed e.g. to logarithms (Seifert, 1971).

The distribution of total counts of Ixodes ricinus on sheep, has been examined and reviewed by Milne (1943). Again the distribution is positively skewed and does not fit a normal or Poisson distribution. Individual susceptability to tick infestation varied between different age groups and within the same age group. Milne suggested that if the distribution is excessively skewed tick counts should be converted to square roots for analysis.

3.2 Materials and methods.

One hundred, $1\frac{1}{4}$ year old Border Leicester ewes were tagged following random selection. Ticks were counted on these sheep at approximately 7 day intervals (days 0, 7, 13, 20, 27 and 34) beginning on 1/12/77. Engorged and unengorged adults were counted on the left and right ears and on the hairy areas of the body, i.e. head, axilla, flank, groin and escutcheon.

The total tick counts for each animal, for each counting period, were then tabulated as a frequency distribution. The same counts were also transformed to logarithms (after the addition of one), and to square roots: these are shown graphically in Figures 3.1 - 3.6.

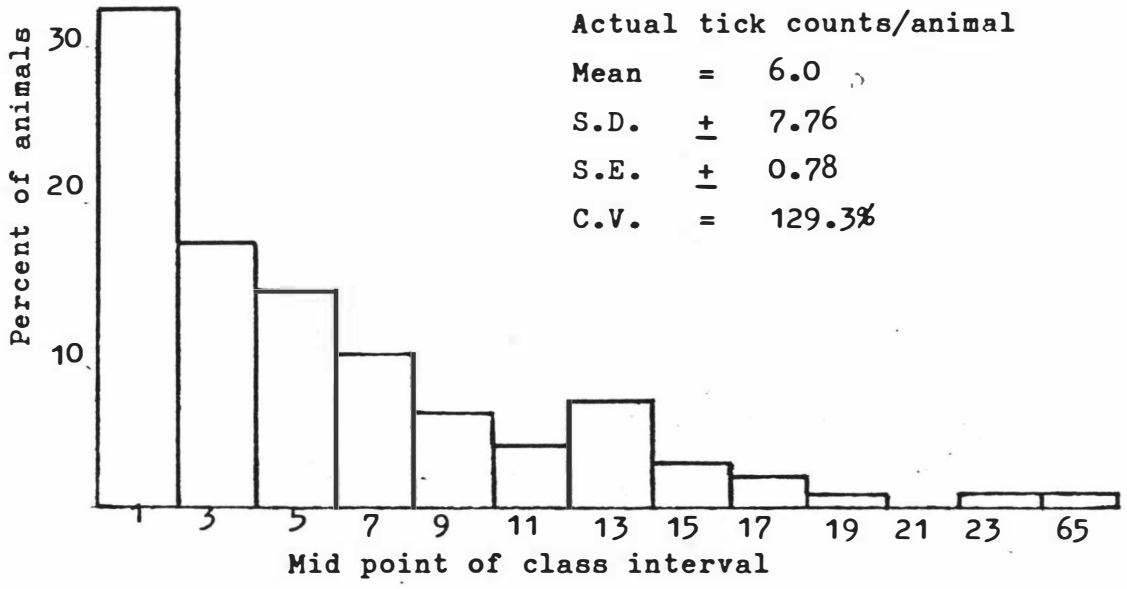
For each day of counting, for actual and transformed tick counts, means and standard deviations were calculated. A normal distribution with the appropriate mean and standard deviation was then fitted to the data and the observed and expected distributions were compared using the chi-square test according to the methods of Sard (1979).

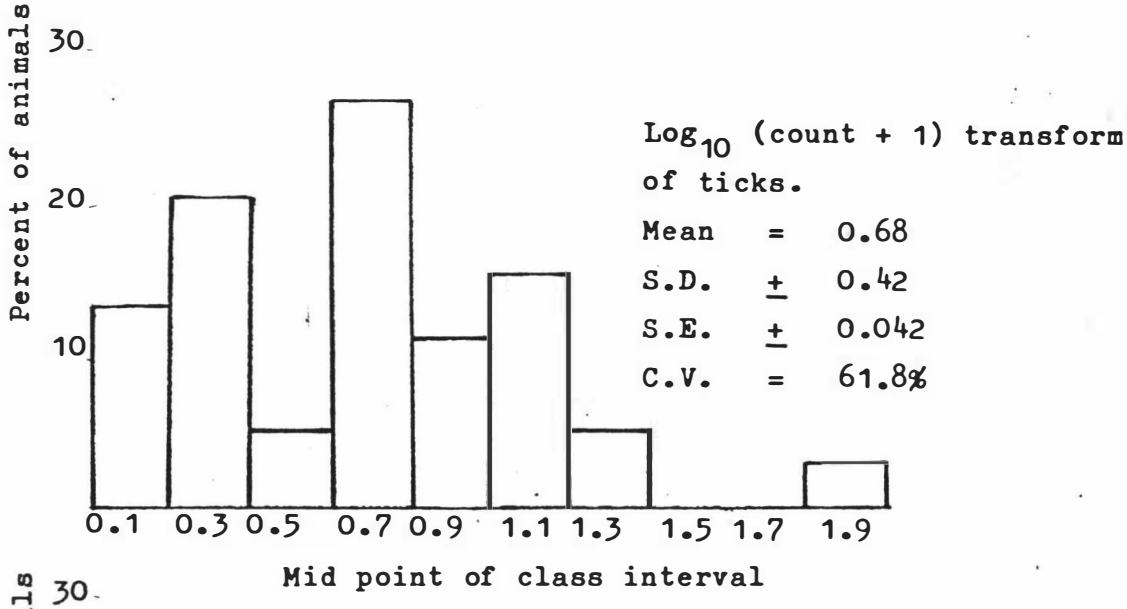
3.3 Results.

These are shown in Tables 3.1, 3.2 and 3.3.

Figure 3.1

Frequency distribution of tick counts (day 0)





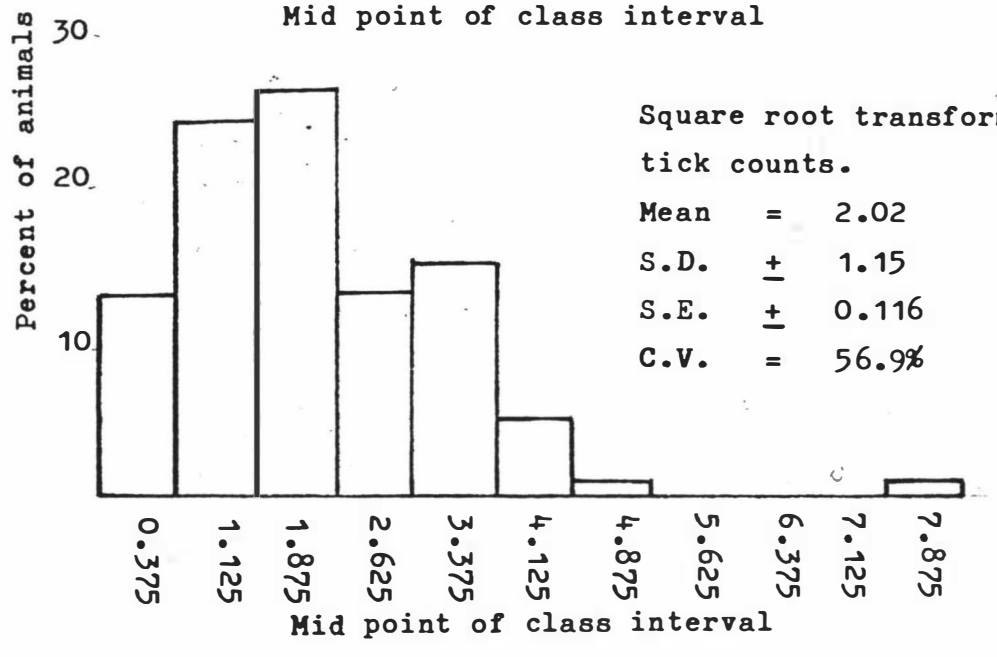


Figure 3.2

Frequency distribution of tick counts (day 7)

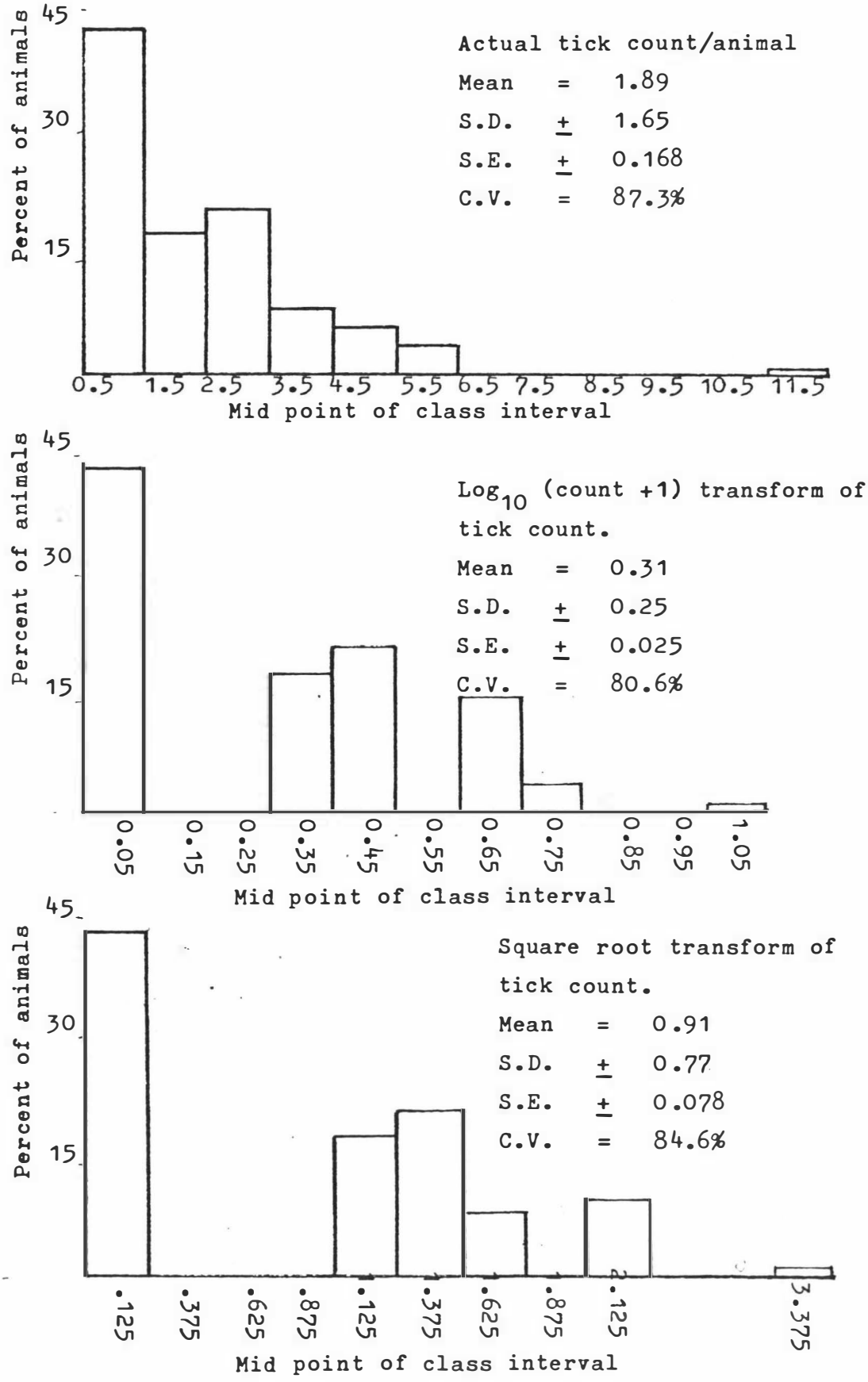
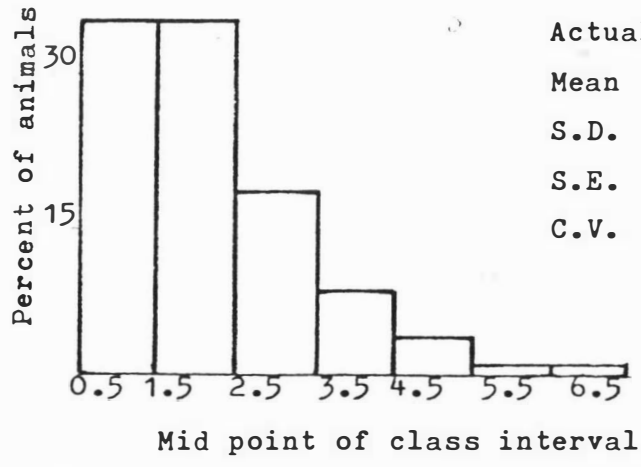


Figure 3.3

Frequency distribution of tick counts (day 13)



Actual tick count

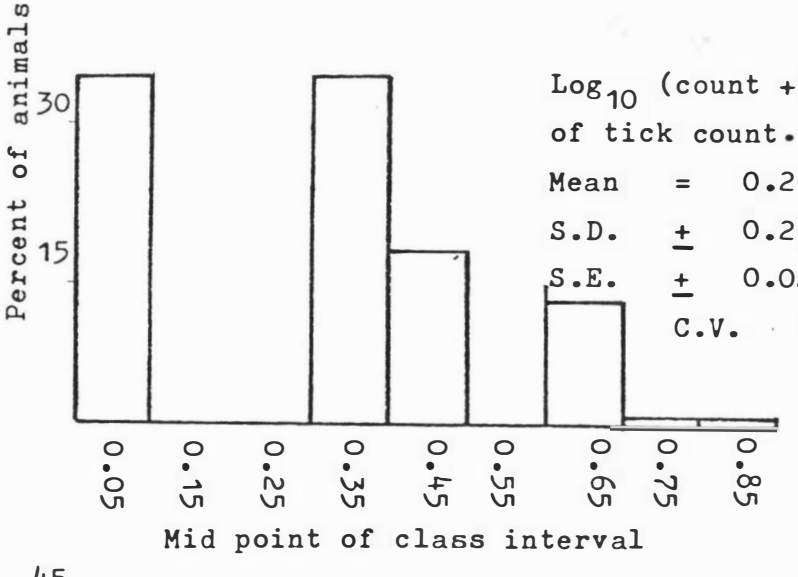
Mean = 1.23

S.D. ± 1.26

S.E. ± 0.129

C.V. = 102.4%

45



Log_{10} (count +1) transform of tick count.

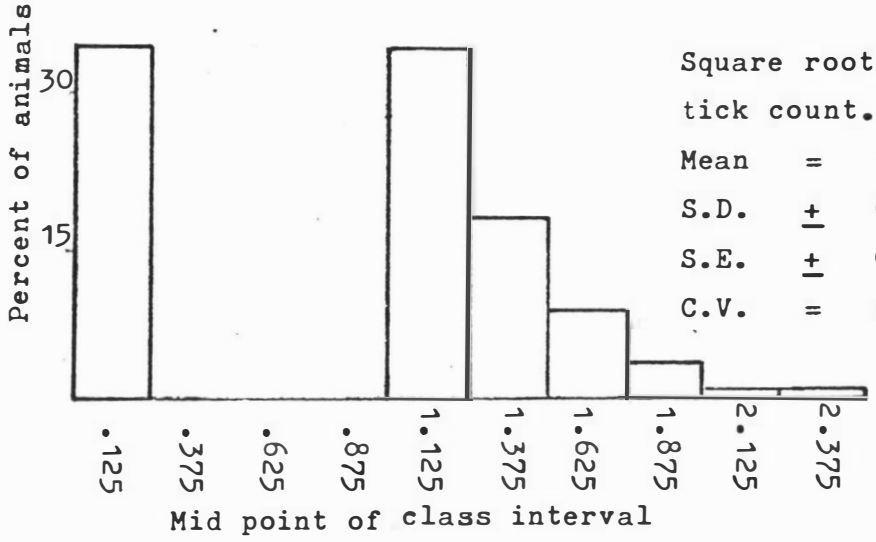
Mean = 0.28

S.D. ± 0.23

S.E. ± 0.023

C.V. = 82.1%

45



Square root transform of tick count.

Mean = 0.86

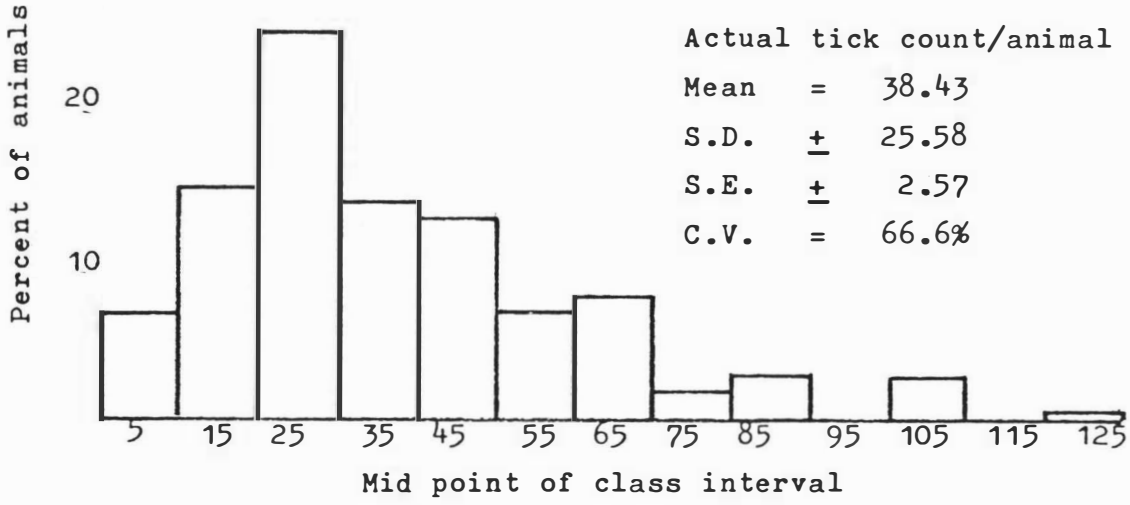
S.D. ± 0.69

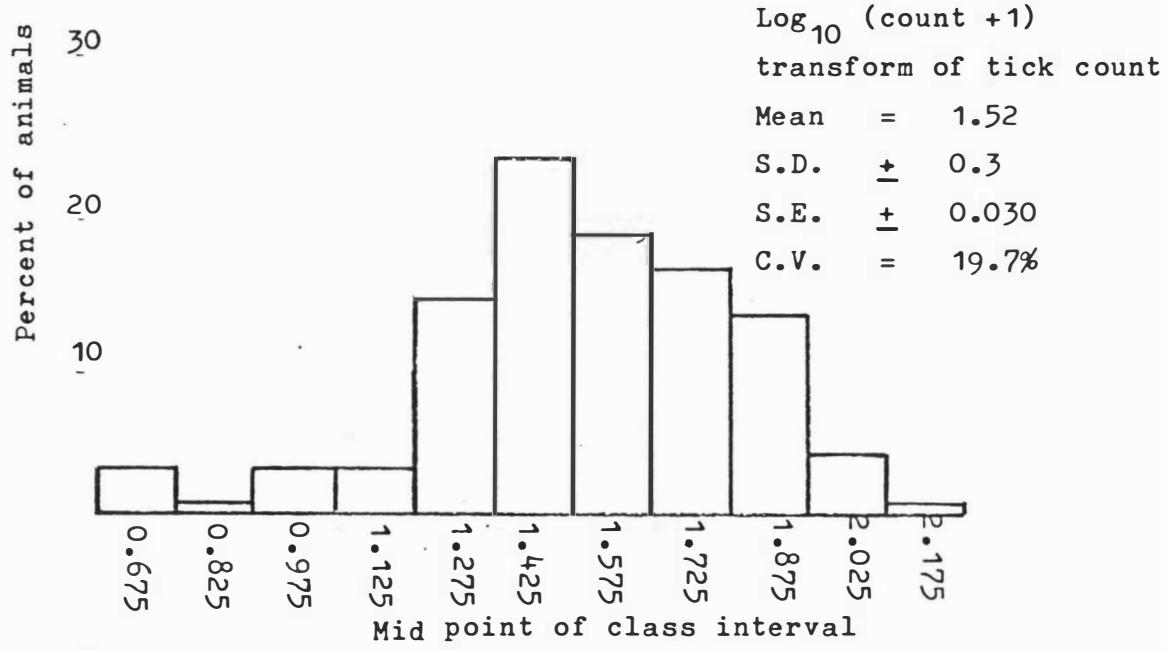
S.E. ± 0.070

C.V. = 80.2%

Figure 3.4

Frequency distribution of tick counts (day 20)





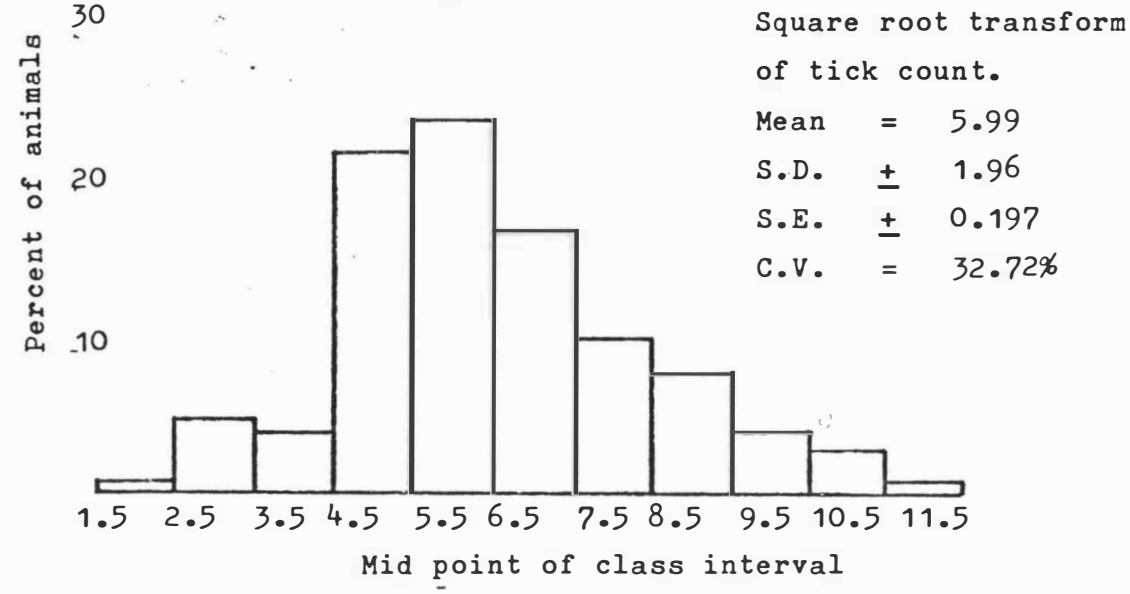
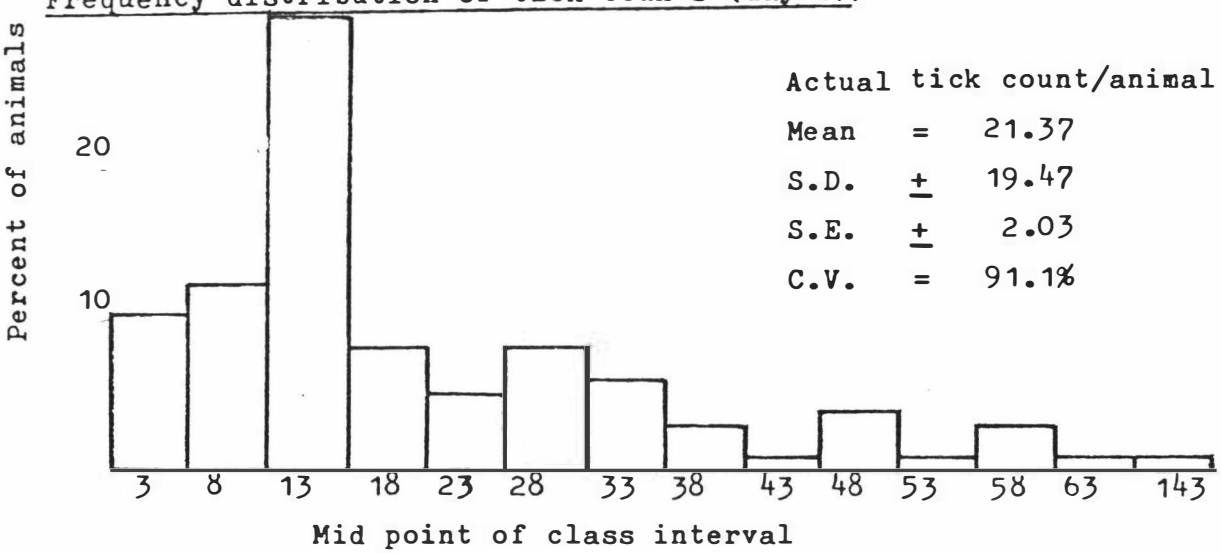
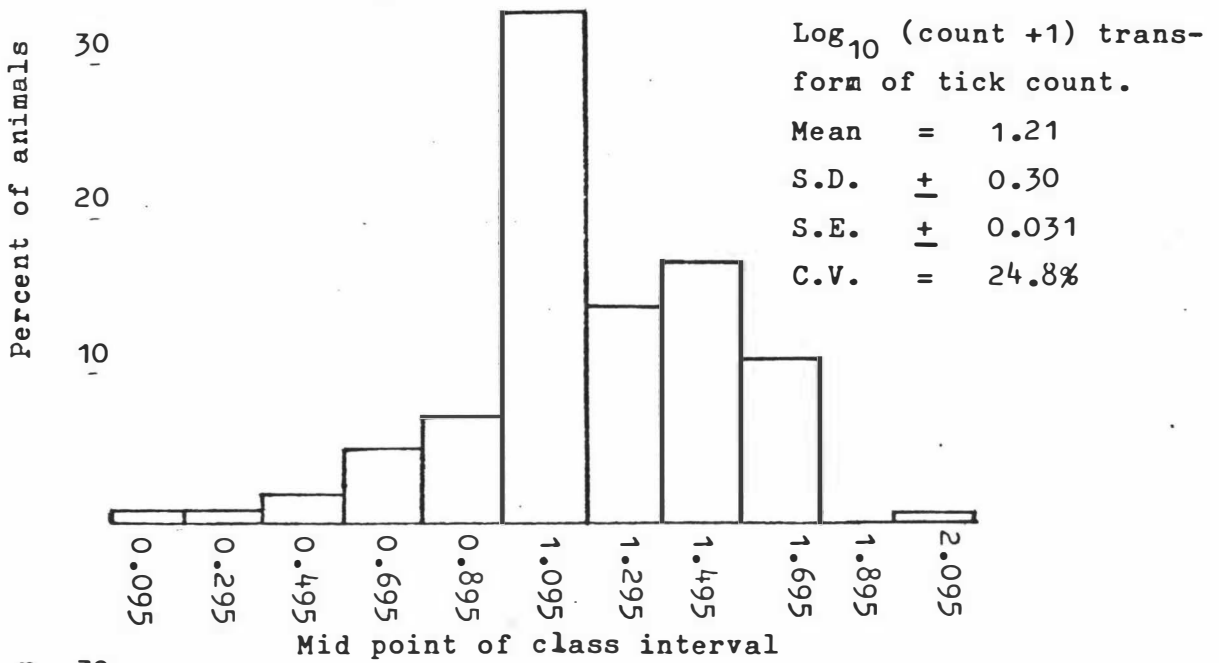


Figure 3.5

Frequency distribution of tick counts (day 27)





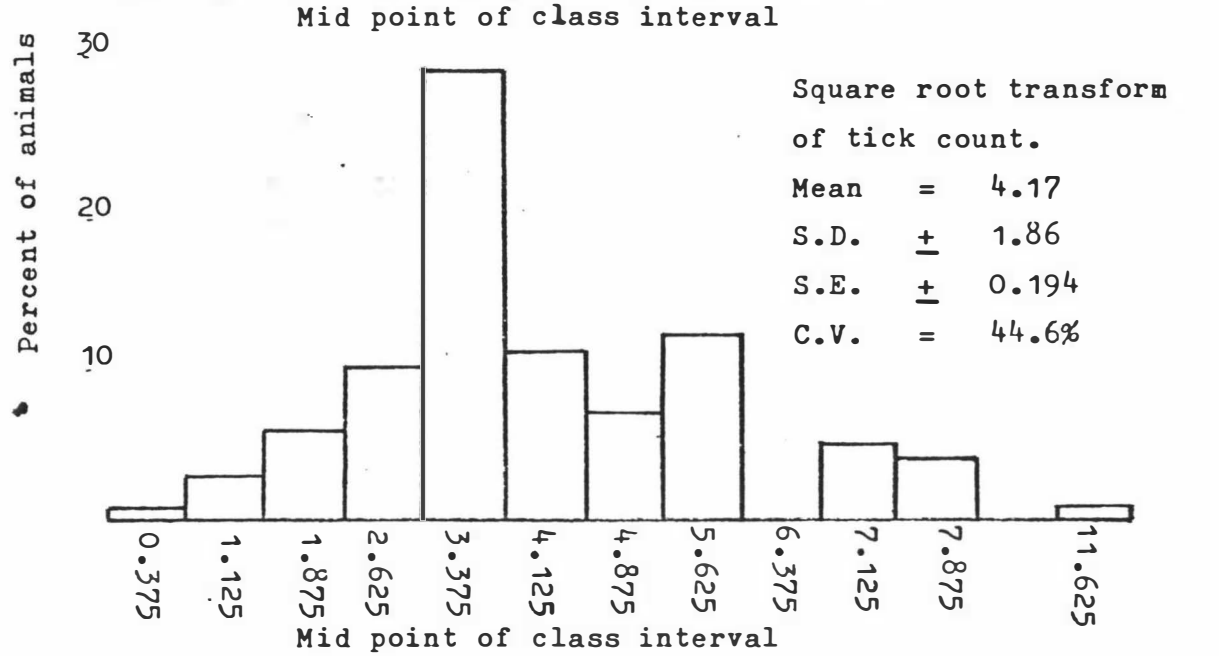
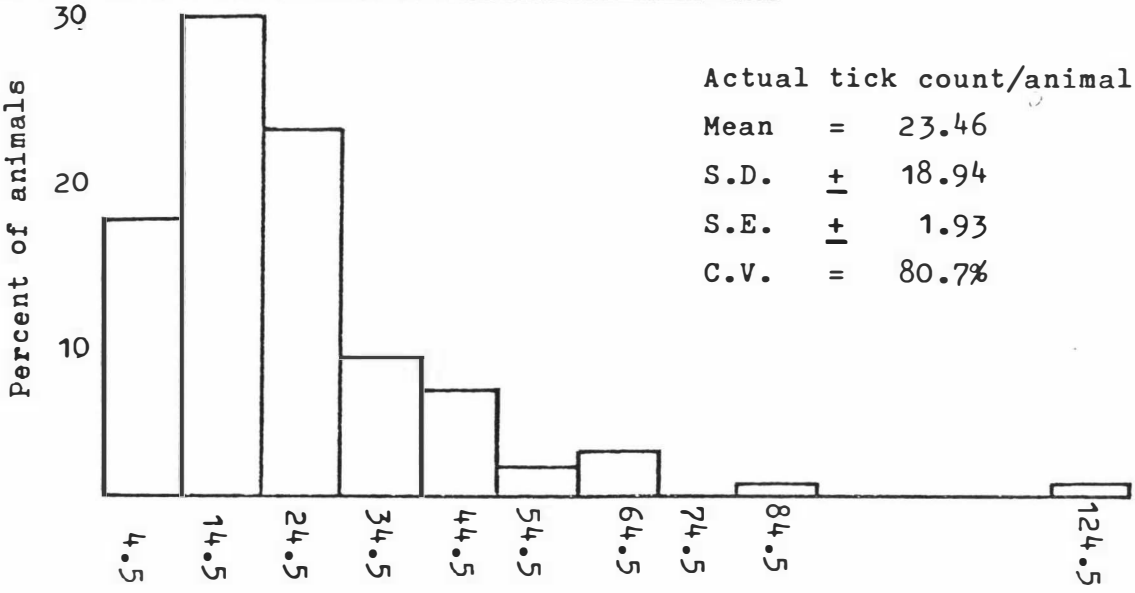


Figure 3.6

Frequency distribution of tick counts (day 34)



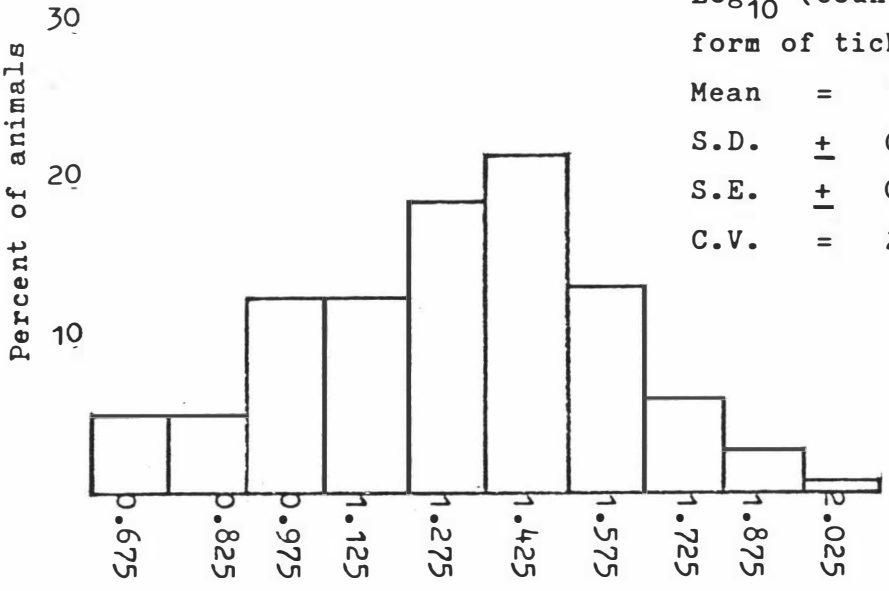
Actual tick count/animal

Mean = 23.46

S.D. ± 18.94

S.E. ± 1.93

C.V. = 80.7%



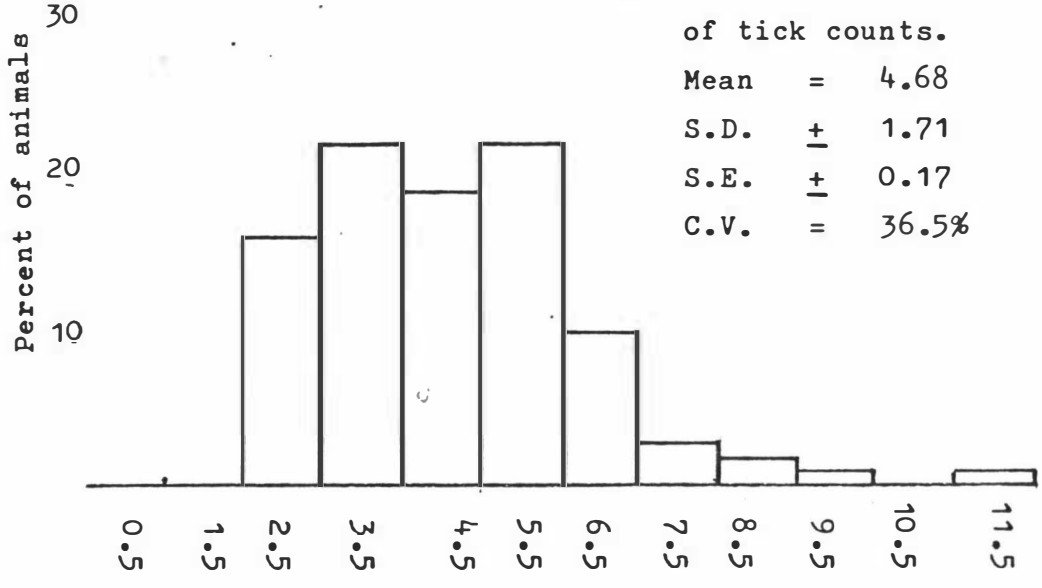
Log_{10} (count + 1) transform of tick counts.

Mean = 1.28

S.D. ± 0.34

S.E. ± 0.035

C.V. = 26.6%



Square root transform of tick counts.

Mean = 4.68

S.D. ± 1.71

S.E. ± 0.17

C.V. = 36.5%

Table 3.1

Chi-squared values from testing goodness of fit of actual tick counts to a normal distribution.

Day of counting	X^2	d.f.	P
0	18.06	16	<0.5
7	10.22	6	<0.25
13	28.79	4	<0.005
20	47.60	10	<0.005
27	65.70	20	<0.005
34	26.31	7	<0.005

Table 3.2

Chi-squared values from testing goodness of fit of actual tick count plus one transformed to logarithms to a normal distribution.

Day of counting	X^2	d.f.	P
0	32.75	7	<0.005
7	79.15	8	<0.005
13	82.29	6	<0.005
20	19.31	8	<0.025
27	25.69	8	<0.005
34	3.1	7	<0.9

Note The smallest X^2 value between the 3 groups for each counting period is underlined.

Table 3.3

Chi-squared values from testing goodness of fit of actual tick counts transformed to square roots to a normal distribution.

Day of counting	X^2	d.f.	P
0	6.44	8	0.75
7	101.40	11	0.005
13	97.78	7	0.005
20	11.65	8	0.25
27	128.37	13	0.005
34	102.32	7	0.005

3.4 Discussion

The lowest values of X^2 represent the smallest differences between the observed and expected distributions. On day 0, square root transforms represent the best method of transforming the data. On days 7 and 13 the animals had low tick counts and variability was low and the data is best examined untransformed. On day 20, the square root transforms show the closest approximation to a normal distribution. On day 27 and 34, the lowest X^2 values were obtained from logarithm transforms. However, one animal with a very high tick count (see Figures 3.5 and 3.6) contributed to the high X^2 values for the square root transforms on days 27 and 34 i.e.

$$X^2 = \frac{(0 - E)^2}{E} = \frac{(1 - 0.01)^2}{0.01} = 98.01$$

If this animal is excluded (i.e. 98.01 subtracted from the X^2 values of the square root transforms on days 27 and 34, the values are almost the same as the logarithm transforms.

In general, except when counts are very low, square root transforms represent the easiest and a satisfactory method of transformation.

It has been suggested by Milne (1943) that there are 3 main reasons for the variability of tick counts from sheep:

(a) Ticks are unevenly distributed in pasture and sheep grazing these pastures will encounter different numbers of ticks. Uneven distribution of H. longicornis in pasture has been observed in Japan (Namba, 1958) and in Australia (Sutherst and Moorhouse, 1972);

(b) Sheep vary in the area they traverse in search of food: the larger the area the sheep traverses the more likely it is to pick up more ticks;

(c) There are variations in susceptibility of sheep to tick infestations.

This last point will be examined the next section.

4. Tick counting: the relationship between ear and body counts of H. longicornis on sheep.

4.1 Introduction.

Ticks need to be counted on the host before and after application of an insecticide so that the effectiveness of the chemical can be assessed. Attached ticks are more commonly found on the hairy areas of the sheep, especially the ears and perineum (Heath, et al, 1977). Therefore, it was considered that a comparison of counts of ticks from a sampling area such as the ears with counts from the rest of the body might indicate the value of ear counts as an estimate of total counts.

4.2 Materials and methods.

Three hundred and two sheep were selected for an insecticide trial which is described in Section 6. On day 0, ticks present on all the animals were recorded from the left ears, right ears and bodies of the animals. Ninety-eight of these sheep remained undipped throughout the trial and counts were also recorded from the left ears, right ears and bodies of these animals on days 7, 13, 20, 27 and 34.

All individual counts for the left ear, right ear and body were transformed to square roots. Transformed counts for each ear, both ears and body were compared by analysis of variance.

4.3 Results.

The results of the comparisons are shown in Tables 4.1, 4.2 and 4.3. As Table 4.1 shows significant differences between combined ear counts and body counts of the 302 animals on day 0 and Table 4.2 shows an overall significant difference between combined ear counts and body counts of the 98 animals over the 6 counting days, data from individual days are examined separately in Table 4.3.

Table 4.1

Comparison by analysis of variance of left ear count, right ear count, combined ear count and body count of ticks present on 302 sheep, on day 0.

Means (square root transformed)

Left ear = 1.0196 Right ear = 0.9806 Both ears = 1.5495
Body = 0.9953.

Comparison	d.f.	F	P
All comparisons	3/1204	23.00	<0.005
Left ear - Right ear	1/602	0.24	N/S
Left ear - Body	1/602	0.076	N/S
Right ear - Body	1/602	0.027	N/S
Both ears - Body	1/602	38.07	<0.005

d.f. = degrees of freedom
F = F value
P = probability
N/S = not significant

There were no significant differences between left ear, right ear and body counts. On day 0 there were significantly more ticks on ears than on bodies.

Table 4.2

Comparison by analysis of variance of total left ear counts, right ear counts, combined ear counts and body counts of ticks present on 98 untreated animals counted on days 0, 7, 13, 20, 27, 34.

Means (square root transformed).

Left ear = 1.3435 Right ear = 1.1840 Both ears = 1.8967
Body = 2.1578.

Comparison	d.f.	F	P
All comparisons	3/2316	66.1	<0.005
Left ear - Right ear	1/1158	76.63	<0.005
Both ears - Body	1/1158	189.77	<0.005

Left ears had significantly more ticks than right ears. There were significantly more ticks on bodies than the combined totals from both ears. Since this is significant no purpose would be served by comparing singly left or right ear counts with body counts.

Table 4.3

Comparison by analysis of variance of combined ear counts with body counts of 98 sheep counted on days 0, 7, 13, 20, 27 and 34.

	Mean* of both ears	Mean* of body
Day 0	1.4722	0.9777
Day 7	0.4537	0.4912
Day 13	0.5190	0.4847
Day 20	3.3059	4.7400
Day 27	2.6447	3.0360
Day 34	3.0252	3.2496

* Means are derived from counts transformed to square roots.

Comparison	day	d.f.	F	P
Both ears - body	0	1/194	9.37	< 0.005
Both ears - body	7	1/194	0.14	N/S
Both ears - body	13	1/192	0.16	N/S
Both ears - body	20	1/194	31.35	< 0.005
Both ears - body	27	1/184	2.29	N/S
Both ears - body	34	1/192	1.11	N/S

Table 4.3 shows that on 2 occasions there were highly significant differences between combined ear and body counts; on day 0 there were significantly more ticks on the ears and the reverse occurred on day 20. Total counts are shown in Table 4.4.

Table 4.4

Ear and body counts at individual observation times for all untreated sheep. Values are actual total counts.

Observation	n	Left Ear	Right Ear	Both Ears	Body	Largest Count
Day 0	302	609	569	1178	694	Ears
Day 7	98	41	26	67	69	Body
Day 13	97	34	28	62	56	Ears
Day 20	98	755	624	1379	2462	Body
Day 27	92	461	410	871	1072	Body
Day 34	96	674	499	1173	1130	Ears
	783	2574	2156	4730	5483	Body

From the above data it can be calculated that on average ear counts contributed 46.3% of all ticks counted. This suggests that if ticks on sheep are counted on several occasions, combined ear counts represent approximately half the total tick burden. Correlations between combined ear and body counts for the 302 sheep at the initial observation and for the 98 sheep that remained untreated are shown in Table 4.5.

Table 4.5

Correlation between combined ear counts and body counts.

Observation	n	r	d.f.	t	P	S.E.	95% C.L. of r
Day 0	302	0.3780	300	21.96	<0.001	0.0493	0.378 ± 0.0967
Day 0	98	0.3224	96	3.33	<0.005	0.0905	0.3224 ± 0.1794
Day 7	98	0.0358		0.35	N/S		
Day 13	97	0.1359		1.35	N/S		
Day 20	98	0.4312	96	5.22	<0.001	0.0818	0.4312 ± 0.162
Day 27	92	0.3746	90	4.13	<0.001	0.0619	0.3746 ± 0.1309
Day 34	96	0.1457		1.44	N/S		

n = number of animals

r = correlation coefficient

d.f. = degrees of freedom

t = t test

P = probability

S.E. = standard error

C.L. = 95% confidence limits of r

N/S = not significant

4.4 Discussion.

On day 0 there was no significant difference between the tick counts of the right and left ears of the 302 sheep (Tables 4.1 and 4.4). Subsequently the left ears of the 98 untreated sheep had significantly more ticks than right ears (Tables 4.2 and 4.4). One reason suggested for this highly significant ($P < 0.005$) difference is that on day 0 all ewes were tagged in the left ear and this tag may have provided more suitable conditions for tick attachment viz. shading by the tag protecting the tick from sunlight or producing lowered skin temperature. Increased numbers of ticks on the tagged ear have been observed in previous tick counting (Neilson, unpublished observations).

Significant differences between combined ear and body counts occurred on two occasions. On day 0 significantly more ticks were present on the ears than on the bodies of the 302 animals counted initially (Table 4.1) and of the 98 that remained untreated subsequently (Table 4.3). The total numbers counted were 1178 ticks from both ears and 694 ticks from the body (Table 4.4). On the 98 untreated animals there were 428 ticks on the ears and 214 on the bodies (Appendix 26). On day 20 this situation was reversed; bodies carried significantly more ticks than both ears (Table 4.3). In total, 2462 ticks were counted on the bodies of 98 animals and 1379 ticks on the ears (Table 4.4).

The reason for the differences is not known. After counting on day 13 the sheep were moved to a new paddock and this was followed by the maximum tick count on day 20. On day 27 more ticks occurred on bodies and on day 34 more ticks occurred on ears but these differences were not significant. The differences could be related to environmental conditions or the density of ticks on the host.

Overall, the number of ticks counted on the ears represents a high proportion (nearly 50%) of all ticks counted. This represents therefore a reasonable area for sampling. On three occasions (day 0, 20 and 27) there were highly significant correlations between combined ear and body counts although the correlation coefficient indicate quite divergent regression lines if these counts are plotted against each other. However the lack of consistent correlation between ear and body counts indicates that one may not predict one from the other.

5. Examination of individual ticks counts from sheep for evidence of resistance to infestation.

5.1 Introduction.

A recent study (Sutherst, Roberts and Wagland, 1979) suggests that cattle (Bos taurus) acquire resistance to H. longicornis from exposure to this parasite. It was though that an examination of tick counts from sheep might also show evidence of resistance to H. longicornis.

5.2 Materials and methods.

Three hundred and two $1\frac{1}{4}$ year old Border Leicester ewes were selected for an insecticide trial which is described later. Prior to treatment, ticks on these animals were counted. The cumulative distribution of the total tick counts for each animal is shown in Table 5.1. It can be seen that about $\frac{1}{4}$ of the animals were carrying $\frac{2}{3}$ of the total ticks.

Table 5.1

Cumulative frequency distribution of total tick counts of 302 sheep on 1.12.77.

Total Tick Count	Frequency	Cumulative Frequency	Cumulative Percent	Cumulative Total Tick Numbers	Cumulative Tick Numbers as at Percent
64 - 66	1	1	0.33	65	3.37
40 - 42	1	2	0.66	106	5.49
33 - 35	4	6	1.99	242	12.54
27 - 29	2	8	2.65	298	15.44
24 - 26	5	13	4.30	423	21.92
21 - 23	4	17	5.63	511	26.48
18 - 20	4	21	6.95	587	30.41
15 - 17	14	35	11.59	811	42.02
12 - 14	18	53	17.55	1045	54.15
9 - 11	22	75	24.83	1265	65.54
6 - 8	38	113	37.42	1531	79.33
3 - 5	70	183	60.60	1811	93.83
0 - 2	119	302	100	1930	100

Of the 302 sheep, 98 were randomly allocated to a non-treatment group to act as controls in the insecticide trial and adult ticks on these animals were counted at approximately 7-day intervals. On the basis of their tick counts on day 0, the 98 animals were split into 3 groups for subsequent analysis. These groups were:

Counts of 0 or 1 tick (32 sheep) (E_L)
Counts of 2 to 8 ticks (44 sheep) (E_M)
Counts of 9 or more ticks (22 sheep) (E_H)

It was reasoned that if the ewes in fact varied in susceptibility to ticks, the ranking of these 3 groups should remain constant when ticks were counted over the next 5 weeks.

Individual counts were transformed to square roots and an analysis of variance carried out according to the method of Snedecor and Cochran (1967) for samples of unequal size.

5.3 Results.

These are shown in Table 5.2.

5.4 Discussion.

At the weekly counts the three groups maintained their ranking and showed highly significant differences in tick numbers. This suggests there was a real difference in susceptibility to tick infestation within the 98 animals. To confirm that sheep can acquire resistance to *H. longicornis*, sheep previously exposed to and those with no previous exposure to *H. longicornis* need to be exposed to ticks on small heavily infested pastures so that each animal would have an equal opportunity to become infested (the method is described by Sutherst, *et al*, 1979).

Table 5.2

Analysis of variance of tick counts of sheep which had been assigned to one of 3 groups on the basis of tick counts on day 0. All data square root transformed.

	Day 0		Day 7			Day 13		
	n	$\bar{x}$	n	$\bar{x}$	d	n	$\bar{x}$	d
E_L	31	0.59	31	0.50	A p	31	0.60	A p
E_M	45	2.03	45	0.80	ABpq	44	0.87	ABpq
E_H	22	3.76	22	1.49	Cq	21	1.30	Bq
F	-			12.06			5.17	
d.f.	-			2/95			2/93	
P	-			<0.01			<0.01	

	Day 20			Day 27			Day 34		
	n	$\bar{x}$	d	n	$\bar{x}$	d	n	$\bar{x}$	d
E_L	31	4.76	Ap	29	3.08	Ap	31	3.86	A p
E_M	45	5.84	Bq	44	4.22	Bq	45	4.72	ABpq
E_H	22	7.86	Cr	19	6.16	Cr	20	5.52	Bq
F		23.98			23.43			7.29	
d.f.		2/95			2/89			2/93	
P		<0.01			<0.01			<0.01	

n = number of animals: $\bar{x}$ = mean: d = Duncan's notation i.e. A, B, C, = significant at 5% level; p, q, r, = significant at 1%, level: F = F value d.f. = degrees of freedom, between means/within samples: P = probability.

The results of Sutherst, et al (1979) suggested that host resistance to H. longicornis in cattle is acquired and is expressed against all instars of the tick. Cattle previously exposed to the tick showed varying degrees of resistance. In the present case it is most likely that the sheep were exposed to adult ticks in the previous season, or to nymphs in the Spring of 1977 and the results seen may reflect a variable level of acquired resistance.

The results indicate that for experiments where ticks are to be counted on sheep, the animals should be ranked according to initial tick counts and then allocated at random to groups on the basis of this initial tick count.

6. Chemical control of H. longicornis on sheep: comparison of the efficacy of two insecticides.

6.1 Introduction.

Except for amitraz, insecticides applied to cattle to control H. longicornis give only 1 - 2 days full protection (see Section 1.14.1). In 1977, I was advised by the manufacturers of amitraz (Boots Ltd, England) that when tested in Australia this chemical protected cattle for up to 10 days against infestation with H. longicornis. At that time information was also available to suggest that amitraz protected cattle against infestation with B. microplus larvae for 7 - 10 days (Roy-Smith, 1975). In addition, work in Scotland (Griffiths, 1975) indicated that amitraz was more efficient than other commercially available insecticides in reducing the numbers of Ixodes ricinus on sheep.

It was thought that amitraz might provide longer protection of sheep against H. longicornis than other currently available insecticides. To provide a comparison for amitraz, chlorfenvinphos was selected as it was known to be one of the most efficient insecticides against H. longicornis on sheep (see Table 1.11).

Amitraz is a diamidide first synthesised in 1969 (Palmer, McCarthy, Kozlik and Harrison, 1973). It is unrelated to all other currently available insecticides.

6.2 Materials and methods.

On the property concerned, a small group of yearling sheep were inspected at fortnightly intervals during the period of nymphal activity. This confirmed that sufficient adult ticks would be present for the experiment.

From 310, 1¼ year old Border Leicester ewes, 3 groups of 70 and one of 100 were chosen at random. This group of 310 was subsequently reduced with missing sheep and sheep that had lost tags. This group of 100 has been referred to in Sections 3, 4 and 5. The sheep had been shorn 6 weeks previously. They were tagged and ticks on them were counted prior to the expected adult peak in December.

The 3 treatment groups of 70 animals were treated in a constant replenishment shower with a 900 litre sump. The treatments were -

Group T0.03 - amitraz 0.03% v/v a.i. of 12.5% E.C.
Group T0.05 - amitraz 0.05% v/v a.i. of 12.5% E.C.
Group S0.06 - chlorfenvinphos 0.06% v/v a.i. of 100% D.F.F.

The emulsifiable concentrate (E.C.) formulation of amitraz was chosen rather than the wettable powder as the manufacturers advised that this might be more effective. The diluent-free-formulation of chlorfenvinphos is available as "Supreme" (Coopers).

The treatment groups were dipped in lots of 35 animals for 3 minutes (top nozzles) and 3 minutes (bottom nozzles only).

The day following dipping (day 1) 20 sheep were examined from each of the 3 treatment groups. Only two live adult ticks were found on the 60 sheep so it was concluded that tick mortality was high and similar in all groups. Thereafter, ticks were counted on the sheep of the 3 treatment groups and the control group on days 7, 13, 20, 27 and 34. Ticks were counted on the left ear, right ear, and body of each animal.

6.3 Results.

The tick counts for each day of counting are shown in appendices 6 to 32. All tick counts were transformed to square roots and treatment groups were compared by analysis of variance. These calculations were carried out by A.C.G. Heath and L. Morrison. An analysis of these results is shown in Tables 6.1 and 6.2. The means shown in Tables 6.1 and 6.2 are derived from square root transformed values.

Table 6.1

Analysis of variance of total tick counts on days 0, 7, and 13 from three treatment groups and a control group.

Day 0			Day 7			Day 13		
$\overline{X}$	d	t	$\overline{X}$	d	t	$\overline{X}$	d	t
2.3331	^{A}	$^{T}0.03$	0.0645	^{B}Q	$^{T}0.03$	0.1275	^{C}R	$^{T}0.03$
1.8715	^{A}	$^{T}0.05$	0.0147	^{B}Q	$^{T}0.05$	0.0441	^{C}R	$^{T}0.05$
2.0134	^{A}	$^{S}0.06$	0.1094	^{B}	$^{S}0.06$	0.5118	^{B}Q	$^{S}0.06$
1.9513	^{A}	C	0.8424	^{A}P	C	0.8617	^{A}P	C

F	1.9177	50.5	42.1
d.f.	3/298	3/289	3/293
P	>0.05	<0.01	<0.01

$\overline{X}$ = mean: d = Duncan's notation; ABC = significant at 5% level; PQR = significant at 1% level; groups with same letter as each other are not significant: t = treatment: $^{T}0.03$ = Taktic (amitraz), 0.03%; $^{T}0.05$ = Taktic (amitraz), 0.05%; $^{S}0.06$ = Supona, 0.06%: C = control: F = F test: d.f. = degrees of freedom: P = probability.

Comments

Day 0. No significant differences. Tick counts at pretreatment on day 0 essentially the same.

Day 7. All insecticides depressed tick numbers but were all of equal effectiveness.

Day 13. All insecticides depressed tick numbers but amitraz was superior at both concentrations.

Table 6.2

Analysis of variance of total tick counts on days 20, 27 and 34 from three treatment groups and a control group.

Day 20			Day 27			Day 34		
$\overline{X}$	d	t	$\overline{X}$	d	t	$\overline{X}$	d	t
2.7916	$^{BC}_{QR}$	$T_{0.03}$	2.6198	$^{B}_{Q}$	$T_{0.03}$	4.2323	$^{A}_{PQ}$	$T_{0.03}$
2.4092	$^{C}_{R}$	$T_{0.05}$	2.4342	$^{B}_{Q}$	$T_{0.05}$	4.0988	$^{AB}_{PQ}$	$T_{0.05}$
3.2965	$^{B}_{Q}$	$S_{0.06}$	2.3209	$^{B}_{Q}$	$S_{0.06}$	3.5623	$^{B}_{Q}$	$S_{0.06}$
5.9236	$^{A}_{P}$	C	4.2243	$^{A}_{P}$	C	4.5917	$^{A}_{P}$	C
F	87.38		26.74			4.37		
d.f.	3/294		3/287			3/287		
P	<0.01		<0.01			<0.01		

$\overline{X}$ = mean: d = Duncan's notation; ABC = significant at 5% level; PQR = significant at 1% level; groups with same letter are not significant: t = treatment: $T_{0.03}$ = Taktic (amitraz), 0.03%; $T_{0.05}$ = Taktic (amitraz), 0.05%; $S_{0.06}$ = Supona, 0.06%: C = control: F = F test: d.f. = degrees of freedom: P = probability.

Comment

Day 20. All insecticides depressed tick numbers but only $T_{0.05}$ was superior to $S_{0.06}$ ($P < 0.01$). There was no significant difference between $T_{0.03}$ and $T_{0.05}$.

Day 27. All insecticides depressed tick numbers but were of equal effectiveness.

Day 34. Only $S_{0.06}$ depressed tick numbers ($P < 0.01$) and it was also superior to $T_{0.05}$ ($P < 0.05$) but no better than $T_{0.03}$. The latter was no better than $T_{0.05}$.

6.4 Discussion

The results indicate that both insecticides were effective in reducing tick numbers.

At day 13, amitraz was more effective than chlorfenvinphos (Table 6.1). On that day 67% of the untreated sheep were carrying ticks compared with 48% of the ^{S}0.06 group, 13.5% of the ^{T}0.03 group, and 4.5% of the ^{T}0.05 group. A similar trend occurred at day 7. This suggests amitraz had a higher initial tick clearance than chlorfenvinphos. At day 20 it appeared that the higher concentration of amitraz was providing better control than chlorfenvinphos but this advantage had disappeared a week later. Partial protection by chlorfenvinphos was evident for a week longer than with amitraz. The results from this investigation are similar to those reported by Platt (1978) in Scotland. He compared the efficiency of amitraz and chlorpyrifos (both at 0.05% a.i.) in controlling infestations of I. ricinus on sheep. The protection afforded by both chemicals declined below 9.0% after 6 weeks although the time of dipping did not accurately coincide with increasing tick numbers.

It could be suggested that the higher concentration (0.06% a.i.) of chlorfenvinphos was responsible for the longer length of protection of this chemical (the product labelling stipulates 0.06% a.i. for tick control). However, indirect evidence suggests that the concentration of amitraz was near the maximum that was safe to use. In the ^{T}0.05 group only, 8 sheep developed posterior inco-ordination immediately after dipping. These signs disappeared within a few hours. It is assumed that the inco-ordination resulted from absorption of amitraz as in mice, rats and guinea pigs excessive dosages cause hyperexcitability, ataxia and tremor (unpublished product information). No adverse reactions were seen in nearly 5000 sheep dipped in Scotland at the same concentration (Platt, 1978).

In conclusion, although amitraz appears to have a higher initial acaricidal capacity, its persistance is slightly inferior to that of chlorfenvinphos. In addition, amitraz has no activity against the larvae of blowflies (unpublished product information). Most currently available insecticides are active against blowfly larvae. This is an advantage since blowfly numbers increase in the North Island of New Zealand at the time when numbers of adult H. longicornis are increasing. Furthermore tick bites can become invaded by blowfly larvae. Thus amitraz does not offer any advantages over insecticides such as chlorfenvinphos for tick control on sheep. Amitraz does however appear the most suitable for control of ticks on cattle. Heath, et al, (1980) have shown recently that amitraz provides significant protection against H. longicornis for at least 10 days, whereas other insecticides protect for only 1 - 2 days.

7. Chemical control of H. longicornis: information from the 1977 New Zealand Sheep Returns on the method and timing of dipping in the East Coast Northern Hawke's Bay Area.

7.1 Introduction.

If strategic dipping is contemplated to control H. longicornis, it is important that dipping be carried out at, or prior to, the expected peak of one or more instars. Information on current methods and timing of dipping may suggest how this could be accomplished without major changes in farm management practices.

7.2 Materials and methods.

On the 1977 New Zealand Sheep Returns, owners or managers of sheep farms were asked to nominate their method of and month for dipping sheep. The information was requested to assist the M.A.F. in formulating a policy on the control of sheep lice. The information was extracted for the Counties of Waiapu, Cook, Waikohu and Wairoa.

7.3 Results.

These are shown in Tables 7.1 and 7.2.

Table 7.1

Main Dipping Method of Four Counties of the East Coast and Northern Hawke's Bay area of the North Island of New Zealand.

County	Main Dipping Method				
	Shower	Plunge	Spray Race	Dust	Total
Waiapu	149	38	62	4	522
Cook	284	107	125	6	265
Waikohu	174	37	54	-	253
Wairoa	269	49	90	3	411
Total	876 (60.4%)	231 (15.9%)	331 (22.8%)	13 (0.9%)	1451

Table 7.2

Month of Dipping Nominated by Sheep-owners in four counties of the East Coast and Northern Hawke's Bay area of the North Island of New Zealand.

Month	County					
	Waiapu	Cook	Waikohu	Wairoa	Total	Cumulative %
June	-	-	-	6	6	0.4
July	-	-	-	1	1	0.47
August	-	-	-	-	-	0.47
September	-	-	-	-	-	0.47
October	-	5	2	3	10	1.2
November	4	12	1	8	25	2.9
December	15	41	19	27	102	10.0
January	97	218	148	179	642	54.2
February	84	161	66	128	439	84.4
March	34	43	17	48	142	94.2
April	12	23	2	7	44	97.2
May	7	19	10	4	40	100
Total	253	522	265	411	1451	

7.4 Discussion.

More than 75% of farms use a shower or plunge dip (Table 7.1). These are more efficient than spray races as the latter provide only short contact times with the insecticide. Even with higher concentrations of insecticide this does not provide adequate concentrations of the insecticide in the wool (Wallace, 1976; Tenquist and Roberts, 1978) for tick control.

Most sheep owners (84.2%) dip between January and March whereas the peak of adult tick numbers usually occurs in December. Over half (54%) the sheep owners dip in either January or March which may be before or after the peak of larval numbers in February.

The information available suggests that more emphasis should be given to dipping in December and/or February. Dipping in February would reduce the larval numbers so that there would be fewer adults the following season.

8.0 The influence of stocking rate on tick survival.

8.1 Introduction.

As H. longicornis spends over 90% of its life on pasture, the micro-environmental conditions at the base of the pasture must influence the survival of the tick. Some authors (Mutch, 1966; Heath, 1973) have suggested that if pastures and other plants associated with cattle and sheep pastures are kept short, this will expose the tick to climatic extremes and reduce survival.

In addition, farmers mention that in holding paddocks which are normally grazed very short, tick numbers are usually low. Farmers also suggest that in paddocks at the back of the farm, which presumably are only lightly grazed, tick numbers are high. In addition, farmers believe that in paddocks where pasture is conserved as autumn saved pasture, tick numbers appear to be high in the following Spring and Summer. It was decided, therefore, to test these observations by investigating the influence of stocking rate on tick survival.

8.2 Materials and methods.

Two equal areas of 1000 m^2 (designated paddock A & C) and two equal areas of 500 m^2 (designated paddocks B & D) were fenced off. Each paddock was stocked with 2 non-pregnant Romney ewes and this was increased to 3 ewes in August as pasture growth increased. Paddocks B & D thus had twice the stocking rate of A & C. The ears of the sheep were examined weekly from August to February and tick counts recorded. Nymphs were present from August to the end of October and adults from November to the end of January.

8.3 Results.

These are shown in Tables 8.1 and 8.2.

Table 8.1

Total nymphs counted on ears of sheep in paddocks A, B, C and D from 2/8/76 to 29/10/76.

Paddock A	Paddock B	Paddock C	Paddock D
High stocking rate	Low stocking rate	High stocking rate	Low stocking rate
172	314	234	324

Table 8.2

Total adults counted on ears of sheep in paddocks A, B, C and D from 10/11/76 to 26/1/77.

Paddock A	Paddock B	Paddock C	Paddock D
High stocking rate	Low stocking rate	High stocking rate	Low stocking rate
24	144	30	86
Survival rate			
14%	56%	13%	27%

8.4 Discussion

In both the low stocking rate paddocks (B & D) more nymphs (27 and 56%) survived to be recorded as adults. In the high stocking rate paddocks (A & C) only a small proportion of nymphs (13 and 14%) survived to be recorded as adults in spite of the availability of more hosts.

These results were not analysed statistically because of the high variability between paddocks and animals.

This investigation needs to be replicated on at least 10 paddocks in order to overcome the analytical problems caused by between-paddock variability. This would involve a high cost in fencing materials. The results do suggest however, that at higher stocking rates, tick survival is reduced. In section 9 the survival at various humidities of unfed instars of H. longicornis is compared. At humidities below 80% R.H. at 28°C adults lose weight and at 60% R.H. and 28°C death occurs after 6 days. It is suggested that tick mortality was higher in the more closely grazed pasture because the relative humidity was lower there than in longer pasture. The relative humidities of the paddocks were not recorded in this experiment. There is, however, considerable evidence (e.g. Waterhouse, 1950; Tukahirwa, 1976) to indicate that R.H. varies considerably between short and long pasture.

9. The water balance of unfed larvae, nymphs and adults of Haemaphysalis longicornis.

9.1 Introduction.

An examination of the way various temperatures and humidities affect tick eggs provides part of a key to understanding the geographical ranges of various tick species (Heath, 1979). In addition, an understanding of the water balance of unfed ticks may explain the reasons for the lengths of survival and longevity of these stages.

Water balance of non-parasitic stages of H. longicornis has been investigated by Heath (1974). Eggs and engorged larvae of this species do not develop when exposed to humidities below 5% R.H. at 25°C. A water loss of 40% of the original weight of eggs was sustained. This was critical and all larvae died within 2 days. However, engorged nymphs moulted after exposure for 11 days to a R.H. below 5% at 25°C and the water loss was only 28%. Engorged females were also resistant to desiccation and survived and oviposited under conditions of low humidity such that the eggs would not survive.

The water balance of unfed stages of H. longicornis has not been examined with the same precision. It has been shown that several tick species can absorb water vapour from air at saturated and subsaturated humidities (see Section 1.12.3). An equilibrium between water vapour uptake and loss by transpiration is maintained only down to a certain level of relative humidity which is specific for each species and this has been referred to as the critical equilibrium humidity (C.E.H.) (Knulle and Wharton, 1964).

Water at ambient temperatures and pressures can exist as both a gas and a liquid. Relative humidity measures the ratio of actual partial pressure of water vapour and the potential saturation vapour pressure, and it therefore cannot be used to measure the concentration of water in solution.

But the unit "activity" can be used for both vapour and liquid phases (see Section 1.12.3). Hence the term critical equilibrium activity (C.E.A.), replaces critical equilibrium humidity (Wharton and Devine, 1968; Wharton and Arlian, 1972; Wharton and Richards, 1978). The calculation of C.E.A. is explained in section 9.3: Results.

The uptake of water vapour from air and the C.E.A. of a tick species is of considerable ecological significance. As Knulle and Wharton (1964) have indicated, the C.E.A. of ticks may be closely related to behaviour patterns, longevity and capacity for survival, and the habitat in which the tick lives.

It has been suggested that H. longicornis could have survived on paspalum seed introduced from Australia. The relative humidity in most cereals with a water content of 14% is approximately 70% (Knulle and Wharton, 1964), although this would depend on temperature. Do larvae of H. longicornis survive at this humidity or is the C.E.A. above 0.7?

In the following experiments, unfed larvae, nymphs and adults of H. longicornis were desiccated and their subsequent weight changes at 6 different R.H.'s, at 28°C, were examined.

9.2 Materials and methods.

Source of ticks. The ticks were from a laboratory colony maintained at Wallaceville Animal Research Centre. The ticks were maintained at 28°C in a Contherm Precision incubator over a solution of H_2SO_4 to produce a R.H. of 96% (Solomon, 1951). Nymphs and adults were engorged on a calf and larvae were fed on a rabbit, according to the methods of Heath (1974). The adults were from nymphs that had engorged 60 days previously i.e. were 45 days of age allowing for a premoult period of 15 days. The nymphs were from larvae that had engorged 18 days previously i.e. 8 days of age allowing for a premoult period of 10 days.

Larvae were from freshly hatched eggs that were laid by adults that had engorged 38 days previously.

Humidity Control. The relative humidities selected were 100%, 95%, 90%, 80%, 70% and 60%. From a prepared stock solution of analytical grade H_2SO_4 and water, of specific gravity 1.507 at 20°C (60.8 g/100 g solution of acid), weighed quantities of acid were added to weighed quantities of water to produce the required humidities, according to the gravimetric method of Solomon (1951). The solutions were transferred to desiccators (Jencons "Dry Seal"). Water only was added to the desiccator required for 100% R.H.

After the desiccators had been transferred to an incubator at 28°C for 4 hours, humidities were checked with cobalt thiocyanate papers as described by Solomon (1945, 1957). Papers were inserted into glass vials 5.3 cm long and 1.2 cm in diameter and exposed for 2 hours. The papers were then transferred with forceps to paraffin oil and compared with standards in a "Lovibond" 1000 comparator with a light box. Humidities were check/ again during the experiment. The humidities remained as intended throughout the experiment. No attempts were made to reduce the development of humidity gradients within the desiccators as this was not found to cause a variation in results by Sauer and Hair (1971).

Handling, desiccation and weighing of ticks. Each unfed stage was tested at 6 humidities following desiccation. Each experiment was replicated once. Five adults (9 adults in the replicate) were transferred at random to each of 6 glass vials (7.6 cm long and 2.4 cm in diameter) with a fine hair brush. Glass vials were covered with fine mesh terylene held in place by a plastic cap with the centre removed.

Adults were weighed daily on a Sartorius model 2474 digital analytical balance accurate to ± 0.01 mg. The adults were transferred by brush to a smaller preweighed container for each weighing.

The adults were desiccated for 24 hours (5 adults per R.H.) or 48 hours (9 adults per R.H.) over anhydrous $CaCl_2$ granules at 28°C.

Prepared nylon bags 4 x 3 cm were used by Osman (1976) to study weight changes of ticks at various humidities. It was found that there was a large daily variation in weight of terylene bags of similar size. Glass vials 5.3 cm long and 1.2 cm in diameter were therefore prepared with a fine steel mesh glued (epoxy resin of polymercaptan and polamide - Ciba-Geigy) to a 1 cm diameter hole in the plastic cap. After the glue hardened the weights of the containers were checked at various humidities; the weights remained constant. This method had the added advantage that weighings included the white guanine excretions of the larvae and nymphs. For both the original experiment and the replicate, 20 nymphs were transferred to prenumbered tubes in order of an assigned number from tables or random numbers.

For the first experiment 8.5 - 36.5 mg of larvae were transferred to randomised tubes. In the replicate 8 - 12.5 mg of larvae were transferred to randomised tubes. All the larvae died at the 2 lowest humidities in the first experiment and these were counted and the mean weight of a larva prior to desiccation was calculated as 0.052 mg (see Table 9.1). The nymphs were desiccated at 28°C, over anhydrous $CaCl_2$ granules for 28 hours and the larvae for 4 hours. Like the adults, nymphs and larvae were then transferred to 6 different humidities and weighed daily.

9.3 Results

The mean weight changes following desiccation of the 3 unfed instars of H. longicornis are shown in Table 9.1.

Unengorged adults were more resistant to desiccation than unengorged nymphs which were more resistant to desiccation than unengorged larvae. As observed by Osman (1976) desiccation limits survival in the order adults > nymphs > larvae.

Table 9.1

Mean weight changes of unfed larvae, nymphs and adults of H. longicornis desiccated for varying periods.

Instar	Number	Mean Initial Weight mg	Desiccation Time Hours	Mean weight after desiccation mg	Weight Change %
Adult	5	2.322	24	2.230	3.96
Adult	9	2.314	48	2.112	8.73
Nymph	20	0.388	28	0.323	16.75
Nymph	20	0.384	28	0.341	11.20
Larvae	430	0.052	4	0.0470	9.45
Larvae	202	0.052	4	0.0466	10.47

Subsequent weight changes following desiccation and transfer to the six humidities are shown in Figures 9.1, 9.2, and 9.3.

The results of the first experiment are shown on the left (a) and of the replicate on the right (b) in each figure.

Figure 9.1

Mean weight changes (expressed as a percentage of original weight) of unengorged larvae of H. longicornis desiccated for 4 hours then transferred to 6 relative humidities and maintained at 28°C.

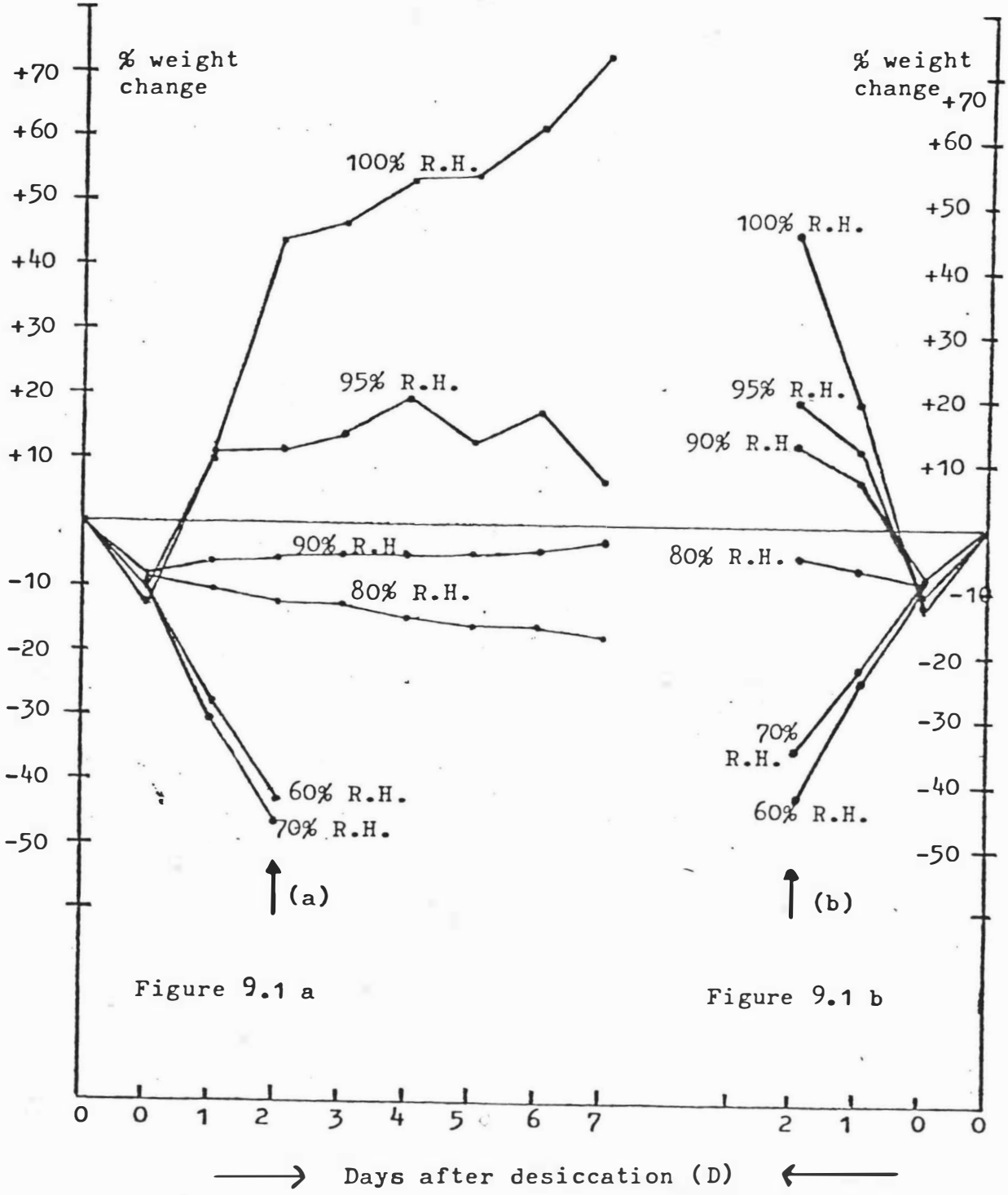


Figure 9.1 a

Figure 9.1 b

Figure 9.2

Mean weight changes (expressed as a percentage of original weight) of unengorged H. longicornis nymphs desiccated for 28 hours then transferred to 6 relative humidities and maintained at 28°C.

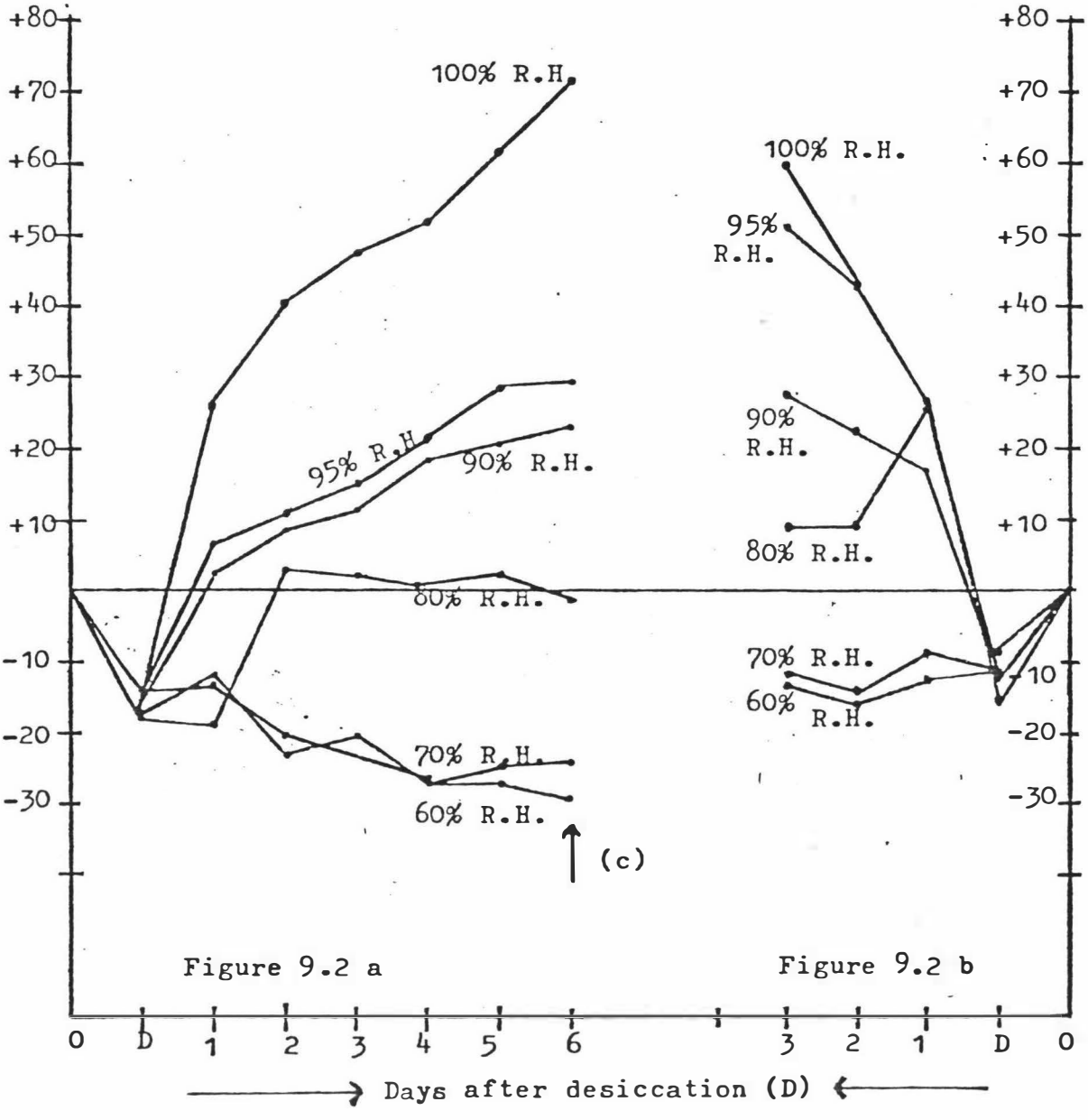


Figure 9.2 a

Figure 9.2 b

Figure 9.3

Mean weight changes (expressed as a percentage of original weight) unengorged H. longicornis females desiccated for 24 hours (figure 9.3a) or 48 hours (figure 9.3b) then transferred to 6 relative humidities at 28°C.

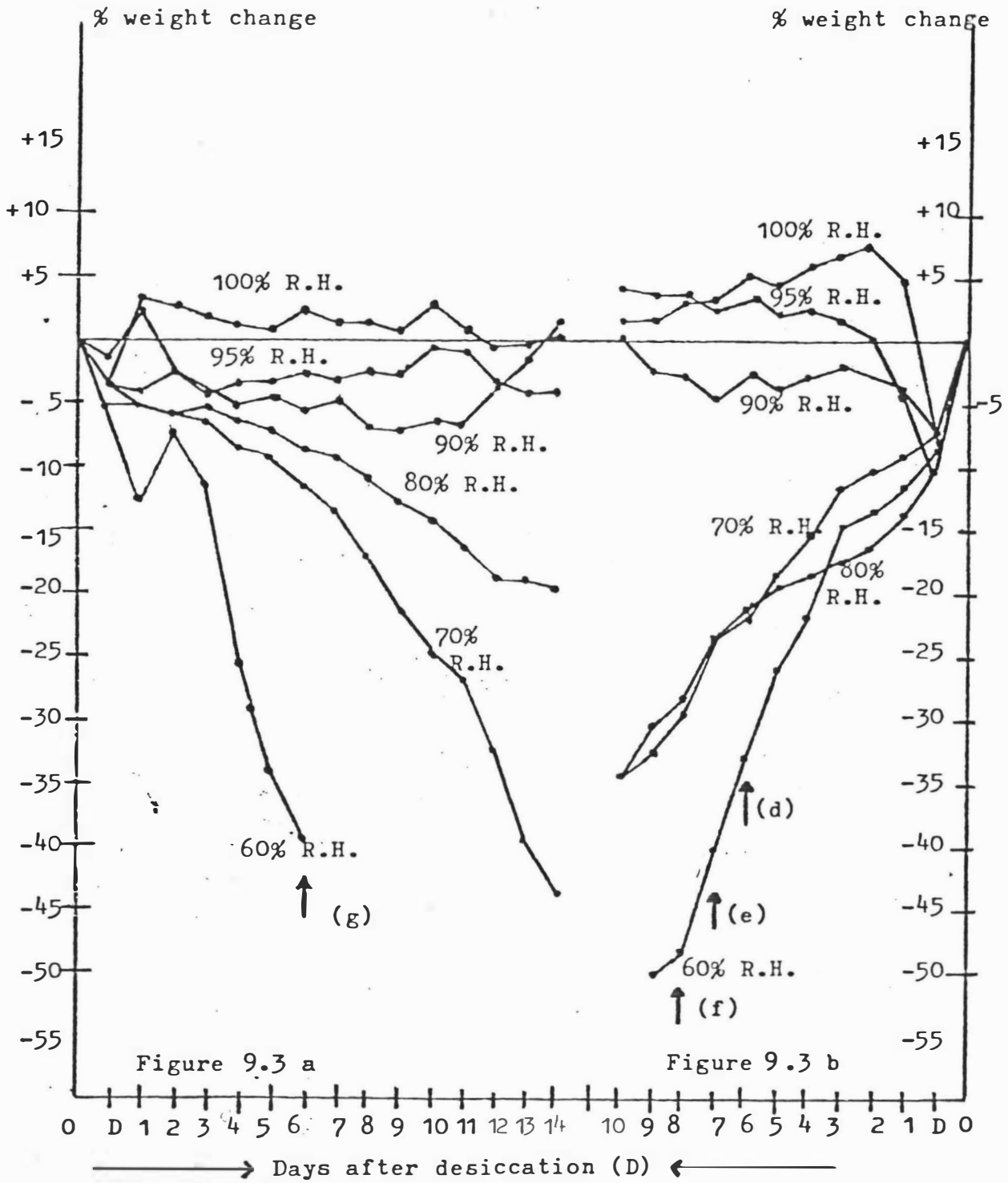


Figure 9.3 a

Figure 9.3 b

All the larvae desiccated for 4 hours and placed at 60% R.H. and 70% R.H. (↑(a) and ↑(b) in Figures 9.1 a and 9.1 b) were dead after 48 hours. Their cumulative weight loss as a percentage of their original fresh weight was in most cases greater than 40% and ranged from 35 to 46%.

After 6 days at a R.H. of 60% 18/20 nymphs were dead (↑(c) in Figure 9.2 a). Their cumulative weight loss was close to 30%.

After 48 hours desiccation, 5/9 adults were dead after 6 days at 60% R.H., 8/9 after 7 days and all were dead after 8 days. (↑(d), ↑(e), and ↑ (f) in Figure 9.3 b). In the first replicate all 5 adults were dead after 6 days at 60% R.H. (↑(g), in 9.3 b). Again with adults a weight loss of 40% of their fresh weight appears to be the critical level. It is unlikely that ticks are able to "shift" dry weight reserves to metabolic water (Lees, 1946); Sauer and Hair, 1971).

The critical equilibrium activity (C.E.A.)

Following desiccation, weight changes in ticks at different humidities need to be measured for more than 24 hours to establish the C.E.A. (Knulle, 1966). In this experiment an "end point" was reached after 2 days when larvae at the lower humidities were all dead. Similarly adults (Figure 9.3 a, ↑(g) died after 6 days at the lowest humidity tested. The replicate experiment for nymphs was terminated after 3 days (see Figure 9.2b). These days were selected to calculate the C.E.A.'s for each instar.

The C.E.A. is calculated from regression of % change in body weight on humidity (Arlian, 1975). The regressions were calculated for % change in desiccated weight for those particular days mentioned above, according to the method of Snedecor and Cochran (1967).

The regressions and regression equations are shown in Figures 9.4 a, 9.5 a, and 9.6 a. Figures 9.4 b, 9.5 b, and 9.6 b are the replicates. From the regression equation where Y = 0 the C.E.H. is calculated and when divided by 100 becomes the C.E.A.

In this experiment the C.E.A.'s were approximately 0.8 for larvae, 0.7 for nymphs and 0.9 for adults.

Figure 9.4

Regression of % change in post-desiccated body weight of unfed *H. longicornis* larvae on relative humidity (2 days after desiccation.)

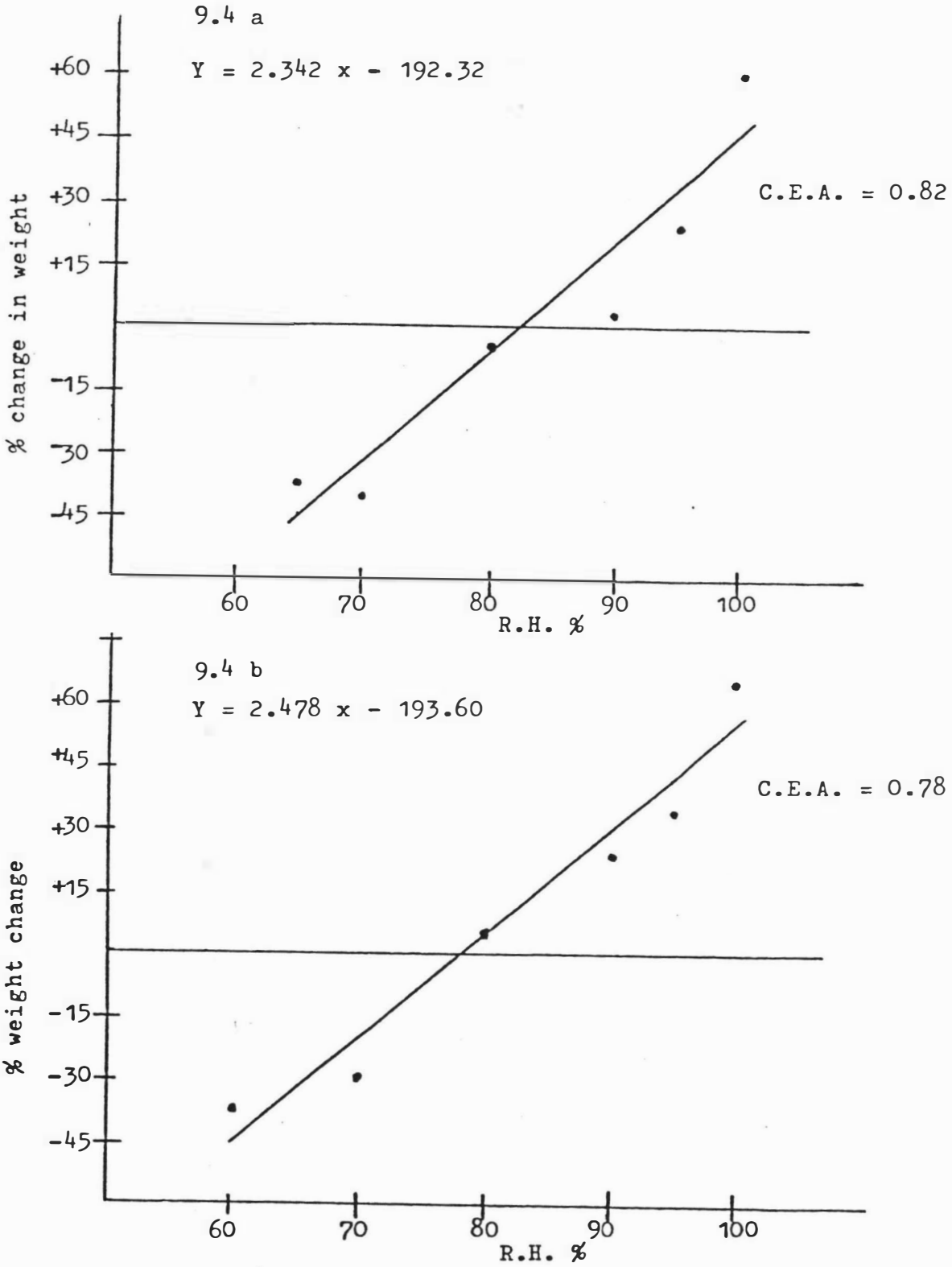


Figure 9.5

Regression of % change in post-desiccated body weight of unfed *H. longicornis* nymphs on relative humidity (3 days after desiccation).

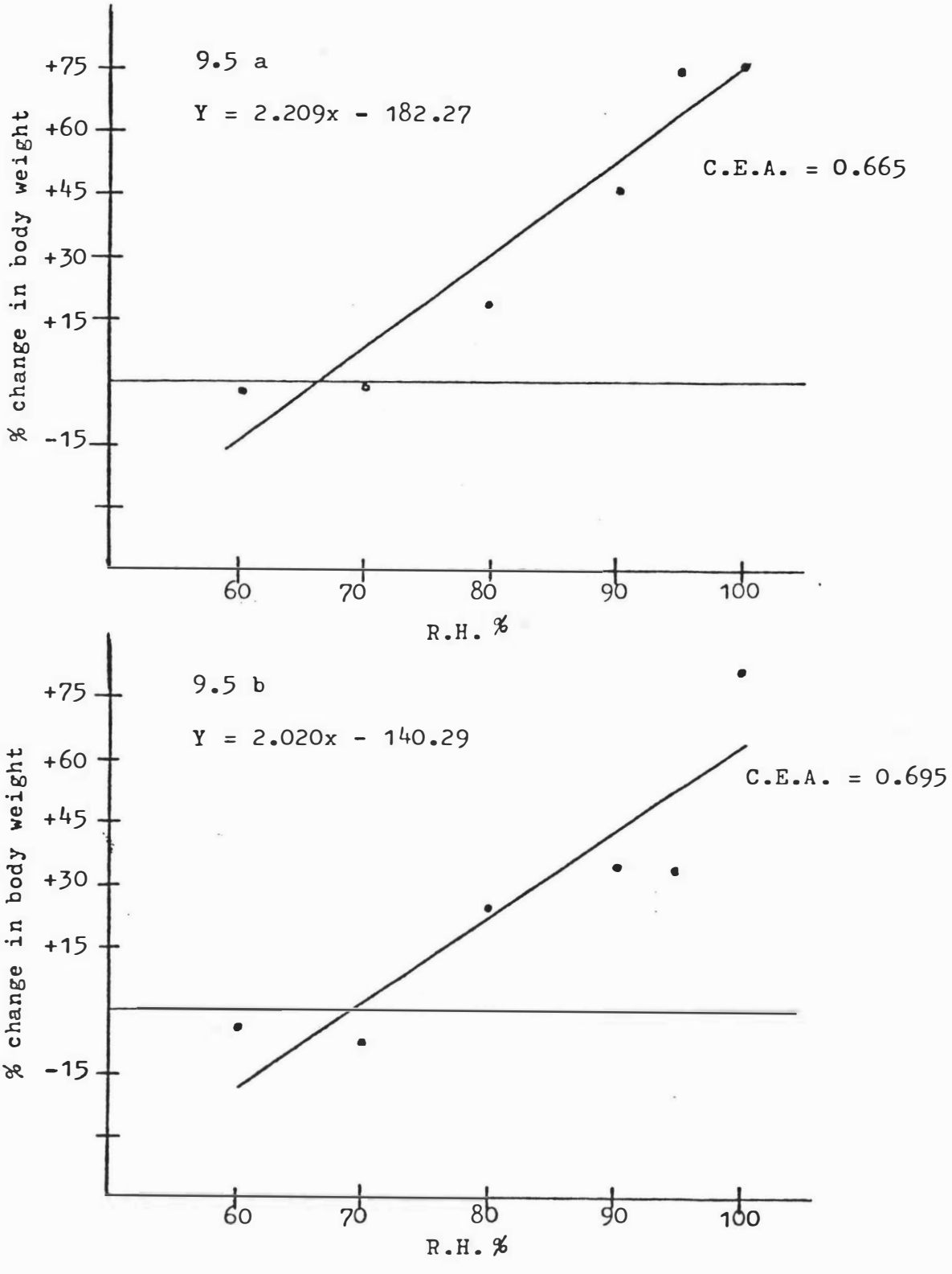
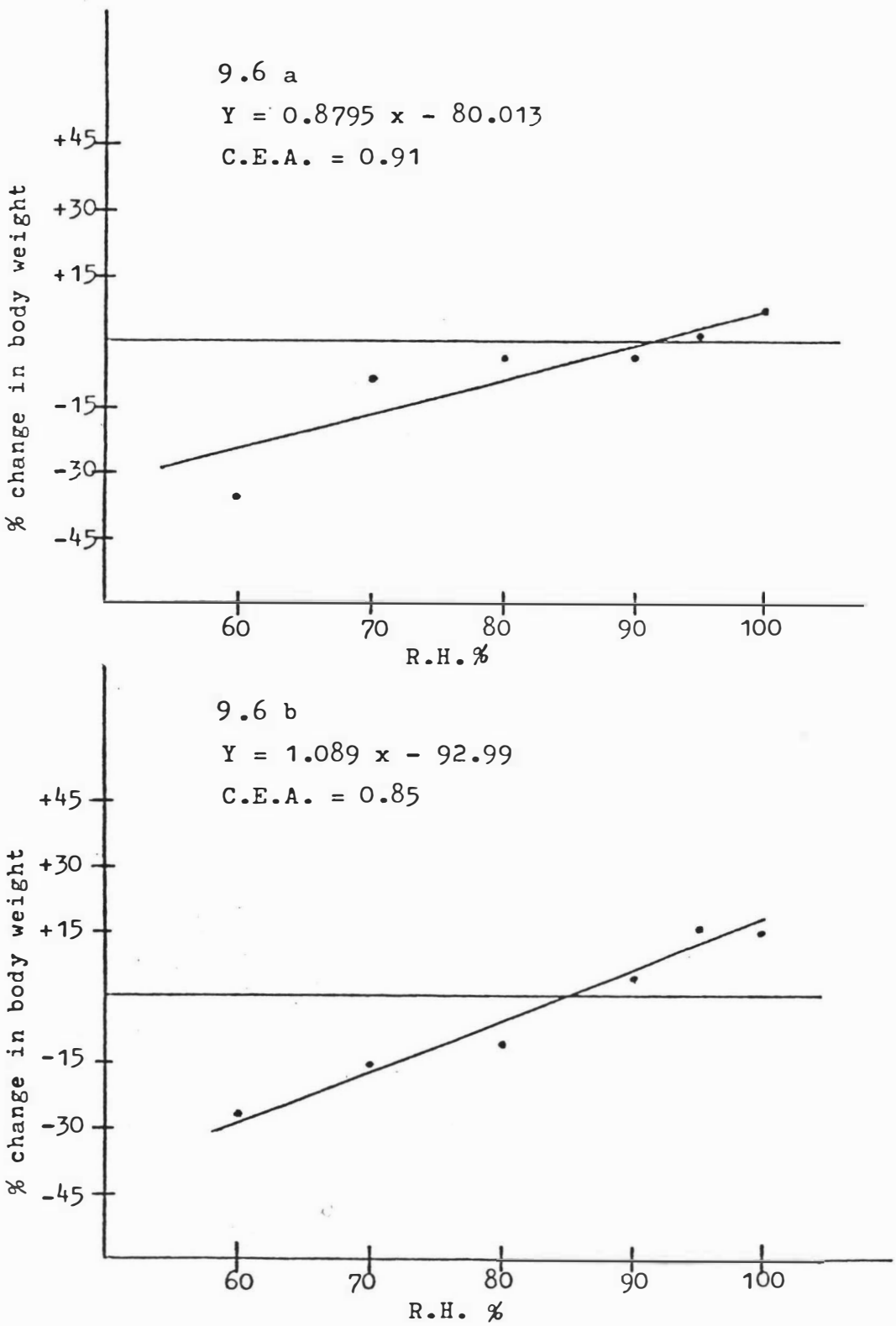


Figure 9.6

Regression of % change in post-desiccated body weight fed *H. longicornis* females on relative humidity (4 days after desiccation).



9.4 Discussion

Weight changes of larvae

The weight losses of larvae of 40 - 50% of original weight (↑ (a) in Figure 9.1 a) and 35 - 42% (↑ (b) in Figure 9.1 b) at 70% R.H. and 60% R.H. are similar to those reported by Heath (1974) for engorged larvae held at 25°C over $CaCl_2$ (5% R.H.). The cumulative weight loss of the engorged larvae was 50% after 48 hours. As expected (see section 1.12.3) unengorged larvae were found to be very susceptible to desiccation. Unfed larvae of *B. microplus* will survive for 12 days at 70% R.H. at 22.2°C (Hitchcock, 1955) compared with only 2 days for *H. longicornis* in this experiment.

At humidities above the C.E.A. there was a large increase in weight of *H. longicornis* larvae above the predesiccated weight (> 70% at 100% R.H.). At constant temperatures of 28°C at humidities above their C.E.A.'s marked increases in weight above predesiccated weights have been observed in larval *Hyalomma dromedarii* and first nymphal instars of *Ornithodorus savignyi* (Hafez, El-Ziady, and Hefnawy, 1970 b).

Weight changes of nymphs

As shown in Figure 9.2 a, 18/20 nymphs were dead 6 days after desiccation (R.H. 60% ↑ (c) in Figure 9.2 a) with a cumulative weight loss of 30%. However, there was some indication that the weight loss of nymphs in the replicate experiment was not as large (see also weight loss of nymphs in Table 9.1). The 95% mortality of unengorged nymphs after 6 days at 60% R.H. was not expected since Heath (1974) found almost 100% survival and moulting of engorged nymphs held for 11 days over $CaCl_2$ with a mean cumulative weight loss of 28%. However, it is unlikely that engorged nymphs would have a response to desiccation similar to that of unengorged nymphs. The response to desiccation of engorged stages is likely to vary during the moulting process.

The nymphs in first experiment (Figure 9.2 a) had been chilled to facilitate handling whereas in the replicate experiment (Figure 9.2 b) the nymphs were not chilled. This may have affected the weight loss of the chilled nymphs. It does suggest weight loss in engorged and unengorged nymphs of H. longicornis should be further investigated under more closely controlled conditions.

Weight changes in adults

Unfed adults of H. longicornis lost approximately 4.0 - 4.5% of their initial weight per day when desiccated over $CaCl_2$ at 28°C. At 25°C, in dry air, the weight loss of Dermacentor reticulatus, D. andersoni, and Rhicephalus sanguineus was only 1 - 3% day. Amblyomma cajennense and A. maculatum lost 5% of their original weight per day (Lees, 1946). This is similar to that recorded here for H. longicornis. The rate of water loss of Ixodes hexagonus, I. canisuga and I. ricinus may exceed that of H. longicornis. In fact in dry air at 25°C, unfed female I. ricinus does not survive for more than 2 days (Lees, 1946).

Compared with nymphs and larvae, the recovery of water by adult H. longicornis at humidities above its C.E.A. was poor. It is asumed that all instars were fully hydrated after being held at 96% R.H. at 28°C prior to the experiment. However, the adults of H. longicornis were older than the nymphs and larvae and the C.E.A. may not be as high as 0.9 for freshly moulted specimens.

It has recently been shown that the ability to recover water by ticks following desiccation, must be included in considerations of resistance to desiccation. For example Osman (1978), compared the resistance to desiccation and subsequent uptake of water following desiccation of three species of Amblyomma.

In Africa, A. lepidum is considered to inhabit drier areas than A. hebraeum and A. variegatum, yet engorged larvae and nymphs and unfed adults of A. lepidum lose water at a faster rate than the latter two species. However, following desiccation, when exposed to humidities above the C.E.A. A. lepidum can recover the equivalent of 10% of its original weight within 24 hours compared with only 5% for the other 2 species (Osman and Campbell, 1978). It was considered that the latter 2 species rely on resistance to desiccation while the former species relies on recovery of water. It was concluded that the restriction of A. lepidum to drier areas was also possibly related to the lower viability of engorged larvae following immersion in water.

The C.E.A. for unfed larvae, nymphs and adults

The figures presented here should be considered only as approximate values as the age of the instars varied. It has been shown by Lees, (1946, 1964), that newly moulted and aged I. ricinus did not take up water from saturated air and the C.E.A. of this species increased from 0.88 to 1.00 over a period of 16 months. This was also observed in the argasid Ornithodorus moubata which, after starvation for 5 months, gradually lost its capacity for sorption of water vapour. The C.E.A. of field-collected adults of Amblyomma americanum was calculated to be 0.85 by Sauer and Hair (1971). However, when recently moulted adults (3 $\pm$ 1 week of age) were tested, the C.E.A. was calculated to be 0.80 - 0.82 (Hair, Sauer and Durham, 1975). It is logical that the C.E.A. would alter with depletion of reserves (Lees, 1969).

While not ignoring the age effect on the C.E.A. it is worth considering whether the C.E.A. differs amongst other instars of the same species. It was first noted by Knulle (1966), that the C.E.A.'s of freshly moulted larval Dermacentor andersoni (0.8) and Amblyomma cajennense (0.85) were lower than that recorded by Lees (1946) for adults of these species i.e. 0.88 and 0.90 respectively.

Knulle (1966) was cautious in interpretating these differences since the adults used by Lees were 1 - 4 months old. In addition the C.E.A. of freshly moulted larval Dermacentor variabilis was found by Knulle (1966) to be 0.85 which is the same value subsequently found for adults (age 3 weeks ± 1 week) of this species (Knulle and Devine, 1972; Hair, et al, 1975). On the other hand Aeschlimann (1963 - cited by Knulle, 1966) recorded a C.E.A. for newly moulted larvae of Amblyomma compressum of 0.8 compared with a C.E.A. of 0.66 for newly moulted nymphs. Furthermore Hafez, El-Ziady and Hefnawy (1970b) also recorded a progressive increase in the C.E.A. for each developmental stage of the ixodid Hyalomma dromedarii and the argasid Ornithodorus savignyi. They related this to the hosts and habitats of the instars. For example, larval H. dromedarii parasitises small burrowing mammals, hares and lizards. While the adults, (which have a higher C.E.A. and are more resistant to desiccation), parasitise larger hosts including camels. The larvae of H. dromedarii require burrows to protect them against desiccation and the C.E.A. is equal to or below the mean annual R.H. in the burrows of two rodent hosts.

The evidence would suggest that the C.E.A.'s found in this study for H. longicornis should be further investigated with instars all of the same age. The results also suggest unfed larvae would not survive in paspalum seed but it is possible that unfed nymphs could do so.

10. The effects of immersion in water on Haemaphysalis longicornis.

10.1 Introduction.

In Section 1.12.3 the evidence available of the effects of immersion in water of various species of ticks was reviewed. The ability to withstand flooding varies between tick species and is also likely to vary between the instars of the same species. Opinions from farmers of the East Coast area of the North Island and Myers (1924) suggested that flooding decreased the survival of H. longicornis. This possibility was investigated under laboratory conditions.

10.2 Materials and methods.

Source of ticks. This was as described in Section 9. Larvae were fed on rabbits and nymphs and adults on a calf as described by Heath (1974). After detachment all stages were incubated at 28°C at 96% R.H. The age of each instar is shown in the subsequent tables of results (this allows for a premoult period of 10 days for nymphs and 15 days for adults and an incubation period for eggs of 27 days.

Immersion and temperature control. Unengorged and engorged stages were placed in glass vials (7.6 cm in length and 2.4 cm in diameter) covered by a plastic cap through which a 1 cm hole was punched. This hole was covered with fine mesh terylene cloth. Sample sizes varied with the numbers available and samples were assigned at random to immersion or control. The immersed instars were placed in tap water in plastic trays filled with water. Care was taken to ensure all air was removed from vial. The controls were placed upside down in open racks immediately above the tray of water.

Two temperatures representing summer and winter conditions were selected viz. 9°C and 25°C. For the lower temperature samples were placed in Contherm Precision refrigerated incubator (Model 190) set at 10°C. A check of the water and air temperature in this incubator showed that the water temperature was maintained at 1°C below the air temperature from the cooling effect of evaporation. A check of the R.H. within the incubator with a Micromech hygrothermograph (Model MM 01) showed that this remained between 97 - 99% R.H.

For the higher temperature a Contherm Precision incubator was set at 27°C to give a water temperature of 25°C. The R.H. within this incubator varied between 82 - 86% R.H. Some samples were incubated in muddy water obtained following rain from a paddock adjacent to the Wallaceville laboratory. In addition some engorged adults were held at 28°C and 96% R.H. to observe oviposition and egg hatch. Following the termination of the experiment (maximum immersion 22 days) samples were dried and replaced in dried glass vials. The engorged adults were dried and placed singly in identified terylene sachets.

10.3 Results.

These are shown in Tables 10.1 and 10.2. The temperatures for the controls are shown as either 1°C above the immersed samples (lower temperature) or 2°C above the immersed samples (higher temperature). In fact, the temperature differences immediately above the tray of water may not have been as great as this.

Table 10.1

Effect of immersion in water on the engorged stages of *H. longicornis*.

n	Temperature	Age of instar	Length of immersion	Remarks
			Engorged Adults	
5	9°C	1 day	3 days (tap water)	3/5 laid normal batch of eggs, 2 dead.
5	10°C	1 day	Control	2/5 laid large batch of eggs 3 dead.
5	25°C	1 day	3 days (tap water)	4 dead, 1/5 laid reduced batch of eggs. Less than 10% eggs embryonated.
5	27°C	1 day	Control	4 dead, 1/5 laid large batch of eggs.
5	28°C	1 day	96% R.H. in an incubator	5/5 laid eggs.
	Examined at removal and after 24 days incubation at 28°C at 96% R.H.			
			Engorged Nymphs	
5	9°C	1 day	17 days (tap water)	2/5 dead, 3/5 in premoult.
5	9°C	1 day	17 days (muddy water)	All 5 dead
5	10°C	1 day	Control	1 moulted, 4/5 in premoult.
5	25°C	1 day	17 days (tap water)	All 5 dead.
5	25°C	1 day	17 days (muddy water)	All 5 dead.
5	27°C	1 day	Control	All 5 moulted.
	Examined at removal and after 13 days incubation at 28°C at 96% R.H.			
			Engorged Larvae	
9	9°C	1 day	22 days (tap water)	6 dead, 3 moulted
9	10°C	1 day	Control	7 dead, 2 moulted
10	25°C	1 day	22 days (tap water)	6 dead, 4 moulted but nymphs dead.
10	27°C	1 day	Control	10 moulted.
	Examined at removal and after 13 days incubation at 28°C at 96% R.H.			

Table 10.2

Effect of immersion in water on the unengorged stages of *H. longicornis*.

n	Temperature	Age	Length of immersion	Remarks
			Unengorged Adults	
10	9°C	42 days	22 days (tap water)	All alive
10	10°C	42 days	Control	All alive
10	25°C	45 days	18 days (tap water)	All alive
10	27°C	45 days	Control	All alive
	Examined at removal and after incubation for 13 days at 28°C at 96% R.H.			
			Unengorged Nymphs	
25	9°C	87 days	22 days (tap water)	All alive
9	9°C	87 days	22 days (muddy water)	All alive
25	10°C	87 days	Control	All alive
20	25°C	94 days	18 days (tap water)	All alive
20	27°C	94 days	Control	All alive
	Examined at removal and after incubation for 13 days at 28°C at 96% R.H.			
			Unengorged Larvae	
50	9°C	1 day	22 days (tap water)	All alive
50	10°C	1 day	Control	All alive
25	25°C	4 days	18 days (tap water)	All alive
25	27°C	4 days	Control	All alive
	Examined at removal and after incubation for 13 days at 28°C at 96% R.H.			

10.4 Discussion.

The results indicate that the unfed stages of H. longicornis can survive immersion in water at temperatures of either 9° or 25°C for at least 18 or 22 days. No end point (e.g. 50% mortality) was reached but it is possible that unfed stages can survive much longer than 18 or 22 days.

It is not known how the unfed stages avoid anoxia while immersed in water. The eggs and larvae of B. microplus can obtain oxygen from water containing 5% dissolved oxygen (Sutherst, 1971). In this experiment no difference in survival was observed between unfed nymphs immersed in muddy water and nymphs immersed in tap water. The low rate of metabolism and hence low oxygen requirements of ticks may assist their survival while immersed in water. In a preliminary experiment unfed adults were removed after 2 days immersion as they would not respond to a tactile stimulus. These adults were very active 24 hours after removal from water. It is assumed that the adults were in a comatose state when removed from water. A similar phenomenon has been observed by Sutherst (1971) when female B. microplus were removed from water following immersion. Another possibility suggested by Sutherst (1971) is that when oxygen is absent, ticks may be able to use the products of intermediate metabolism as oxidising agents.

None of the engorged nymphs immersed in either tap water or muddy water at 25°C were alive after 17 days whereas all the controls held over the water at a slightly higher temperature moulted to adults. Similar results were found for engorged larvae. Of those immersed in tap water at 25°C, 4/10 moulted but subsequently died whereas all 10 controls successfully moulted to nymphs.

After immersion for 3 days engorged adults were removed from water as signs of bloating were observed. Four adults from both the immersed and control groups died.

It is not known why 4 adults in the control group died. It is possible that they were contaminated with H_2SO_4 in the desiccator.

The immersed and control groups of the engorged stages held at 9^{o} or $10^{o}C$ showed similar mortalities. These results probably reflect the interaction of temperature.

The experimental findings indicate a marked difference in survival between unfed and engorged stages when immersed in water. The variable results found with engorged stages show the need for further investigation. The survival of engorged stages, following immersion, needs to be investigated in a factorially designed experiment which considers preconditioning (temperatures maintained at prior to immersion), age of the instar, the level of oxygenation of the water, various water temperatures, and the relative humidity at the subsequent incubation following immersion.

The shortage of time meant that the experiment could not be replicated. In addition, maximum survival periods were not obtained for the unfed stages when immersed in water. Other unfed ticks such as Dermacentor reticulatus have been reported to survive under water at $10^{o}C$ for more than 110 days (Honzakova, 1971). Large numbers of H. longicornis are required to demonstrate this so that immersed samples can be removed at regular intervals and mortality can be analysed by probit analysis.

No differences were detected between survival in muddy water and tap water. It is assumed that the level of oxygenation of tap water was higher than that of the muddy water. The survival of engorged and unfed species of some ixodid ticks was found to be much shorter in water contaminated with organic matter compared with clean water (Honzakova, 1971).

Unfed larvae, nymphs and adults of H. longicornis were observed climbing up the walls of glass vials while immersed in water. However, climbing behaviour was not studied in this experiment. There are differences between ixodid ticks in their ability to climb while immersed in water. Smith (1973) has shown that Rhipecephalus appendiculatus climbs more actively under water than Amblyomma variegatum. This behaviour is potentially important not only in climbing above surface water during rainfall but also in host-seeking during rain.

11. Summary and conclusions.

In 1974 the distribution and prevalence of ticks in the East Coast and Hawke's Bay areas was investigated with the use of a postal questionnaire. Only a few farmers (7%) reported ticks in Central Hawkes Bay but in the Northern H.B. and East Coast areas ticks were present on the majority (59%) of farms. On more than half the latter farms ticks were considered a significant problem. Tick distribution was compared with altitude, rainfall, temperature and soil type. There was a general association of ticks with high annual rainfall combined with relatively high winter temperatures. Tick-infested farms were confined almost exclusively to areas below 300 m a.s.l. It was concluded that the factors determining tick prevalence and distribution can only be explained when more detailed studies are undertaken under controlled conditions.

The frequency distribution of tick counts was skewed and when tick counts exceed a mean of 5 per sheep the counts must be transformed for statistical analysis. Square root conversions of the individual tick counts are suitable for statistical analysis. Tick counts of the ears of sheep were adequate for sampling but there was a lack of consistent correlation between ear and body counts. Analysis of individual counts of sheep indicated that they develop a variable level of resistance to H. longicornis.

The efficacy of amitraz against ticks was compared with Chlorfenvinphos and although amitraz was initially superior its persistence was not as long as that of chlorfenvinphos. Census information from farmers in the Northern H.B. and East Coast areas showed that most (76%) have access to adequate facilities for insecticidal treatment of sheep, but only a few (11%) apply insecticides at a time which will produce maximum tick mortality.

Even with the presence of more hosts per unit area tick mortality was higher in shorter pasture compared with longer pasture and it is suggested that this may have been related to the lower humidities in the more closely grazed pasture.

Unfed nymphs required a relative humidity at or above 70% to maintain their water balance whereas unfed larvae required 80% and unfed adults 90%. At humidities below the C.E.A. the rate of water loss was faster in unfed larvae than unfed nymphs than unfed adults and the rate of water recovery at humidities above the C.E.A. was in the reverse order. I am not aware of this intriguing difference being reported for the 3 instars of any other 3-host ixodid. Larvae and eggs of H. longicornis are very susceptible to desiccation and the results suggest that adults may also be susceptible to desiccation in a dry summer.

Unfed larvae, nymphs and adults survived immersion in water for at least 18 or 22 days. Some unengorged larvae, nymphs and adults survived immersion in water at lower temperatures ($9^{\circ}C$) but their mortality was high when immersed in water at $25^{\circ}C$. More detailed studies are necessary to evaluate the effects of immersion on the fed and unfed stages of H. longicornis. Where flooding occurs some plants may protrude above the water level so that the climbing behaviour under water of H. longicornis requires investigation. The effects on the immobile egg stage of immersion in water should also be examined. Circumstantial evidence of results of an investigation into deaths in deer (Appendix 33) suggested that H. longicornis can be of major economic importance.

A major objective of this study was to attempt to determine ecological factors which affect the prevalence and distribution of H. longicornis for as Theiler (1959) has indicated, a study of the ecology of the parasite is a sine qua non before control measures are contemplated. Tick numbers appear to fluctuate widely from year to year and it is obvious that this in part must be related to climatic factors.

Ticks bites produce a characteristic lesion in lamb pelts and it is suggested that frequency and extent of these lesions could be monitored at a freezing works in a tick-area. These must be monitored for at least 10 years. The results could then be related to various climatic parameters and a correlation established. When the climatic parameters are known it is possible that increases and decreases in tick numbers could be predicted as there is possibly a lag effect on the tick cycle.

APPENDIX 1

COPY OF A QUESTIONNAIRE POSTED TO FARMERS IN DECEMBER 1974

Ministry of Agriculture & Fisheries

FARM OR STATION NAME:

OWNERS NAME:

ADDRESS:

DATE:

THE NEW ZEALAND CATTLE TICK QUESTIONNAIRE

It appears that the N.Z. Cattle Tick is becoming an increasing problem in the district. Te measure the extent to which cattle tick is spreading and the economic loss it is causing, it would be appreciated if you could complete this questionnaire and post or return to:

F.J.A. Neilson
Field Veterinarian
Ministry of Agriculture & Fisheries
P.O. Box 724
GISBORNE

Place a tick by the appropriate answer

1. Does cattle tick occur on your property

YES	✓
NO	

(Note - if cattle tick does not occur on your property the remainder of this questionnaire does not require answering)

2. If cattle tick occurs on your property, is it -

(a) becoming more of a problem	✓
(b) becoming less of a problem	
(c) same as usual	
(d) a problem only in some seasons	✓
(e) no problem at all	

3. On your property has cattle tick -

(a) always been present (more than 10 years)	
(b) only recently arrived (1 to 10 years)	✓
(c) been present and now disappeared	
(d) don't know	

4. On your property does cattle tick cause deaths in

(a) lambs	✓
(b) ewes	✓
(c) calves	
(d) cows	

Tick all boxes if all apply

5. Do you spray (dip) stock for control of cattle tick

	YES	NO
Lambs	✓	
Ewes	✓	
Cattle	✓	

6. Do you try to control rushes and long pasture to control cattle tick

YES	✓
NO	

7. Are lambs slow to fatten as a result of cattle tick infestation

YES	✓
NO	

8. Now often do you spray (dip) stock

	Lambs	Ewes	Cattle
Once			
Twice	✓	✓	✓
Three times			
Four or more			

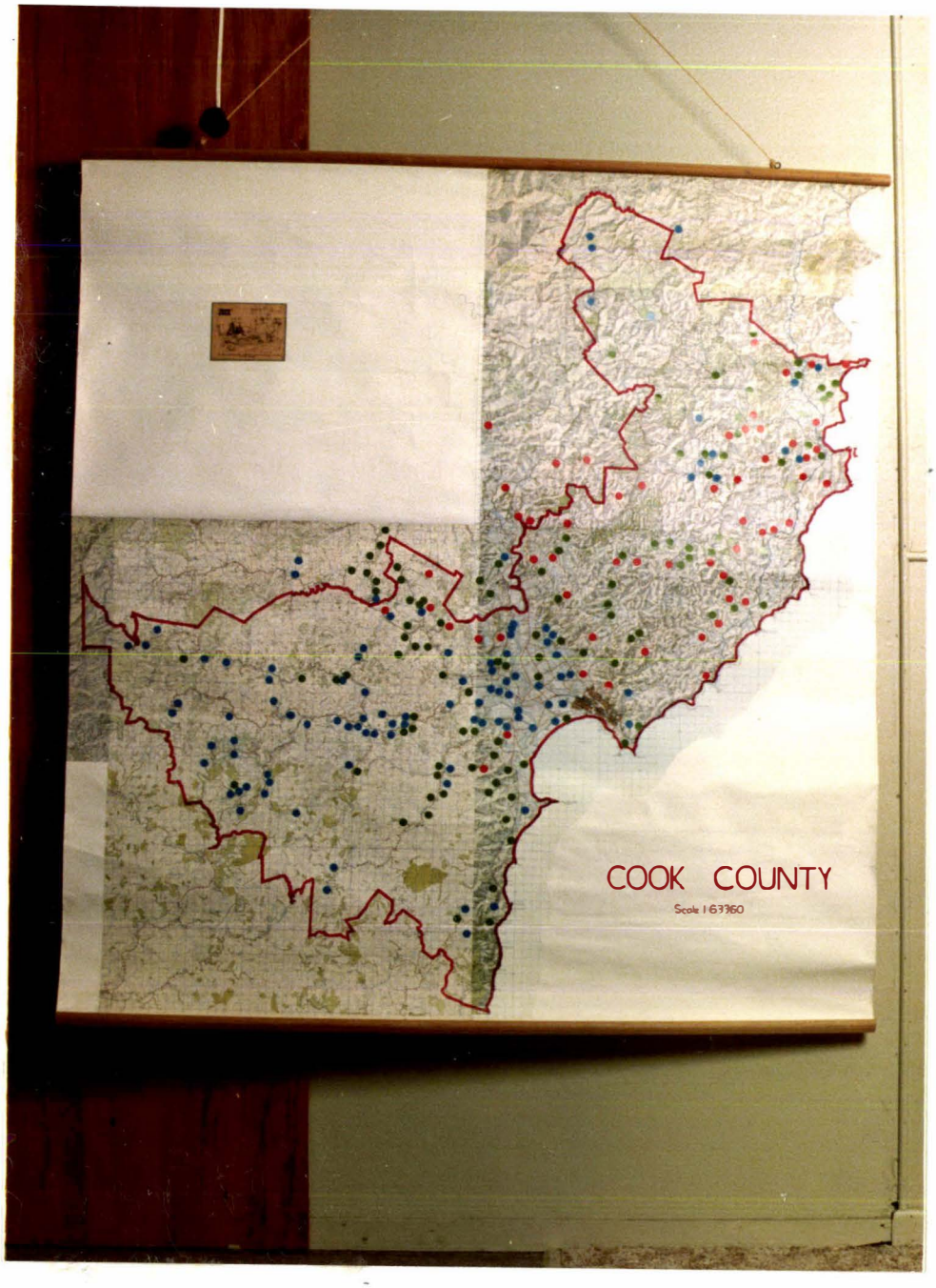
9. Comments

[illegible]e tick is definitely on the increase in [illegible]s area. Warm conditions + country facing the [illegible]orth seem to be its home in most cases. The tick [illegible] the major problem on this farm, eradication will be along & costly operation.

[illegible] [illegible]

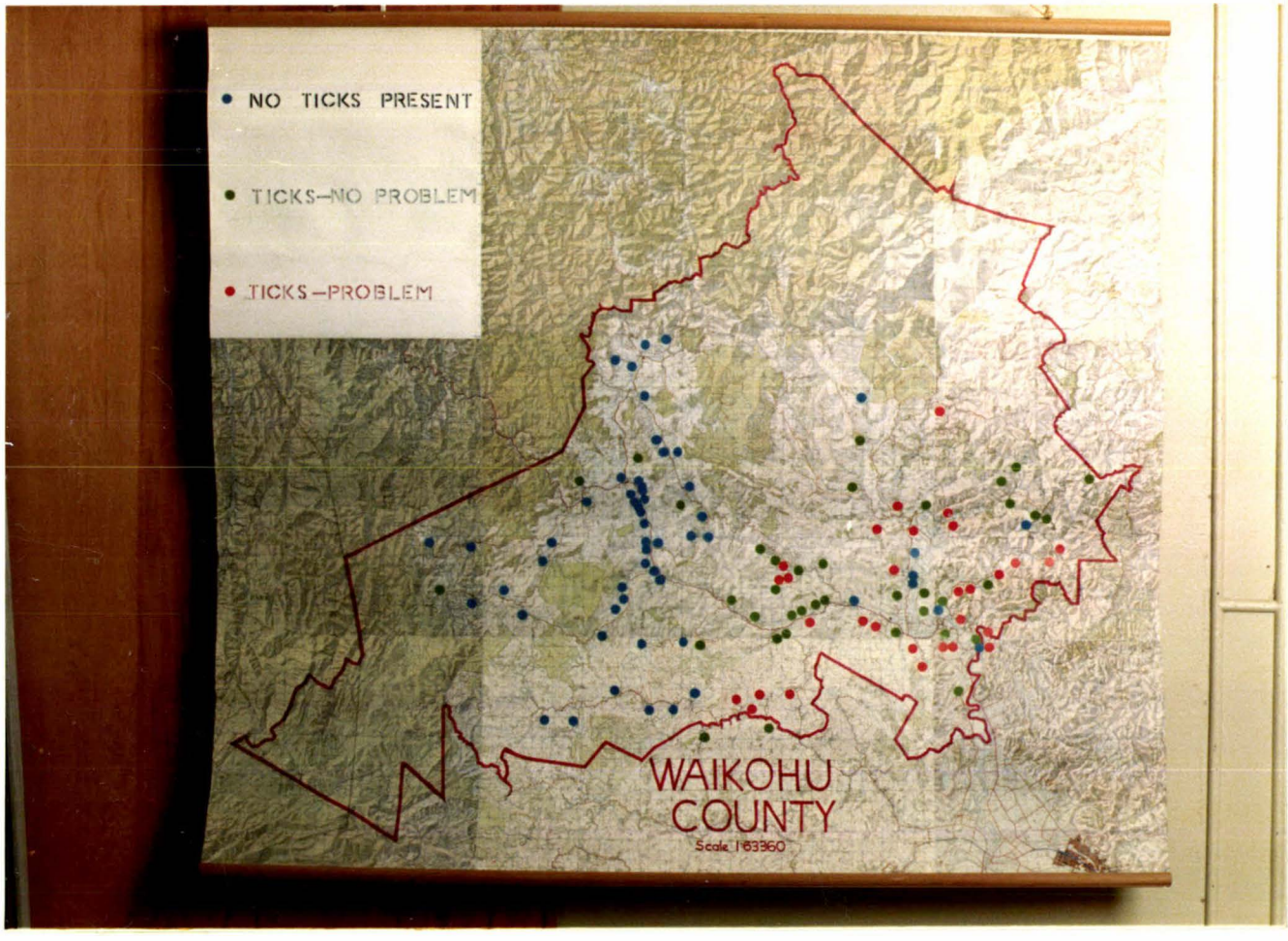
Appendix 2

Location of owners or managers of farms in the Cook County who replied to the questionnaire. This is a photograph of a large scale (1 : 63,360) topographical map. The colour code is: blue, no ticks on property; green, ticks present but not considered a problem; red, ticks present and considered a problem.



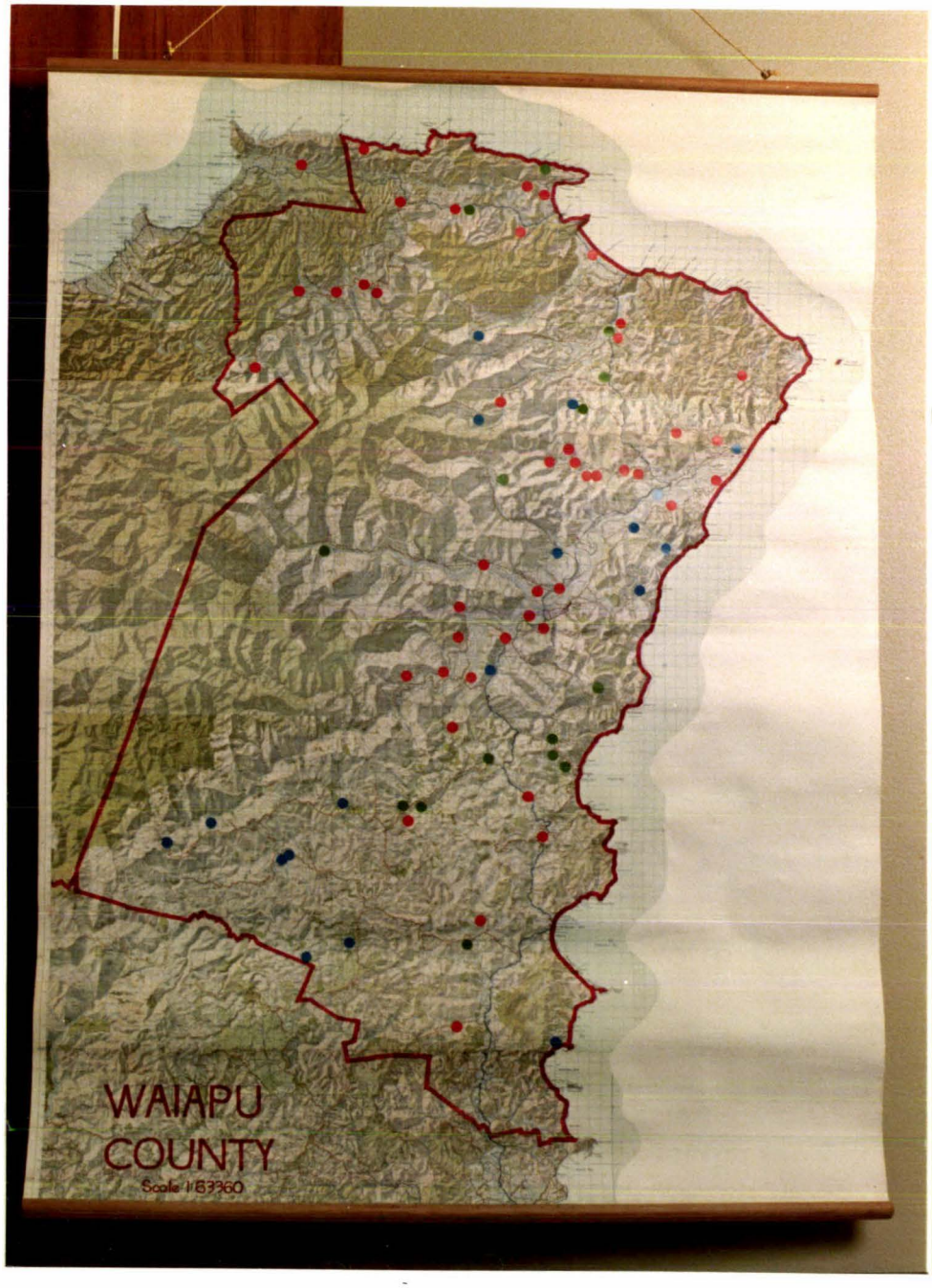
Appendix 3

Location of owners or managers of farms in the Waikohu County who replied to the questionnaire. This is a photograph of a large scale (1 : 63,360) topographical map. The colour code is: blue, no ticks on property; green, ticks present but not considered a problem; red, ticks present and considered a problem.



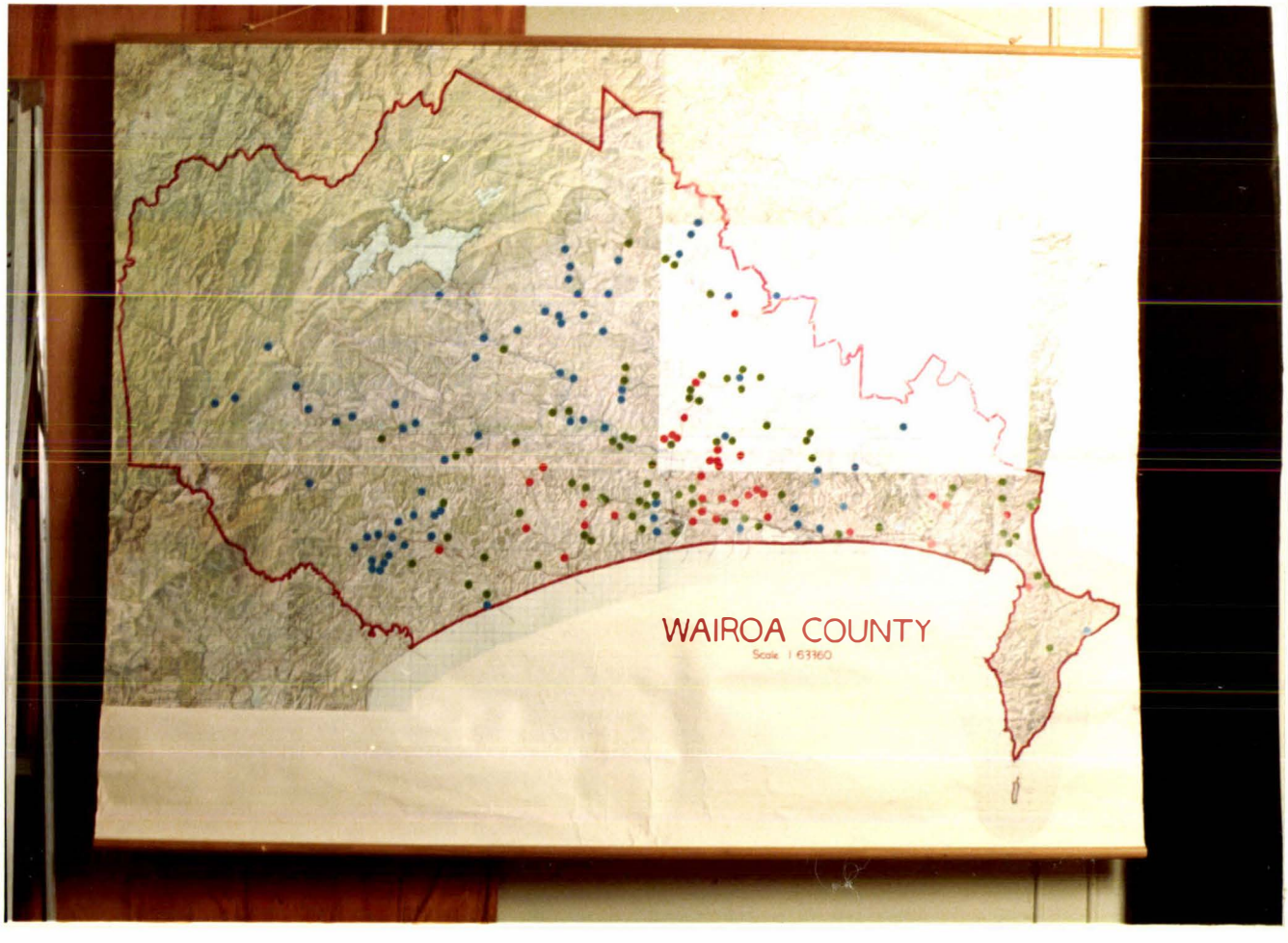
Appendix 4

Location of owners or managers of farms in the Waiapu County who replied to the questionnaire. This is a photograph of a large scale (1 : 63,360) topographical map. The colour code is: blue, no ticks on property; green, ticks present but not considered a problem; red, ticks present and considered a problem.



Appendix 5

Location of owners or managers of farms in the Wairoa County who replied to the questionnaire. This is a photograph of a large scale (1 : 63,360) topographical map. The colour code is: blue, no ticks on property; green, ticks present but not considered a problem; red, ticks present and considered a problem.



APPENDIX 6

Tick Counts of Treatment Group (Amitraz 0.03%, a.i., v/v)

	Day 0 (1.12.77)			Day 7 (8.12.77)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
G 1	0	0	0	0	0	0
G 2	3	2	2	0	0	0
G 3	6	4	5	0	0	0
G 4	6	7	2	0	0	0
G 5	3	1	6	0	0	0
G 6	2	0	2	0	0	0
G 7	1	0	0	0	0	0
G 8	3	6	25	0	0	0
G 9	2	0	0	0	0	0
G10	0	3	0	0	0	0
G11	1	1	3	0	0	0
G12	0	1	0	0	0	0
G13	2	8	6	0	0	0
G14	0	0	1	0	0	0
G15	0	0	0	0	0	0
G16	1	1	1	Missing		
G17	7	5	2	1	0	0
G18	1	0	0	0	0	0
G19	0	2	0	1	0	0
G20	5	2	0	0	0	0
G21	8	2	15	0	0	0
G22	12	3	0	0	0	0
G23	1	0	0	0	0	0
G24	1	0	0	0	0	0
G25	4	7	0	0	0	0
G26	2	1	5	0	0	0
G27	7	5	2	Missing		
G28	1	1	5	0	0	0
G29	0	4	17	Missing		
G30	3	2	5	0	0	0
G31	6	3	5	0	0	0
G32	0	0	0	0	0	0
G33	1	0	0	0	0	0
G34	13	0	5	0	0	0
G35	5	3	0	0	0	0

APPENDIX 7

Tick Counts of Treatment Group (Amitraz 0.03%, a.i. v/v)

	Day 0 (1.12.77)			Day 7 (8.12.77)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
G36	1	1	4	0	0	0
G37	6	7	10	Missing		
G38	0	1	0	Missing		
G39	0	0	4	0	0	0
G40	2	1	0	0	0	0
G41	0	2	1	0	0	0
G42	0	0	1	0	0	0
G43	0	0	0	0	0	0
G44	1	0	1	0	0	0
G45	0	1	0	0	0	0
G46	8	3	2	Missing		
G47	2	0	0	0	0	1
G48	2	1	0	0	0	0
G49	6	3	3	0	0	0
G50	0	0	0	0	0	0
G51	6	2	0	0	0	0
G52	1	0	4	0	0	0
G53	4	2	15	0	0	0
G54	13	12	1	1	0	0
G55	0	1	2	0	0	0
G56	3	1	1	0	0	0
G57	0	1	0	0	0	0
G58	0	0	5	0	0	0
G59	0	3	0	Missing		
G60	0	2	0	0	0	0
G61	3	1	2	0	0	0
G62	2	0	2	0	0	0
G63	0	2	1	0	0	0
G64	0	0	0	0	0	0
G65	4	1	3	Missing		
G66	0	0	0	0	0	0
G67	9	5	2	0	0	0
G68	7	10	12	0	0	0
G69	0	1	0	0	0	0
G70	4	2	7	0	0	0
Total	197	140	197	3	0	1

APPENDIX 8

Tick Counts of Treatment Group (Amitraz 0.03%, a.i., v/v)

	Day 13 (11.12.77)			Day 20 (21.12.77)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
G 1	0	0	0	1	0	1
G 2	0	0	0	2	0	4
G 3	0	0	0	12	5	5
G 4	1	0	0	22	6	10
G 5	0	0	0	5	0	2
G 6	0	0	0	1	0	0
G 7	0	0	0	4	3	5
G 8	0	0	0	2	0	7
G 9	0	0	0	1	0	0
G10	0	0	0	1	0	0
G11	0	0	0	1	0	2
G12	0	0	0	5	1	2
G13	0	0	0	3	4	5
G14	0	0	0	2	1	0
G15	0	0	0	0	0	3
G16	0	0	0	1	2	20
G17	1	1	0	9	5	2
G18	0	0	0	1	1	3
G19	0	0	0	2	0	0
G20	0	0	0	13	6	1
G21	0	0	0	3	4	12
G22	0	0	0	3	5	2
G23	0	0	0	0	1	1
G24	0	0	0	0	1	2
G25	0	0	0	2	2	1
G26	0	1	0	3	4	8
G27	Missing			Missing		
G28	0	0	0	0	3	0
G29	Missing			0	0	1
G30	Missing			4	12	8
G31	0	0	0	10	5	1
G32	0	0	0	2	7	2
G33	0	0	0	3	3	0
G34	0	0	0	3	6	1
G35	0	0	0	6	4	10

APPENDIX 9

Tick Counts of Treatment Group (Amitraz 0.03%, a.i., v/v)

	Day 13 (14.12.77)			Day 20 (21.12.77)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
G36	0	0	0	2	3	2
G37	0	0	0	1	0	0
G38	0	0	0	4	1	3
G39	1	0	0	7	4	4
G40	0	0	0	3	0	4
G41	0	0	0	1	6	2
G42	0	0	1	4	1	4
G43	0	0	0	1	3	0
G44	0	0	0	0	2	1
G45	0	0	0	0	2	1
G46	Missing			Missing		
G47	0	0	0	0	1	2
G48	0	0	0	2	4	1
G49	0	0	0	1	3	3
G50	0	0	0	0	0	1
G51	0	0	0	3	0	0
G52	0	1	0	2	0	3
G53	0	0	0	3	2	10
G54	1	0	0	16	10	22
G55	0	0	0	0	1	5
G56	0	0	0	2	2	1
G57	0	0	0	3	8	4
G58	0	0	0	4	2	5
G59	0	0	0	4	2	1
G60	0	0	0	1	4	5
G61	0	0	0	4	1	2
G62	0	0	0	3	5	5
G63	0	0	0	2	0	5
G64	0	0	0	1	1	0
G65	0	0	0	3	1	0
G66	0	0	0	2	6	6
G67	0	0	0	5	7	1
G68	0	0	0	3	4	5
G69	0	0	0	0	2	0
G70	0	0	1	3	2	6
Total	4	3	2	217	181	235

APPENDIX 10

Tick Counts of Treatment Group (Amitraz 0.03%, a.i., v/v)

	Day 27 (28.12.77)			Day 34 (4.1.78)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
G 1	0	2	0	2	0	0
G 2	3	5	11	5	6	20
G 3	8	2	7	9	3	6
G 4	6	4	6	9	5	7
G 5	4	2	1	8	4	8
G 6	0	1	4	0	0	0
G 7	0	3	4	2	1	1
G 8	2	4	7	11	2	17
G 9	1	0	0	4	2	0
G10	8	5	2	10	3	4
G11	1	2	2	9	5	11
G12	1	1	8	12	3	16
G13	3	12	2	23	11	6
G14	1	2	1	4	0	5
G15	2	1	1	0	1	2
G16	0	2	2	5	12	6
G17	8	2	0	14	5	2
G18	0	0	2	0	1	2
G19	4	3	1	8	1	0
G20	15	4	2	25	12	14
G21	2	5	7	20	13	40
G22	3	7	7	21	11	17
G23	0	0	1	0	0	3
G24	0	0	2	0	0	1
G25	4	2	2	3	11	4
G26	4	3	9	4	2	5
G27	Missing			Missing		
G28	0	0	0	0	0	9
G29	Missing			Missing		
G30	8	9	8	14	13	21
G31	6	4	7	4	4	7
G32	0	0	0	0	0	3
G33	2	0	0	7	2	2
G34	4	1	0	11	0	2
G35	6	5	2	12	4	18

APPENDIX 11

Tick Counts of Treatment Group (Amitraz 0.03%, a.i., v/v)

	Day 27 (28.12.77)			Day 34 (4.1.78)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
G36	1	0	3	2	0	17
G37	1	2	1	4	4	3
G38	2	3	6	4	3	5
G39	7	1	0	5	4	15
G40	2	0	4	1	0	14
G41	2	2	0	4	3	1
G42	0	0	1	4	0	5
G43	2	3	0	3	3	12
G44	3	2	0	16	0	13
G45	0	1	0	8	5	8
G46	Missing			Missing		
G47	Missing			2	2	7
G48	1	5	0	6	17	8
G49	0	0	7	9	0	5
G50	0	0	0	0	1	4
G51	3	0	2	2	1	1
G52	0	0	2	16	4	2
G53	2	1	7	0	0	17
G54	5	28	38	23	25	15
G55	0	0	8	0	3	8
G56	1	4	0	1	6	10
G57	3	1	0	7	1	1
G58	0	0	6	3	2	14
G59	1	2	2	13	0	5
G60	1	2	9	21	1	17
G61	0	3	3	23	7	15
G62	0	0	0	10	1	7
G63	1	1	2	0	0	7
G64	0	0	0	2	3	3
G65	3	1	8	8	5	14
G66	7	7	4	8	1	6
G67	2	7	0	18	7	4
G68	2	3	4	24	1	22
G69	1	0	4	1	1	3
G70	11	7	7	2	4	14
Total	170	179	236	506	252	561

APPENDIX 12

Tick Counts of Treatment Group (Amitraz 0.05, a.i., v/v)

	Day 0 (1.12.77)			Day 7 (8.12.77)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
B 1	1	4	2	0	0	0
B 2	1	0	0	0	0	0
B 3	2	3	0	0	0	0
B 4	0	0	1	0	0	0
B 5	6	1	0	0	0	0
B 6	0	1	0	0	0	0
B 7	0	0	0	0	0	0
B 8	0	3	1	0	0	0
B 9	1	1	1	0	0	0
B10	5	6	0	0	0	0
B11	0	0	0	0	0	0
B12	0	2	2	0	0	0
B13	0	0	0	0	0	0
B14	6	3	0	0	0	0
B15	5	0	1	0	0	0
B16	7	4	1	0	0	0
B17	0	0	0	0	0	0
B18	0	0	1	0	0	0
B19	1	1	1	0	0	0
B20	0	0	4	0	0	0
B21	0	0	0	0	0	0
B22	16	16	2	0	0	0
B23	1	4	2	0	0	0
B24	0	0	1	0	0	0
B25	3	0	0	0	0	0
B26	10	6	10	0	0	0
B27	0	0	0	0	0	0
B28	0	0	0	0	0	0
B29	6	6	0	0	0	0
B30	0	0	0	0	0	0
B31	0	1	0	0	0	0
B32	8	3	3	Missing		
B33	1	0	0	0	0	0
B34	0	1	1	0	0	0
B35	1	2	4	0	0	0

APPENDIX 13

Tag Number	Day 0 (1.12.77) Left Ear	Right Ear	Body	Day 7 (8.12.77) Left Ear	Right Ear	Body
B36	0	0	0	0	0	0
B37	Missing			0	Not 0 dipped	
B38	0	3	3	0	0	0
B39	0	1	9	0	0	0
B40	1	1	3	0	1	0
B41	0	0	0	0	0	0
B42	3	8	5	0	0	0
B43	2	1	1	0	0	0
B44	2	10	14	0	0	0
B45	7	15	11	0	0	0
B46	3	2	6	0	0	0
B47	0	0	1	0	0	0
B48	0	2	2	0	0	0
B49	2	1	0	0	0	0
B50	1	0	0	0	0	0
B51	1	0	0	0	0	0
B52	7	2	0	0	0	0
B53	0	0	0	0	0	0
B54	1	0	2	0	0	0
B55	1	0	0	0	0	0
B56	1	1	0	0	0	0
B57	2	3	0	0	0	0
B58	0	0	0	0	0	0
B59	0	0	2	0	0	0
B60	1	3	0	0	0	0
B61	0	0	6	0	0	0
B62	0	3	0	0	0	0
B63	0	3	3	0	0	0
B64	2	1	0	0	0	0
B65	Missing			0	Not 0 dipped	0
B66	3	2	1	0	0	0
B67	1	1	0	0	0	0
B68	Died					
B69	0	0	0	0	0	0
B70	4	1	3	0	0	0
Total	126	132	110	0	1	0

APPENDIX 14

Tick Counts of Treatment Group (Amitraz 0.05%, a.i., v/v)

	Day 13 (14.12.77)			Day 20 (21.12.77)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
B 1	0	0	0	4	4	1
B 2	0	0	0	0	0	0
B 3	0	0	0	9	3	0
B 4	0	0	0	1	1	2
B 5	0	0	0	12	2	0
B 6	0	0	0	3	1	0
B 7	0	0	0	1	0	0
B 8	0	0	0	4	1	2
B 9	0	0	0	0	1	3
B10	0	0	0	3	1	0
B11	0	0	0	0	0	1
B12	0	0	0	6	7	4
B13	0	0	0	0	1	0
B14	0	0	0	1	0	1
B15	0	0	0	5	11	0
B16	0	0	0	9	3	1
B17	0	0	0	2	0	0
B18	0	1	0	1	2	0
B19	0	0	0	3	9	0
B20	0	0	0	3	1	4
B21	0	0	0	0	0	6
B22	0	0	0	25	30	10
B23	0	0	0	1	1	1
B24	0	0	0	0	1	1
B25	0	0	0	5	0	0
B26	0	0	0	18	13	2
B27	0	0	0	1	4	1
B28	0	0	0	0	0	1
B29	0	0	0	5	15	2
B30	0	0	0	2	1	2
B31	0	0	0	0	0	1
B32	0	0	0	1	1	9
B33	0	0	0	4	1	1
B34	0	0	0	0	0	0
B35	0	0	0	3	5	0

APPENDIX 15

Tick Counts of Treatment Group (Amitraz 0.05 %, a.i., v/v)

Tag Number	Day 13 (14.12.77) Left Ear	Right Ear	Body	Day 20 (21.12.77) Left Ear	Right Ear	Body
B36	0	0	0	1	1	2
B37	0	Not Odipped	0	1	Not Odipped	1
B38	0	0	1	0	2	0
B39	0	0	0	0	0	5
B40	Missing			3	2	1
B41	0	0	0	0	0	1
B42	0	0	0	7	13	8
B43	0	0	0	0	0	0
B44	0	0	0	1	0	0
B45	0	0	0	2	4	2
B46	0	0	0	1	1	0
B47	0	0	0	0	0	0
B48	0	0	0	Missing		
B49	0	0	0	1	1	3
B50	0	0	0	2	2	3
B51	0	0	0	1	0	5
B52	1	0	0	12	18	1
B53	0	0	0	1	1	7
B54	0	0	0	2	0	5
B55	0	0	0	2	0	2
B56	0	0	0	1	0	7
B57	0	0	0	13	8	0
B58	0	0	0	0	0	1
B59	0	0	0	2	1	0
B60	0	0	0	10	8	0
B61	0	0	0	1	1	2
B62	0	0	0	2	1	1
B63	0	0	0	0	0	0
B64	0	0	0	1	1	1
B65	0	Not Odipped	0	0	Not 1dipped	4
B66	0	0	0	2	0	0
B67	0	0	0	3	6	0
B68						
B69	0	0	0	0	6	4
B70	0	0	0	4	2	0
Total	1	1	1	207	199	117

APPENDIX 16

Tick Counts of Treatment Group (Amitraz 0.05%, a.i., v/v)

	Day 27 (28.12.77)			Day 34 (4.1.78)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
B 1	4	3	1	6	21	16
B 2	0	0	0	0	1	4
B 3	8	11	3	26	14	11
B 4	0	0	4	4	2	14
B 5	6	2	2	1	4	3
B 6	0	0	1	0	0	10
B 7	0	3	0	0	0	2
B 8	5	4	1	13	17	0
B 9	5	3	1	24	4	3
B10	1	3	1	25	16	14
B11	0	0	0	1	1	5
B12	16	11	1	13	16	2
B13	0	0	2	3	2	13
B14	4	1	1	8	2	17
B15	3	2	1	13	12	2
B16	8	0	0	14	0	0
B17	1	0	2	6	2	9
B18	2	0	1	0	00	4
B19	5	17	4	12	9	24
B20	0	0	2	1	0	8
B21	0	0	0	0	0	2
B22	51	42	18	14	10	14
B23	0	3	2	0	2	5
B24	0	0	3	1	3	19
B25	4	14	0	7	6	0
B26	4	1	2	10	10	10
B27	1	1	2	3	7	1
B28	1	1	2	0	0	6
B29	1	9	3	11	19	6
B30	3	2	7	13	17	20
B31	0	0	0	1	0	6
B32	0	0	5	9	2	17
B33	0	0	0	0	0	1
B34	0	0	2	1	1	3
B35	0	1	2	Missing		

APPENDIX 17

Tick Counts of Treatment Group (Amitraz 0.05%, a.i. $^{v}/_{v}$)

	Day 27 (28.12.77)			Day 34 (4.1.78)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
B36	1	0	2	8	3	10
B37	0	Not dipped	0	1	Not dipped	5
B38	0	2	0	3	10	6
B39	1	1	2	4	0	12
B40	2	3	1	5	0	6
B41	1	0	1	0	0	4
B42	3	9	3	7	16	9
B43	4	2	3	15	23	4
B44	0	0	1	4	2	17
B45	6	8	6	23	10	7
B46	0	1	0	13	26	13
B47	3	1	5	9	4	2
B48	2	1	2	4	3	1
B49	0	3	1	3	2	4
B50	2	2	7	3	3	9
B51	1	1	2	8	5	18
B52	23	28	4	14	10	36
B53	0	0	3	1	1	11
B54	2	0	3	0	0	8
B55	2	4	3	0	9	1
B56	5	6	8	26	14	31
B57	22	13	1	23	21	17
B58	1	0	1	0	0	5
B59	0	1	1	0	1	6
B60	8	3	0	19	14	13
B61	0	0	1	0	0	3
B62	0	0	0	0	0	0
B63	0	0	3	0	0	2
B64	0	0	0	0	0	4
B65	6	Not dipped	13	3	Not dipped	14
B66	0	0	1	1	0	0
B67	2	3	0	29	4	7
B68						
B69	Died - prolapsed rectum					
B70	4	4	0	20	8	4
Total	228	230	141	482	389	541

APPENDIX 18

Tick Count of Treatment Group (Supona 0.06%, a.i., $^{v}/v$)

	Day 0			Day 7		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
Or 1	0	0	0	0	0	0
Or 2	0	0	5	0	0	0
Or 3	3	3	5	0	0	0
Or 4	2	7	0	0	0	0
Or 5	0	0	0	0	0	0
Or 6	2	0	0	0	0	0
Or 7	1	0	14	0	0	1
Or 8	0	4	1	0	0	0
Or 9	1	1	0	0	0	0
Or 10	Missing			Not dipped		
Or 11	1	0	4	0	0	1
Or 12	0	0	1	0	0	0
Or 13	1	3	11	Missing		
Or 14	0	0	3	0	0	0
Or 15	7	10	6	0	0	0
Or 16	0	0	0	0	0	0
Or 17	2	0	0	0	0	0
Or 18	Missing			Not dipped		
Or 19	Missing			Not dipped		
Or 20	2	0	0	0	0	0
Or 21	12	7	15	Missing		
Or 22	7	7	5	0	0	0
Or 23	2	1	3	0	0	0
Or 24	3	0	14	0	0	1
Or 25	1	2	0	0	0	0
Or 26	1	0	2	0	0	0
Or 27	3	4	1	0	0	0
Or 28	1	4	0	0	0	0
Or 29	1	0	2	0	0	0
Or 30	0	0	0	0	0	0
Or 31	0	1	0	0	0	0
Or 32	0	1	0	0	0	0
Or 33	1	1	1	0	0	0
Or 34	10	6	9	0	0	0
Or 35	3	2	3	0	0	1

APPENDIX 19

Tick Counts of Treatment Group (Supona 0.06%, a.i., v/v)

Day 0				Day 7		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
Or36	0	0	0	0	0	0
Or37	0	1	0	0	0	0
Or38	2	1	1	1	0	0
Or39	0	1	0	0	0	0
Or40	0	2	0	Missing		
Or41	4	3	3	0	0	0
Or42	0	0	0	0	0	0
Or43	4	1	4	0	0	0
Or44	2	2	13	0	0	0
Or45	3	5	11	0	0	0
Or46	0	0	0	0	0	0
Or47	0	2	0	0	0	0
Or48	0	0	6	0	0	0
Or49	15	15	12	0	0	0
Or50	0	0	1	0	0	0
Or51	0	0	0	0	0	0
Or52	0	0	0	0	0	0
Or53	1	8	0	0	0	0
Or54	1	1	0	0	0	0
Or55	3	0	0	0	0	0
Or56	0	2	5	0	0	1
Or57	1	0	1	0	0	0
Or58	0	0	1	0	0	0
Or59	2	2	0	0	0	0
Or60	3	8	2	0	1	0
Or61	0	0	0	0	0	0
Or62	0	0	0	0	0	0
Or63	1	0	1	0	0	0
Or64	0	0	0	0	0	0
Or65	0	0	0	Missing		
Or66	7	5	0	0	0	0
Or67	5	0	0	1	0	0
Or68	4	2	4	0	0	0
Or69	1	1	0	0	0	0
Or70	1	2	3	0	0	0
Total	127	128	173	2	1	5

APPENDIX 20

Tick Counts of Treatment Group (Supona 0.06%, a.i., v/v)

Tag Number	Day 13 (14.12.77) Left Ear	Right Ear	Body	Day 20 (21.12.77) Left Ear	Right Ear	Body
Or 1	0	0	0	0	0	4
Or 2	0	1	0	2	2	6
Or 3	0	0	0	4	0	12
Or 4	0	0	0	10	5	1
Or 5	0	0	0	4	6	6
Or 6	2	0	0	0	1	2
Or 7	0	0	1	5	1	7
Or 8	0	0	0	0	0	1
Or 9	0	0	0	3	1	1
Or10	Not dipped			26	Not dipped	19
Or11	0	0	0	6	4	3
Or12	0	0	2	3	2	6
Or13	0	0	0	1	0	4
Or14	0	0	0	1	1	10
Or15	Missing			10	5	1
Or16	0	0	0	1	7	15
Or17	0	2	1	1	3	3
Or18	Not dipped			Not dipped		
Or19	Not dipped			Not dipped		
Or20	0	0	0	1	2	6
Or21	0	0	0	1	6	10
Or22	0	0	0	5	7	1
Or23	0	0	1	2	1	7
Or24	0	0	0	5	3	10
Or25	0	0	0	1	1	3
Or26	0	0	0	0	0	5
Or27	0	0	1	11	7	31
Or28	0	0	0	2	0	4
Or29	0	1	0	4	7	7
Or30	0	0	0	2	6	10
Or31	0	0	0	2	0	21
Or32	1	1	0	0	3	5
Or33	0	0	1	0	0	4
Or34	2	0	0	9	4	15
Or35	0	0	0	Missing		

APPENDIX 21

Tick Counts of Treatment Group (Supona 0.06%, a.i., v/v)

	Day 13			Day 20		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
Or36	0	0	1	2	0	0
Or37	0	1	0	0	0	0
Or38	0	0	0	5	1	1
Or39	0	0	0	3	4	3
Or40	1	0	0	3	3	0
Or41	0	0	0	0	2	1
Or42	0	1	0	5	4	14
Or43	1	2	0	5	1	2
Or44	0	1	1	9	7	20
Or45	0	1	0	6	6	35
Or46	0	0	0	1	0	12
Or47	1	0	0	1	1	9
Or48	0	0	1	0	0	10
Or49	1	0	0	7	4	9
Or50	0	0	0	3	1	8
Or51	0	0	0	1	2	2
Or52	0	0	0	0	0	4
Or53	0	0	0	5	1	5
Or54	0	0	0	2	0	1
Or55	0	0	2	5	5	5
Or56	0	0	0	3	5	3
Or57	0	0	0	1	7	14
Or58	0	0	0	0	0	6
Or59	0	0	0	4	3	3
Or60	1	0	0	5	7	4
Or61	0	0	0	0	1	0
Or62	1	0	0	2	0	5
Or63	0	0	1	4	1	1
Or64	0	0	1	0	0	4
Or65	0	0	0	1	0	9
Or66	0	2	0	12	16	35
Or67	0	0	0	4	2	4
Or68	0	1	0	1	1	5
Or69	0	0	0	4	2	6
Or70	1	0	1	0	0	10
Total	12	14	15	200	172	471

APPENDIX 22

Tick Counts of Treatment Group (Supona 0.06%, a.i., v/v)

Tag Number	Day 27 (28.12.77) Left Ear	Right Ear	Body	Day 34 (4.1.78) Left Ear	Right Ear	Body
Or 1	0	0	2	0	0	4
Or 2	2	1	0	2	1	11
Or 3	7	2	3	10	3	10
Or 4	1	0	0	1	4	8
Or 5	1	0	3	6	13	7
Or 6	1	0	3	0	0	0
Or 7	2	3	0	4	2	4
Or 8	2	2	0	10	0	1
Or 9	2	0	0	3	0	3
Or10	6	Not dipped	18	4	Not dipped	16
Or11	3	4	2	0	1	5
Or12	1	0	4	2	0	7
Or13	0	1	6	0	3	1
Or14	1	1	3	2	0	12
Or15	6	5	2	33	8	16
Or16	1	2	4	13	5	10
Or17	1	1	0	3	0	2
Or18	Not dipped			Not dipped		
Or19	Not dipped			Not dipped		
Or20	0	0	2	0	5	0
Or21	0	1	4	Missing		
Or22	4	4	2	8	7	9
Or23	2	1	0	1	2	3
Or24	0	0	1	2	0	5
Or25	0	0	1	2	1	3
Or26	0	0	4	0	0	1
Or27	4	2	16	6	6	9
Or28	2	0	0	8	5	1
Or29	1	4	0	4	2	3
Or30	2	3	2	2	6	11
Or31	0	2	3	9	8	7
Or32	2	1	2	2	8	0
Or33	1	3	1	0	1	3
Or34	8	0	0	50	26	8
Or35	5	4	0	6	4	11

APPENDIX 23

Tick Counts of Treatment Group (Supona 0.06%, a.i., v/v)

	Day 27 (28.12.77)			Day 34 (4.1.78)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
Or36	1	1	2	2	3	4
Or37	1	0	0	0	0	1
Or38	5	3	4	4	6	2
Or39	1	1	1	3	2	1
Or40	1	7	3	30	14	10
Or41	2	2	1	5	9	7
Or42	2	0	2	2	2	4
Or43	3	4	1	7	4	13
Or44	1	3	11	0	0	14
Or45	11	10	1	12	11	12
Or46	1	1	2	0	2	12
Or47	0	0	0	3	1	17
Or48	1	2	1	0	3	6
Or49	4	5	8	15	12	11
Or50	0	0	4	0	0	8
Or51	3	0	1	1	2	6
Or52	0	0	0	1	0	3
Or53	1	1	0	4	2	1
Or54	1	0	3	1	0	1
Or55	0	3	11	2	6	17
Or56	1	0	0	2	5	6
Or57	0	0	4	0	0	3
Or58	2	0	8	3	0	14
Or59	2	4	0	2	7	4
Or60	3	9	4	8	12	10
Or61	0	1	0	0	1	3
Or62	1	1	3	1	1	5
Or63	4	1	1	3	1	7
Or64	1	1	4	2	3	8
Or65	0	0	8	1	2	13
Or66	9	15	9	13	22	16
Or67	5	2	2	7	4	2
Or68	1	0	1	0	0	3
Or69	2	1	1	2	0	10
Or70	0	2	3	7	1	11
Total	132	127	174	332	259	440

APPENDIX 24

Tick Counts of Control Groups

	Day 0 (1.12.77)			Day 7 (8.12.77)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
W 1	4	5	5	1	1	0
W 2	1	0	1	0	0	3
W 3	0	4	0	1	0	2
W 4	0	0	0	0	0	0
W 5	1	0	0	1	0	0
W 6	2	1	5	0	0	0
W 7	1	0	3	0	0	1
W 8	1	1	1	0	0	2
W 9	3	2	1	0	0	1
W10	0	0	0	2	0	0
W11	0	0	3	0	1	0
W12	2	1	2	0	1	0
W13	4	4	4	2	2	1
W14	2	0	0	Missing		
W15	6	3	6	0	1	1
W16	0	0	2	0	0	0
W17	0	1	0	0	0	0
W18	3	0	6	0	0	0
W19	1	2	1	1	1	1
W20	8	3	1	0	0	2
W21	1	0	1	0	0	0
W22	0	0	0	2	0	0
W23	0	0	6	0	0	0
W24	2	2	2	0	0	0
W25	3	2	1	0	0	1
W26	1	0	0	0	0	1
W27	2	8	2	0	0	0
W28	1	0	0	0	0	0
W29	0	1	0	0	1	0
W30	1	5	0	1	1	0
W31	2	1	8	0	0	2
W32	0	1	3	0	0	0
W33	0	0	0	0	0	0
W34	2	2	2	2	0	0
W35	0	0	1	0	0	0

APPENDIX 25

Tick Counts of Control Group

Tag Number	Day 0 (11.12.77) Left Ear	Right Ear	Body	Day 7 (8.12.77) Left Ear	Right Ear	Body
W36	0	1	0	0	0	5
W37	8	3	4	0	0	0
W38	3	1	2	0	0	1
W39	1	4	1	0	0	1
W40	2	1	0	1	0	0
W41	0	0	0	0	0	2
W42	0	0	1	0	0	0
W43	2	3	4	0	0	2
W44	1	1	1	0	0	3
W45	8	5	0	2	1	1
W46	1	0	0	0	0	0
W47	3	2	3	1	1	0
W48	1	0	0	1	0	0
W49	0	2	1	1	0	3
W50	3	10	9	0	3	1
W51	0	0	0	0	0	0
W52	0	0	0	0	0	0
W53	0	0	1	0	0	0
W54	0	0	0	0	0	0
W55	2	12	2	4	3	4
W56	1	2	0	0	0	0
W57	2	1	7	0	0	4
W58	3	1	0	0	0	1
W59	2	2	8	2	0	1
W60	0	0	1	2	1	0
W61	3	5	0	1	1	0
W62	0	1	0	0	0	0
W63	4	0	7	1	1	0
W64	2	2	14	1	0	0
W65	7	6	3	0	0	2
W66	4	4	1	2	2	0
W67	1	0	2	0	0	0
W68	6	5	2	Missing		
W69	0	1	2	0	0	0
W70	3	1	3	0	0	0

APPENDIX 26

Tick Counts of Control Group

	Day 0 (1.12.77)			Day 7 (8.12.77)		
Tag Number	Left Ear	Right Ear	Body	Left Ear	Right Ear	Body
W71	2	1	0	0	0	0
W72	3	0	1	0	0	0
W73	11	11	42	3	2	0
W74	2	5	3	0	0	2
W75	0	0	0	0	0	0
W76	0	1	0	0	0	0
W77	0	1	0	0	0	0
W78	0	0	2	1	1	1
W79	1	2	0	0	1	0
W80	0	1	3	0	0	0
W81	1	3	0	2	0	1
W82	1	3	0	0	0	0
W83	Missing			2	0	3
W84	2	1	4	0	0	4
W85	0	0	0	0	0	0
W86	0	4	0	0	0	0
W87	0	0	0	0	0	2
W88	1	1	2	0	0	0
W89	0	2	1	0	0	0
W90	0	3	1	0	0	1
W91	Missing			0	0	2
W92	3	0	0	0	0	0
W93	0	0	0	0	0	0
W94	1	0	0	0	0	0
W95	0	1	0	1	0	0
W96	0	0	0	0	0	0
W97	0	2	9	0	0	2
W98	1	0	0	0	0	2
W99	3	1	0	0	0	0
W100	3	1	0	0	0	0
Total	159	169	214	41	26	69

APPENDIX 27

Tick Counts of Control Group

Tag Number	Day 13 (14.12.77) Left Ear	Right Ear	Body	Day 20 (21.12.77) Left Ear	Right Ear	Body
W 1	1	1	1	30	30	34
W 2	1	0	0	3	1	20
W 3	2	0	2	0	0	26
W 4	0	0	0	2	0	2
W 5	0	0	0	11	6	16
W 6	1	0	1	3	1	17
W 7	0	0	0	3	1	27
W 8	0	0	1	3	5	33
W 9	0	0	2	0	3	27
W10	0	0	0	1	0	4
W11	0	0	0	3	4	28
W12	2	1	1	15	20	40
W13	2	2	2	5	9	21
W14	0	0	0	12	1	29
W15	0	0	2	15	18	71
W16	0	0	0	8	3	7
W17	0	1	0	3	0	7
W18	0	0	0	3	5	11
W19	1	1	3	21	18	23
W20	1	2	0	7	15	42
W21	0	0	0	5	5	25
W22	1	0	0	4	5	26
W23	0	0	0	2	1	48
W24	0	0	1	2	6	22
W25	0	1	2	17	9	29
W26	0	0	0	1	1	6
W27	1	0	1	2	1	31
W28	1	0	0	0	1	3
W29	1	2	0	3	6	13
W30	0	0	2	7	11	6
W31	0	2	0	30	12	22
W32	0	0	1	0	3	18
W33	0	0	0	1	4	8
W34	0	0	1	4	7	13
W35	0	0	0	9	6	13

APPENDIX 28

Tick Counts of Control Group

Tag Number	Day 13 (14.12.77) Left Ear	Right Ear	Body	Day 20 (21.12.77) Left Ear	Right Ear	Body
W36	0	0	0	23	3	51
W37	1	1	0	13	10	19
W38	0	0	0	2	9	33
W39	0	1	0	1	0	17
W40	1	0	0	2	3	46
W41	0	0	0	3	1	21
W42	0	0	1	1	0	15
W43	1	0	1	12	6	30
W44	0	0	2	5	1	17
W45	0	0	0	20	15	25
W46	0	0	1	10	7	35
W47	0	1	0	20	20	25
W48	0	0	0	0	0	45
W49	1	0	0	7	10	40
W50	1	1	0	7	13	48
W51	0	1	3	1	5	25
W52	0	0	0	1	2	18
W53	0	0	0	6	1	38
W54	0	0	0	6	3	19
W55	1	1	1	26	27	57
W56	1	0	0	6	5	15
W57	0	0	1	30	12	40
W58	1	0	1	2	7	11
W59	0	0	0	7	4	38
W60	0	0	0	2	3	6
W61	0	1	1	9	2	15
W62	0	1	0	2	2	13
W63	1	1	0	8	12	20
W64	0	0	1	8	3	14
W65	0	2	1	30	15	20
W66	1	0	0	23	20	40
W67	0	0	0	10	9	10
W68	Missing			Missing		
W69	0	0	0	1	2	25
W70	1	0	0	6	5	19

APPENDIX 29

Tick Counts of Control Group

Tag Number	Day 13 (14.12.77) Left Ear	Right Ear	Body	Day 20 (21.12.77) Left Ear	Right Ear	Body
W 71	0	0	0	2	0	17
W 72	0	1	0	3	8	15
W 73	1	0	1	23	28	78
W 74	1	0	1	18	11	22
W 75	0	0	0	0	0	11
W 76	1	0	0	1	1	1
W 77	0	0	2	9	7	20
W 78	0	0	0	5	3	16
W 79	0	0	1	12	10	23
W 80	0	0	0	1	0	17
W 81	0	0	0	16	10	22
W 82	1	0	2	6	4	32
W 83	Missing			9	4	31
W 84	0	0	1	8	9	48
W 85	Missing			0	1	15
W 86	1	0	0	11	15	13
W 87	0	0	1	0	2	6
W 88	0	0	1	1	0	37
W 89	0	0	0	1	1	30
W 90	1	0	0	6	0	20
W 91	0	1	2	9	7	47
W 92	0	0	1	7	5	16
W 93	1	0	0	8	0	14
W 94	0	0	1	5	3	11
W 95	0	0	0	6	8	10
W 96	0	0	1	6	11	67
W 97	0	2	2	19	15	70
W 98	1	0	1	4	3	30
W 99	0	0	1	4	2	38
W100	0	0	0	10	1	7
Total	34	28	56	755	624	2462

APPENDIX 30

Tick Counts of Control Group

Tag Number	Day 27 (28.12.77) Left Ear	Right Ear	Body	Day 34 (4.1.78) Left Ear	Right Ear	Body
W 1	13	6	14	13	11	13
W 2	2	4	10	1	0	10
W 3	3	2	7	2	0	15
W 4	0	2	9	0	0	6
W 5	2	1	9	5	9	10
W 6	3	2	4	5	1	10
W 7	3	0	9	2	2	15
W 8	7	3	8	5	1	12
W 9	2	1	6	6	2	12
W10	0	0	2	0	3	5
W11	6	6	23	15	21	12
W12	12	13	33	25	12	31
W13	16	7	8	15	5	7
W14	14	0	15	14	4	16
W15	2	3	32	6	2	6
W16	4	1	7	Missing		
W17	2	3	6	5	6	8
W18	6	2	5	12	4	4
W19	6	7	2	11	14	10
W20	Missing			1	3	10
W21	2	0	1	0	0	8
W22	7	1	2	3	0	15
W23	0	0	12	1	1	23
W24	1	6	44	1	4	11
W25	14	4	11	15	2	6
W26	1	1	0	1	3	6
W27	2	3	38	4	3	7
W28	0	1	2	4	0	2
W29	1	4	0	2	3	3
W30	Missing			8	11	6
W31	14	9	17	14	5	18
W32	3	3	6	3	2	8
W33	1	1	10	1	0	8
W34	11	9	8	24	6	13
W35	1	6	17	27	26	33

APPENDIX 31

Tick Counts of Control Group

Tag Number	Day 27 (28.12.77) Left Ear	Right Ear	Body	Day 34 (4.1.78) Left Ear	Right Ear	Body
W36	12	9	6	9	6	17
W37	Missing			13	8	5
W38	8	10	7	13	6	9
W39	2	3	22	13	2	16
W40	0	3	21	16	9	10
W41	1	1	4	1	3	5
W42	Missing			5	0	10
W43	0	1	6	6	4	17
W44	4	2	7	1	1	15
W45	27	30	7	17	25	17
W46	7	2	2	14	5	19
W47	4	3	27	17	11	36
W48	3	6	5	2	0	24
W49	3	3	4	3	6	17
W50	3	7	9	4	6	15
W51	1	4	9	1	1	3
W52	Missing			3	0	5
W53	0	0	17	1	0	16
W54	5	5	6	0	5	8
W55	19	21	17	10	7	7
W56	3	2	3	0	0	4
W57	17	7	23	6	3	20
W58	1	3	7	12	3	13
W59	5	3	21	7	1	17
W60	1	2	6	2	2	11
W61	1	2	6	5	4	18
W62	3	7	2	9	8	10
W63	6	3	2	6	3	5
W64	14	13	22	7	8	25
W65	19	8	20	16	13	12
W66	6	6	11	15	16	17
W67	4	1	7	3	5	8
W68	Missing			Missing		
W69	2	1	17	5	3	7
W70	10	9	0	Missing		

APPENDIX 32

Tick Counts of Control Group

Tag Number	Day 27 (28.12.77) Left Ear	Right Ear	Body	Day 34 (4.1.78) Left Ear	Right Ear	Body
W 71	0	0	3	0	0	12
W 72	4	3	1	0	5	6
W 73	32	27	83	35	40	46
W 74	10	14	35	3	7	14
W 75	0	0	0	1	1	2
W 76	1	2	3	0	0	8
W 77	3	1	7	4	0	2
W 78	5	1	23	2	0	9
W 79	4	12	20	23	28	9
W 80	0	2	0	3	0	5
W 81	10	4	7	17	7	21
W 82	3	17	13	3	12	13
W 83	1	1	28	0	0	4
W 84	5	5	22	8	8	27
W 85	2	3	8	4	4	9
W 86	2	4	5	2	6	24
W 87	0	1	14	2	0	2
W 88	0	0	14	0	1	3
W 89	0	1	2	0	0	10
W 90	1	1	9	3	5	9
W 91	2	1	9	4	0	11
W 92	Missing			15	9	5
W 93	0	1	6	7	1	2
W 94	0	0	12	2	1	11
W 95	10	5	4	6	2	2
W 96	Missing			9	16	31
W 97	6	13	27	Missing		
W 98	0	0	5	0	1	5
W 99	3	3	6	12	5	4
W100	5	0	6	16	0	7
Total	461	410	1072	674	493	1130

Appendix 33

Anaemia and deaths in Red Deer (Cervus elaphus) associated with heavy infestations of Haemaphysalis longicornis.

33.1 Introduction.

Deer shot in the Whakatane River Valley area East of Whakatane in the North Island of New Zealand have been reported as carrying heavy infestations of H. longicornis (Newbold, 1963). The author stated that 3 species of Cervidae, Sambar (C. unicolor), Rusa (C. timoriensis) and Red Deer were plentiful in the area and by inference it is assumed all 3 species of deer carried ticks. The same article indicated that the deer, despite carrying large numbers of ticks, were in good condition. It has also been suggested that more than 50 ticks per velvet antler did not appear to alter the general condition of Red Deer although haemoglobin concentrations were observed to be in a lower range (9.6 - 14.0 g/dl) than normal (12.4 - 19.0 g/dl) (Wilson, 1979).

33.2 History.

On a 30 hectare deer farm in the Wairoa County, 3 young fawns died 5 days after the onset of calving in December 1979. These deaths were not investigated. During the next 8 to 15 days, 30 fawns, 3 mature hinds and one stag died. Some of these animals were examined and all had heavy infestations of H. longicornis. No necropsies were performed but based on the anaemia observed clinically, it was assumed that deaths were from blood loss caused by the ticks (D.H. Mossman, pers. comm.)

Two fawns that had died 15 days after birth were examined by myself the day after death. These fawns had been stored in a deep freeze so necropsies were not performed and no samples were collected for histopathology.

Ticks were still attached to the animals and there were approximately 160 adult ticks per ear. Based on sheep counts this could represent about 800 ticks per animal. At this visit, blood samples were collected from 4 live fawns.

33.3 Findings.

The dead fawns all showed signs of anaemia viz. white mucous membranes of the mouths and conjunctivae. The result of haematological examination of blood samples from the 4 fawns is shown in Table 10.1. For comparison the "normal range" of blood values for Red Deer is shown in Table 33.2.

Table 33.1

Haematological examination of 4 fawns.

	Fawn 1	Fawn 2	Fawn 3	Fawn 4
Haemoglobin g/dl	5.4	5.7	5.8	15.0
Erythrocytes $X10^{12}/l$	3.72	3.33	3.15	8.43
Haeatocrit l/l	0.18	0.16	0.18	0.41
M.C.H.C. g/dl	30.0	35.6	35.2	36.5
M.C.V. fl	48.4	48.0	57.0	48.6
M.C.H. pg	14.5	17.1	18.4	17.8

On clinical examination Fawn 4 appeared heavier than the others with normal colour of the mucous membranes. These animals had been treated with coumaphos so it was not possible to relate tick counts to the haematology.

Table 33.2

Normal values for cellular consituents of Red Deer.

	Chapman (1977)		McAllum (pers. comm.)	
	Mean	Range	Mean	S.E.
Haemoglobin g/dl	16.2	12.4 - 20.6	17.12	± 0.14
Erythrocytes x 10^{12}/l	11.3	7.1 - 16.5	-	-
Haematocrit l/l	0.45	0.33 - 0.55	0.477	± 0.004
M.C.H.C. g/dl	36		36.11	± 0.37
M.C.V. fl	40		-	
M.C.H. pg	14		-	
Age	1 m - 2 yr old		9 m - 18 m	
Number of samples	160		110	

33.4 Discussion.

The anaemia observed was macrocytic. Most macrocytic anaemias are transitory; they are commonly seen in animals recovering from an acute blood loss. It is said to reflect an active phase of erythrocyte regeneration (Coles, 1967).

As necropsies were not performed on any of the dead animals the possible role of other agents must remain uncertain. However, in view of the young age of the animals, intestinal parasitism as a cause of the anaemia, can be ruled out. The deaths coincided with the approximate peak of adult tick numbers for the district. Although the evidence is only circumstantial, it seems likely that ticks were the major, if not the sole cause of the deaths of the deer calves and perhaps of the adults.

The financial loss from the deaths was estimated, on the basis of prices paid for deer in 1979, to be $28,000.

The deer farm in question had been operating for 6 years. The manager had deliberately kept the property under-stocked so that hay and/or concentrates were not required for supplementary feeding of the deer during the winter. Over the previous 6 years, ticks had been seen on deer but only in low numbers. The pasture had never been grazed heavily by cattle or sheep.

It is possible that tick numbers had increased on the farm because of insufficient grazing pressure. The blackberry and long pasture present provided ideal conditions for tick survival. Red Deer and other stock grazing immediately adjacent to the farm in question were reported to be carrying only low numbers of ticks. On this adjacent area, pasture was much shorter.

There are deer farms in other areas of the North Island on New Zealand where conditions are suitable for tick survival. It would be prudent to ensure that pastures are grazed adequately to make conditions less suitable for tick survival so that tick numbers do not build up. Peak adult tick activity coincides with calving when animals are usually left unsupervised and it is difficult to handle and treat animals at this time.

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