Studies of the sheep tick, Ixodes ricinus, in S.W.Scotland

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by

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CONTENTS

SUMMARY

The seasonal activity of the tick, Ixodes ricinus, in S.W. Scotland was studied by sampling by blanket dragging in two adjacent habitats, an area of rough grazing pasture and a coniferous woodland. Most ticks, particularly nymphs, were found in the wood which shows the importance of vegetational cover in the distribution of I. ricinus. Adult ticks were found in low numbers at both sites. A spring peak of activity from May to July was observed for nymphs and larvae. Weather conditions were found to influence tick activity.

Small mammals were trapped and examined for ticks from March to December in a coniferous plantation. Wood mice and bank voles were infested with I. ricinus and I. trianguliceps larvae which comprised 82% and 13% respectively of the ticks found. Nymphs of both species were also found. I. ricinus larvae were found from April to November the peak of infestation being in late June and early July with a smaller peak in September. Most ticks were found on the head, especially the ears.

An outdoor insectary was used to study the life cycle of I. ricinus by observing the times taken for the pre-oviposition, egg development, larval and nymphal development periods. The insectary allowed maximum accessibility to observe tick development with little

disturbance to the ticks. Larvae and nymphs feeding by June developed into the next stage by autumn of the same year while those feeding from July onwards entered developmental diapause and completed development the following year. Female ticks feeding between April and June produced eggs which developed into larvae in autumn of the same year. The observed development times were compared with predicted times from a computer prediction model, the most accurate predictions were for pre-oviposition and egg development times.

Dry and wet heat extractions were used with similar success to recover ticks (I. ricinus) from turves artificially infested with ticks. Adult male ticks were most efficiently extracted (61% success). Nymphs and adult females were extracted with less success (32% and 21% recovery respectively). Neither method is thought to be practical for assessment of tick populations.

Tick control trials were carried out to assess and compare the efficacies of various insecticidal preparations containing synthetic pyrethroids to control I. ricinus on sheep. Dip and pour-on formulations, containing cypermethrin, gave good control of ticks for at least 8 weeks post-treatment. A deltamethrin pour-on was the least effective of the treatments used.

The literature review covered aspects of the biology of *I. ricinus* including; environmental factors influencing tick distribution, hosts, tick behaviour and physiology, and disease aspects of tick infestation especially of livestock.

CHAPTER 1

Seasonal Activity of the Sheep Tick, Ixodes ricinus on Farm and Woodland Habitats in Ayrshire

INTRODUCTION

The annual cycle of activity of the sheep tick, Ixodes ricinus, has been studied in various parts of the British Isles. Most of the studies have been carried out on hill farm or rough pasture situations. Different patterns of tick activity have been found by various people in different areas of Britain. It has mostly been found that tick activity throughout the year has two peaks, the larger peak occurring in spring, April to late May or early June, followed by a lower peak of activity from September to October. During the summer there was a low level of activity, with almost no activity during the winter months (Macleod, 1939b) Greater activity in spring compared to autumn was found to be the case by Macleod (1932), Evans (1951a) and Barnett (1965). Edwards and Arthur (1947) found that although biannual activity was found in S. Wales, in mid-Wales only a single summer peak of activity occurred.

A single annual peak was found to occur in N.E. Northumberland and in the Ettrick valley of S. Scotland (Hendrick et al, 1938). Hendrick et al (1938) concluded from observations on shot deer and on sheep in N.E.

Scotland that tick activity was continuous throughout the year with the seasonal incidence being greater in summer and lowest in winter.

This study compares the tick populations of 2 different types of habitat in adjacent sites, these being rough pasture grazed by livestock and coniferous woodland from which domestic livestock had been excluded. Only one other similar study has been made in the U.K. by Barnett (1965) who compared the tick activity on rough pasture and coppice, to that in a pine forest plantation. Several continental studies have looked at the life cycle and development of I. ricinus in forest habitats. (Daniel et al, 1976, Daniel et al, 1977).

MATERIALS AND METHODS

The following sites were selected for the study of seasonal activity because previous observations by Moore (1984) had shown them to be infested with sheep ticks:

Site 1. Chapelton Wood, Kilkerran Estate, Ayrshire
Grid ref: NS 318032

The site consisted of coniferous woodland with various tracks leading through it (Plate 1.1). The wood was surrounded mainly by scrub land with rough grasses, young conifers and brambles. Roe deer, hares and pheasants were present in and around the woods. Cattle and sheep were

excluded from the area by stone walls. Vegetation was sampled along the edge of the tracks and consisted of bents, Agrostis spp; heather, Calluna vulgaris , rushes, Juncus spp; and bracken Pteridium aquilinum . The soil pH was found to be approximately 5.5. Tick sampling was carried out from April to December, 1984 and from February to December, 1985.

Site 2. Barony Hill, Kilkerran Estate, Ayrshire
Grid ref: NS 304022

This site was a large field on a gently sloping hillside with a N.W. aspect (Plate 1.2). The field was grazed by Blackface sheep for most of the year with some cattle during the summer months. The lower part of the field was bounded by mixed mature woodland and was poorly drained whereas the upper part of the field tended to be better drained and stock preferred to graze here. Vegetation consisted of rough grasses including bents, Agrostis spp; rushes, Juncus spp; and bracken, Pteridium aquilinium . The soil pH was found to be approximately pH 5.5. Tick sampling was carried out from April to November, 1984 and from February to November, 1985.

Blanket dragging was the sampling method used at each of the sites. A white wool blanket measuring 1.85m x 0.85m was attached to a length of wood along the leading edge, to which a length of cord was attached at each end. The trailing edge was weighed down by 2 pieces of wood along

its length. The blanket was dragged for 25m at a slow walking pace and then the upper side checked for ticks before turning up the underside for examination. 20 x 25m blanket drags were carried out in succession at site 1 and in pairs at site 2, between 1100 and 1500 hours. At site 1, temperature and humidity were recorded using a thermohygrograph. Additional meteorological data were obtained from the nearest meteorological station to the sites, 25 miles away, at Cumnock in Ayrshire.

RESULTS

Site 1 Chapelton Wood, Kilkerran.

Tick activity for all stages during 1984 is shown in Fig.1.1. When sampling began in April 1984 tick activity was already well established for nymphs and adults. Numbers of nymphs peaked on 10th. May and then dropped until 28th. June from which there were continuous, though erratic, nymphal counts gradually decreasing until 8th. November. Adult activity tended to be fairly constant from April to October during 1984 although peaks were evident around 16th. May and 1st. August. Larval activity began on 9th. May in 1984 and peaked around the end of May/beginning of June. Few larvae were found between 13th. June and 15th. August although there was a late summer peak on 22nd. August followed by larval activity at a lower level until the end of September.

Tick activity for all stages in 1985 is shown in Fig.1.3. Sampling began in February 1985 and very low levels of nymphal and adult activity occurred until the beginning of April. Nymphal counts tended to increase from April, peaked in mid-May and gradually decreased until mid-June. A second peak of nymphal activity occurred in early July and from late July numbers were erratic but tended to decrease until early November. Occasional nymphs were still being found in December. Adult numbers in 1985 were more constant though they tended to be lower than in 1984 with adult activity being observed from February to December, the greatest numbers being found in early July. Larval activity commenced in mid May, peaked in early June and again in early July with low levels of larvae occurring until the end of October. All sampling and weather data are shown in Tables I and III.

Site 2 Barony Hill, Kilkerran

Tick activity for all stages during 1984 is shown in Fig.1.2. In 1984 the highest nymphal count obtained at site 2 was on the 1st day of sampling i.e. 12th. April, the next peak occurring in mid May with a gradual though uneven decline in activity until the end of September when activity ceased. During 1984 adults were caught on 2 occasions. Larval activity began in early May, peaked in early June and declined to zero by early July followed by a very small peak in mid September with no larvae being found between mid July and mid September.

Tick activity for all stages in 1985 is shown in Fig.1.4. Nymphal activity was first observed in late March with the spring peak occurring in mid April with numbers remaining high until mid June. This was followed by low activity from the end of June until the beginning of September. Adult activity began and peaked in early April with a lesser peak in early July after which there was no more adult activity. The numbers of adults were much higher in 1985 compared to 1984. Larval activity began in early May, peaked in mid May with numbers falling dramatically by mid June. There was low continuous larval activity from mid June until the end of August which was followed by a smaller peak in early September with some larval activity continuing until the end of October. All sampling and weather data are shown in Tables II and IV.

Seasonal Activity and Weather Conditions

A Comart computer was used in conjunction with a MINITAB programme to analyse the relationship between tick activity and weather conditions. The weather conditions which were used to compare statistically with active tick numbers were: mean weekly maximum air temperature, maximum air temperature on day of sampling, total weekly rainfall and hours of sunshine on day of sampling.* Meteorological data were obtained from the meteorological station at Cumnock, Ayrshire

Tick activity correlated more significantly with weather conditions when the results were statistically analysed on

* Tables V - VIII give the results of correlation analysis.

the basis of activity during February to May and during June to December than when the activity results were analysed for the whole year.

The hours of sunshine on the day of sampling were found to correlate significantly with the activity of larvae and nymphs at both sites 1 and 2. The total weekly rainfall was not found to correlate significantly with any tick activity. For 1984, all stages i.e. adults, nymphs and larvae, from June to December were found to correlate significantly with the daily maximum air temperature and the daily hours of sunshine. Both adult and nymphal activity correlated significantly with the mean weekly maximum air temperature and similar relationships were found between June and December of 1985. During February to May of 1985, at both sites, mean weekly maximum air temperature was found to correlate with larval activity and with nymphal activity at site 1.

DISCUSSION

The two phase curve of activity generally expected for I.ricinus in the British Isles was not found in this study in S.W. Scotland. Adult ticks tended to be found in small numbers from May to August and because numbers were low, peaks in adult activity were not evident. Nymphal numbers were highest between May and July and there was little evidence to suggest an increase in numbers in the

autumn. Larvae tended to show 2 peaks of activity, these occurring between May and July, the main period of larval activity, and around September to October.

In comparing the woodland and rough grazing sites most ticks, particularly nymphal stages, were found in the wood. Fewer nymphs and adult ticks were found on the rough pasture field. Nymphal activity remained higher for longer periods in the wood than in the field. Nymphal numbers dropped in the field from June onwards whereas in the wood, numbers remained high until August. The influence of different habitats on tick populations was studied by Barnett (1965) who compared tick populations on rough, poorly drained pasture and coppice, with populations in a pine forest plantation, both sites being free from domestic livestock. He observed the activity peak persisted longer in the forest ticks, this being most marked in the nymphal stages. He also found larger numbers of larvae in the forest compared to the rough pasture.

In the present study the wood had a much higher population of ticks than the field as judged by nymphal numbers caught by blanket dragging. Tick populations have been found to be denser on a pasture the more even the distribution of adequate cover. This is probably due to the fact that the tick cannot move far once it has dropped from the host therefore the more uniform the distribution of dense cover the more likely the tick is to survive and

develop (Milne, 1950). The wood is more sheltered, shaded and less likely to dry out than the field therefore the chances of survival are greater in the wood, thus leading to the higher numbers being found there.

Assuming there is adequate cover in the wood, the limiting factor to the tick population may be the number of available hosts. It was found from the trapping study (Chapter 2) that small mammals i.e. bank voles and wood mice, were abundant in the wood but fewer larger animals had access other than roe deer, hares and birds. The field was grazed by Blackface sheep throughout the year plus wild animals and birds. Since the host potential of the field would seem to be as high or higher than the wood, the tick populations here are unlikely to be restricted by lack of hosts. Thus ground cover would seem to be the important factor. The pasture would be more likely to dry out during a hot summer and also be more exposed to frost, sun and wind.

Weather conditions influenced the tick population at site 1, the woodland site, more than at the other site in that the numbers of active ticks correlated with air temperature and sunshine more consistently. Ticks found on grazings may be subject to more disturbances e.g. grazing animals, wind, sun, than ticks found within the sheltered wood.

Correlations between air temperature and tick activity may be explained by results from a study of geotropic responses made by Macleod (1935). He showed that temperature determines how the tick responds to gravity, the tick being negatively geotropic at temperatures between 14 degrees C and 24 degrees C, but above and below these temperatures the tick response is geotropically positive. Since the geotropic response of the tick is altered by changes in temperature, the temperature will determine where in the vegetation the tick is likely to be found i.e. between the limits of temperature where the geotropic response is negative it would be expected that ticks would be found at the tips of vegetation. There, the ticks are more likely to be picked up by a host than if they are lower in the vegetation.

Milne (1945a) found that blanket dragging on consecutive days and nights indicated that fewer ticks are active by night than by day and this fluctuation seems to closely follow the diurnal fluctuation in atmospheric temperature. Temperature fluctuations may be of importance in rousing the tick from quiescence at the base of roots and in the mat layer thus initiating a phase of activity.

Macleod (1936b) claimed to show that infestation of sheep only occurred when the mean maximum air temperature lay between 7 degrees C and 16 degrees C. Gray et al (1978) studied tick activity in County Wicklow, Ireland and concluded that since Macleod's upper limit of 16 degrees C

was not reached until after the spring activity had ceased and the adult autumn peak occurred when the average weekly maximum air temperatures were well above 16 degrees C, seasonal activity must be controlled by factors other than air temperature as suggested by Macleod. Gray et al (1978) were also of the opinion that weather would seem to have little effect on active ticks once the temperature threshold of around 7 degrees C has been reached. He found the current air temperature threshold to vary depending on the sampling method, this being 7 degrees C for ticks on sheep and 10 degrees C on blankets.

The most important point to emerge from this study was the greater tick population of the woodland habitat when compared with adjacent rough grazing land. Often, well-grazed pastures on hill and upland farms may be bordered by areas of land which are ideal tick habitats e.g. bracken or copse, thus providing a source of infestation for grazing stock. Forestry plantations, though usually fenced, may also act as a reservoir for tick infestation. Sheep straying into such areas may avoid chemical treatment for tick control and thus may help to maintain the tick population of the rough grazing.

Plate 1.1. Blanket dragging at Chapelton Wood, Kilkerran.

Plate 1.2. Blanket dragging at Barony Hill, Kilkerran.

Fig.1.1.

NUMBERS OF TICKS RECOVERED BY BLANKET DRAGGING AT CHAPELTON WOOD, KILKERRAN DURING 1984.

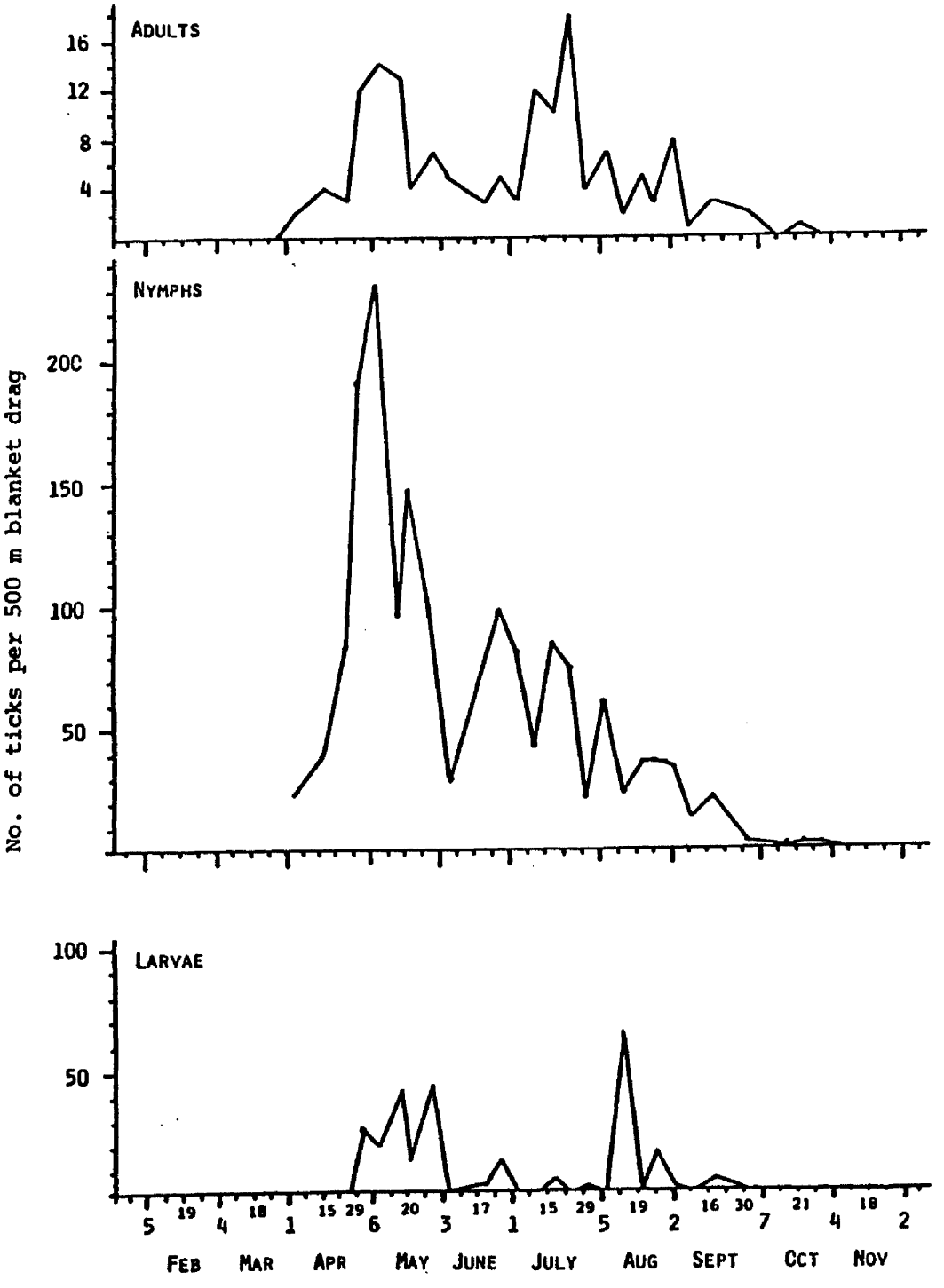


Fig.1.2.

NUMBERS OF TICKS RECOVERED BY BLANKET DRAGGING AT BARONY HILL, KILKERRAN DURING 1984.

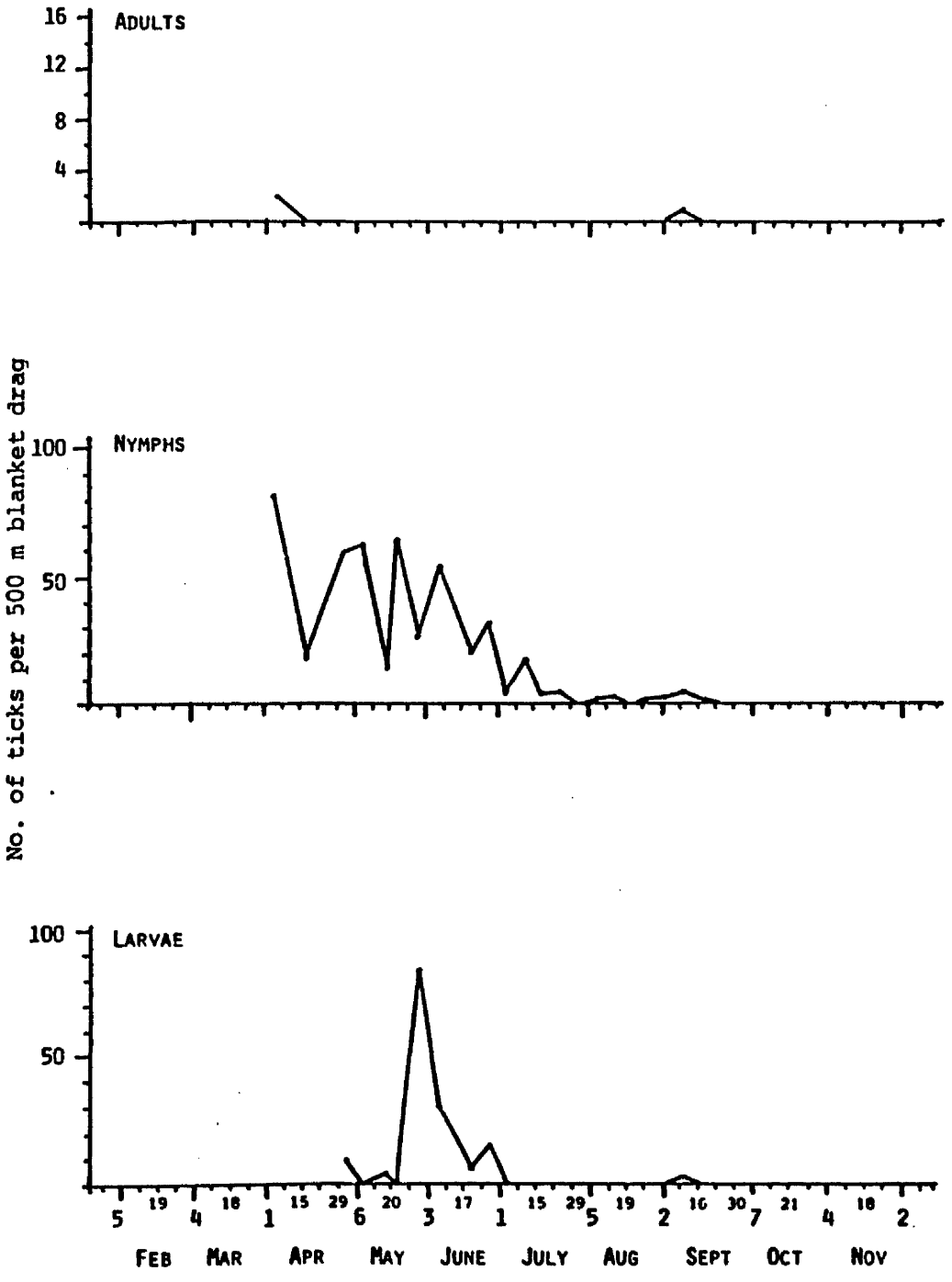


Fig.1.3.

NUMBERS OF TICKS RECOVERED BY BLANKET DRAGGING AT CHAPELTON WOOD, KILKERRAN DURING 1985.

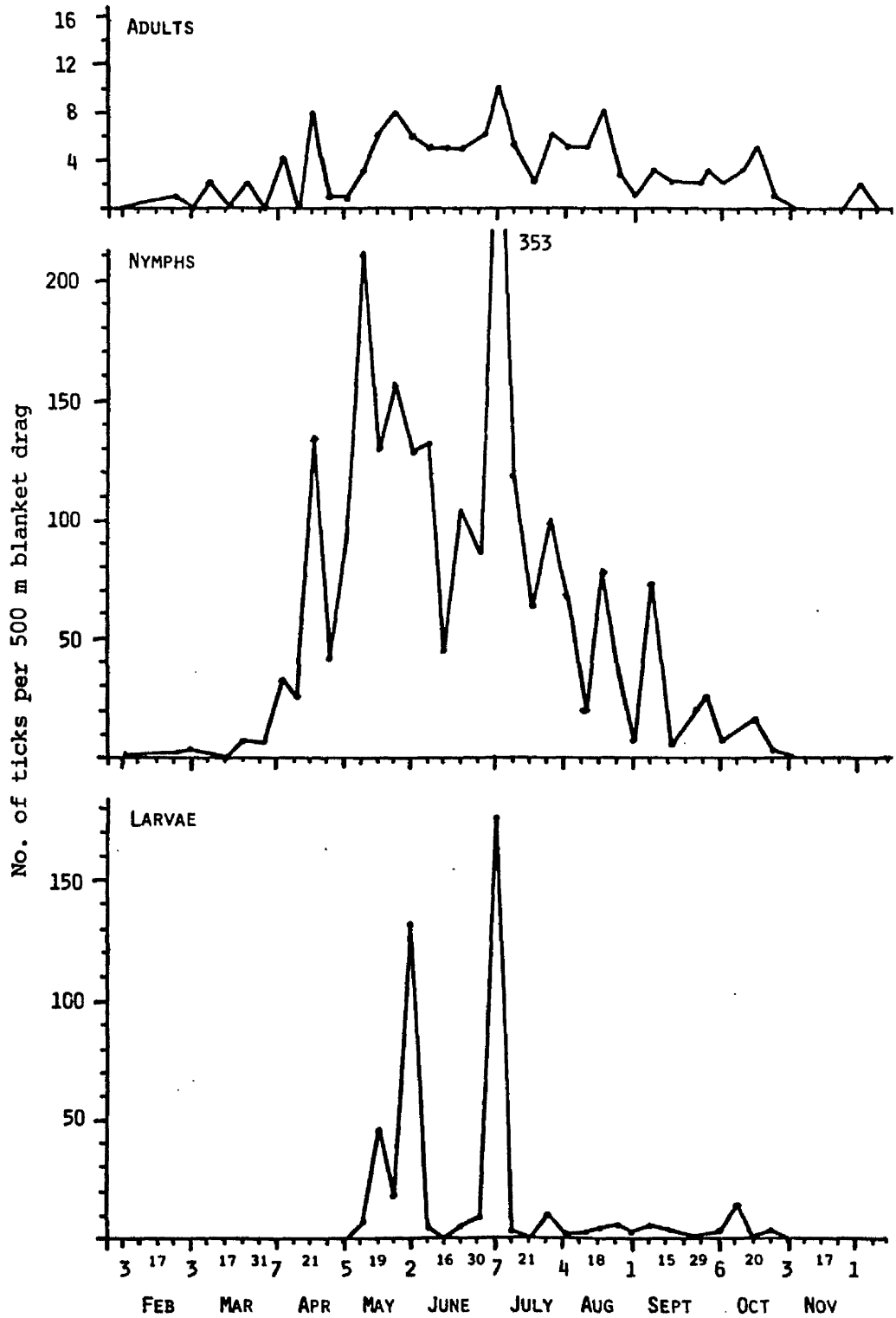
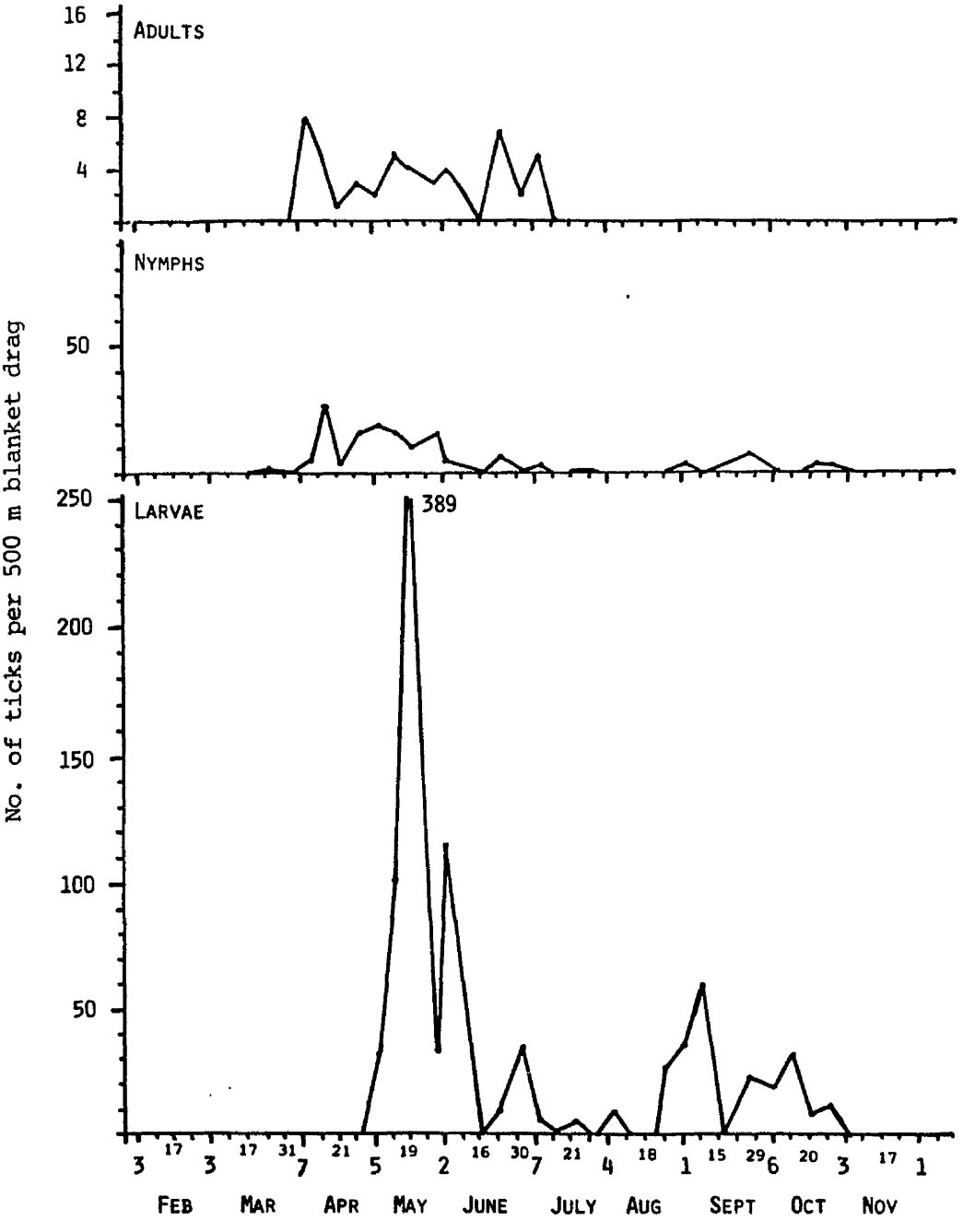


Fig.1.4.

NUMBERS OF TICKS RECOVERED BY BLANKET DRAGGING AT BARONY HILL, KILKERRAN DURING 1985.



CHAPTER 2

The Seasonal Infestation of Small Mammals with Ticks in Ayrshire

INTRODUCTION

There have been many studies in the British Isles of the seasonal activity of Ixodes ricinus on rough pasture where the main emphasis has been on the relationship between tick populations and tick-borne diseases in sheep and cattle. In contrast continental studies have concentrated on woodland habitats and the transmission of arboviruses to humans (Gresikova, 1974). The transmission of disease to man by I. ricinus from scrub and woodland habitats has recently become important in relation to Lyme disease in the United Kingdom and Eire (Muhlemann & Wright, 1987).

In U.S.A., in areas endemic for Lyme disease, small mammals are an important reservoir for one of the causal organisms of the disease, the spirochaete, Borrelia burgdorferi (Donahue et al, 1987). There is limited information on the tick infestations of small mammals in the U.K. Randolph (1975a) studied Ixodes trianguliceps infestations on small mammals in the south of England but only a brief reference was made to Ixodes ricinus. Langley and Fairley (1982) studied the parasitic infestations of a wood mouse, Apodemus sylvaticus, population in the West of Ireland and the parasites found included I. ricinus larvae.

Milne (1948b) studied the tick infestations of the wild fauna on a hill sheep farm, consisting mainly of rough grazing, in Northumberland. Included in the animals examined were a small number of shrews, Sorex araneus, voles, Microtis agrestis, and wood mice, Apodemus sylvaticus, which were found to be infested with larval I. ricinus.

The present study is the first study that has looked at the role of small mammals in the lifecycle of I. ricinus in a woodland habitat.

MATERIALS AND METHODS

The study site was a coniferous woodland at Chapelton Wood Kilkerran Estate, Ayrshire, Scotland (Nat. Grid Ref. NS 320 030). The woodland was traversed by tracks frequented daily by roe and some red deer. Domestic livestock were excluded from the woodland by a surrounding wall. The vegetation on the tracks consisted mainly of rough grasses, heather and moss with some bracken.

Trapping was carried out from March to December 1985. Traps were placed on the ground at the margins of the tracks at the edge of the tree plantations. A total of ten Longworth and ten Trip-traps were used. The nest box of each trap was loosely filled with straw for bedding and several pellets of commercial mouse food. Some pellets of food were scattered close to the trap as an attractant.

Traps were out for two to three nights depending on the number of small mammals caught on the first and second nights. Periods of trapping were at three or four week intervals.

The traps were emptied into a large plastic bag and the animal euthanased using a pad of cotton wool soaked in diethyl ether. The animals were returned to the laboratory for examination. The position of any ticks on the host animals were recorded after which the ticks were carefully removed using forceps and placed in glass tubes containing 70% alcohol. Ticks were examined under a binocular dissecting microscope and identified by means of a key (Arthur, 1963).

RESULTS

A total of 69 small mammals were trapped and examined for ticks. All results are recorded in Table IX in the Appendix. There were 57 wood mice, Apodemus sylvaticus, (Linnaeus), 11 bank voles, Clethrionomys glareolus (Schreber), and 1 common shrew, Sorex araneus (Linnaeus). Fig.2.1. and Table 2.1. summarise the results of the tick stages found on the small mammals. The most prevalent tick instar was I. ricinus larva, 82% of the ticks recorded. Nymphs of I. ricinus were much less prevalent and comprised 4% of the ticks recorded. No adult I. ricinus were present. Small mammals in this study were also infected with I. trianguliceps of which the larvae

and nymphs made up 13% and 1% respectively of the total ticks recorded.

Tables 2.2. and 2.3. show when tick larvae were found infesting the small mammals. I. ricinus larvae were found from mid April to mid November. Peak infestation occurred in late June/early July with another smaller peak occurring in September. I. trianguliceps had two periods of feeding activity, one in June to July and the main feeding period from late August to November.

Both I. ricinus and I. trianguliceps larvae were found to have preferential feeding sites on small mammals (Tables 2.4 & 2.5). Highest numbers of I. ricinus larvae were found on the ears, with appreciable numbers on the face, tail and feet. I. trianguliceps were found exclusively on the face.

In the present study the wood mouse had a slightly higher tick burden, with a mean of 2.47 I. ricinus larvae per individual. The difference was not statistically significant (Appendix Table X). There was a statistically significant difference between the numbers of I. ricinus larvae and I. trianguliceps larvae found on the wood mice ($P<0.01$). The single shrew was not infested with ticks.

DISCUSSION

In previous studies by Moore (1984), from the same study site, only tick larvae were recorded from small mammals. In other studies only I. ricinus larvae were recorded on bank voles in France by Chatelain et al (1979) and from wood mouse populations in the West of Ireland (Langley and Fairley,1982). Mermod et al (1973), however reported finding nymphs of I. ricinus on small mammals collected in the Staatswald Forest in Switzerland. As in the present study nymphs were present in much smaller numbers than larvae, the proportion varying from 2 to 12% of the monthly catch.

Arthur (1963) regarded the feeding activity by I. ricinus as being biannual, most feeding on hosts between March and May or August and October. In the present study, as in that of Langley and Fairley (1982), ticks showed feeding activity over the summer months. There was, however, a maximum peak of feeding activity at the end of June with a much smaller peak of activity observed in mid-September (Fig.2.1). In the Staatswald Forest, tick activity peaked slightly earlier in June with a second smaller peak in August (Mermod et al, 1973).

Randolph (1975a) collected small mammals from woodland in Southern England and also found the feeding activity of I. trianguliceps larvae to be bimodal with the major peak occurring in the autumn with a minor peak in June and

July.

Results from the study by Moore (1984) found considerably more I. ricinus larvae on the wood mouse when compared with the bank vole although the sample size was very small. Nilsson and Lundqvist (1978) also found the wood mouse to carry considerably more ticks than the bank vole. In laboratory studies the wood mouse had a higher acceptance level of ticks with 53% of introduced I. ricinus larvae becoming engorged compared with only 8% becoming engorged on the bank vole. Observations of ticks in the fur showed a larger proportion to have directed and faster movements towards the predilection places on the head of the wood mouse as compared with the bank vole. It was suggested that differences in the distribution of ticks did not necessarily depend exclusively on the deticking ability of the host and that the different stimuli for ticks to move and settle in predilection sites were important. Randolph (1975b) considered, whilst the question of deticking requires careful investigation on the basis of the field evidence it was not an important factor determining differential infestation levels of this tick on various host species.

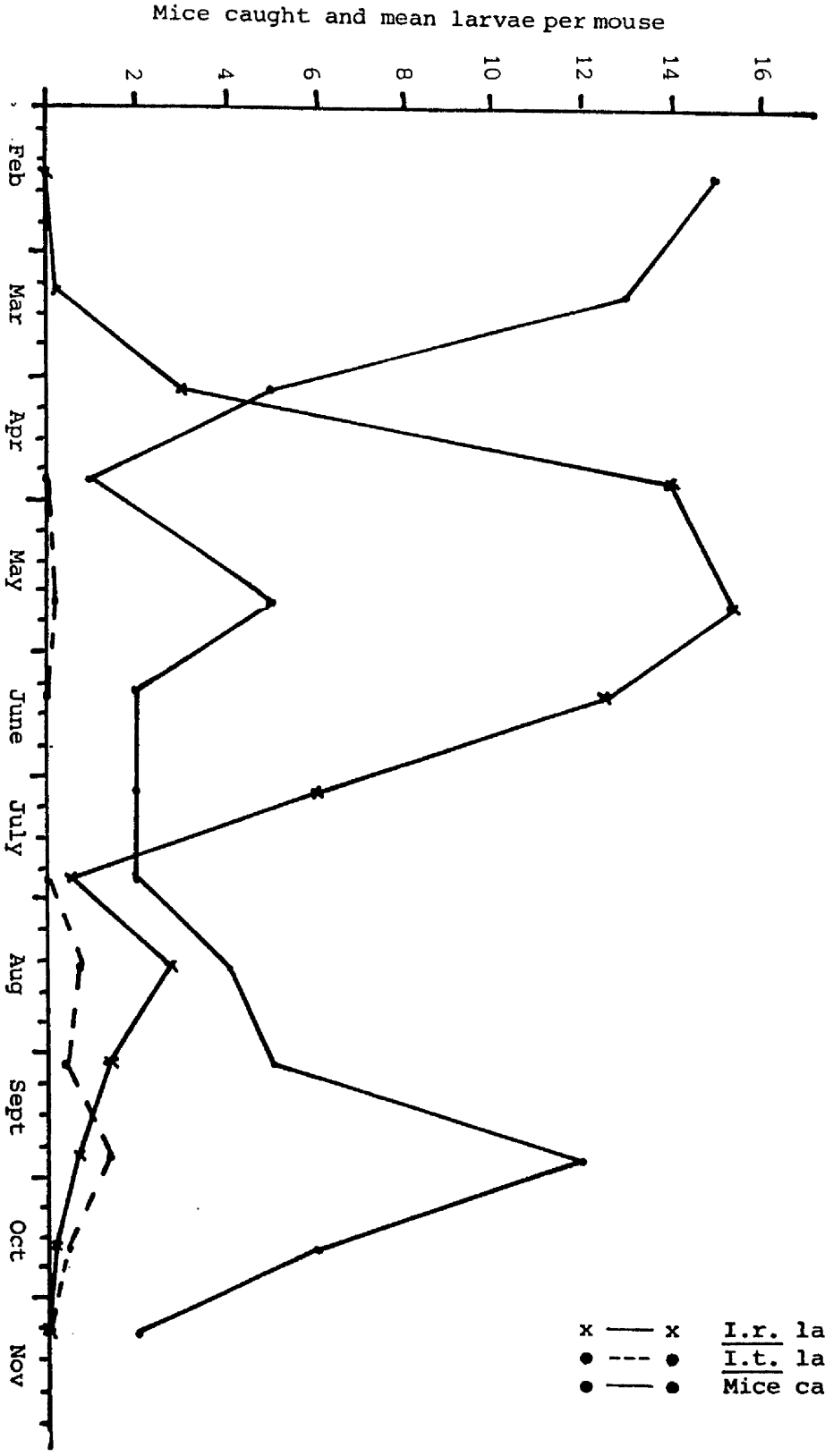


Fig.2.1.

Tick Larvae Recovered from Mice Caught at Chapelton Wood, Kilkerran during 1985

Table 2.1.

SUMMARY OF THE TICK INFESTATION ON SMALL MAMMALS.

Host	Total Nos. of Hosts Caught	*I. ricinus* Larvae	*I. ricinus* Nymphs
A. sylvaticus	57	2.49 ± 4.71	0.12 ± 0.38
C. glareolus	12	2.25 ± 7.17	0

		I. trianguliceps Larvae	*I. trianguliceps* Nymphs
A. sylvaticus	57	0.40 ± 0.75	0
C. glareolus	12	0.33 ± 0.89	0.17 ± 0.39

Mean numbers and standard deviations for each tick stage found on each host species.

(Standard deviation means little due to the non-normal distribution of the tick infestations.)

Table 2.2.

TICK LARVAE FOUND INFESTING THE WOOD MOUSE, A. SYLVATICUS IN 1985.

	I. ricinus					I. trianguliceps			
Date	No. of Hosts	No. of Infested Hosts	No. of larvae	* x	* s.d.	No. of Infested Hosts	No. of larvae	* x	* s.d.
20-21.3.85	12	0	0	0	0	0	0	0	0
16-17.4.85	8	3	4	0.5	0.8	0	0	0	0
8- 9.5.85	5	5	15	3	1.2	0	0	0	0
29.5.85	1	1	14	14	-	0	0	0	-
25-26.6.85	4	4	52	13	6.4	0	0	0	0
16-17.7.85	2	2	25	12.5	10.6	0	0	0	0
8.8.85	1	1	6	6	-	0	0	0	-
27.8.85	1	0	0	0	-	0	0	0	-
16-17.9.85	3	2	11	3.7	3.2	0	0	0	0
8-10.10.85	4	4	6	1.5	0.6	2	3	0.8	1
29.10. - 1.11.85	12	5	8	0.7	0.9	10	17	1.4	0.8
19-22.11.85	4	1	1	0.25	0.5	2	3	0.8	1

* x, s.d. for all animals trapped.

Table 2.3.

TICK LARVAE FOUND INFESTING THE BANK VOLE, C. GLAREOLUS IN 1985.

		I. ricinus				I. trianguliceps			
Date	No. of Hosts	No. of Infested Hosts	No. of larvae	* x	* s.d.	No. of Infested Hosts	No. of larvae	* x	* s.d.
21.3.85	1	0	0	0	-	0	0	0	-
16.4.85	3	0	0	0	0	0	0	0	0
25.6.85	1	1	25	25	-	1	1	1	-
27.8.85	1	1	1	1	-	0	0	0	-
18.9.85	1	0	0	0	-	1	3	3	-
9.10.85	1	1	1	1	-	0	0	0	-
22.11.85	2	0	0	0	0	0	0	0	0
10-11.12.85	2	0	0	0	-	0	0	0	-

* x, s.d. for all animals trapped.

Table 2.4.

TICK INFESTATION ON BODY REGIONS OF THE WOOD MOUSE, A. SYLVATICUS.

Body Regions	LARVAE		NYMPHS		Total each region
	I. ricinus	I. trianguliceps	I. ricinus	I. trianguliceps	
Ears	63	19	3	0	85
Head	41	0	2	0	43
Tail	18	0	0	0	18
Feet	9	0	1	0	10
Legs	5	0	0	0	5
Fur	3	1	1	0	5
Chest	0	0	1	0	1
Scrotal sac	1	0	0	0	1
Unattached	1	3	0	0	4
TOTAL	141	23	8	0	172

Table 2.5.

TICK INFESTATION ON BODY REGIONS OF THE BANK VOLE, C. GLAREOLUS.

Body Regions	LARVAE		NYMPHS		Total each region
	I. ricinus	I. trianguliceps	I. ricinus	I. trianguliceps	
Ears	19	4	0	2	25
Head	7	0	0	0	7
Tail	1	0	0	0	1
Feet	0	0	0	0	0
Legs	0	0	0	0	0
Fur	0	0	0	0	0
Chest	0	0	0	0	0
Scrotal sac	0	0	0	0	0
Unattached	0	0	0	0	0
TOTAL	27	4	0	2	33

CHAPTER 3

The Development and Maintenance of the Sheep Tick, *Ixodes ricinus*, in an Outdoor Insectary

INTRODUCTION

The four stages in the life cycle of the sheep tick are eggs, larvae, nymphs and adults. The time taken to develop between these stages has been studied in the laboratory by Macleod (1935a, 1935b, 1943) and Campbell (1948). More recently development of the sheep tick has been studied under field conditions in Eire by Gray (1981). In Gray's study ticks were confined in plastic mesh tubes placed in the vegetation mat. In the present study ticks were confined in glass tubes in an outdoor insectary. This method was found to be successful in studying the life span of the sheep headfly *Hydrotaea irritans* (Berlyn, 1979).

The observed times for each stage of tick development in the insectary were compared with the predicted development times generated by a weather-based computer prediction model that had been proposed for the development phases of the sheep tick (Gardiner et al, 1981; Gardiner and Gettinby, 1983). The predictions were based on daily maximum and minimum air temperatures obtained from a meteorological station on the same site at a distance of 400m from the insectary.

MATERIALS AND METHODS

Sheep on a farm in S.W. Scotland with a known tick problem were examined for ticks during the months of April to November. Ticks were only found on the sheep during the months April, May and June. Engorged adult female ticks were collected from the sheep and placed singly in vertical open-ended glass cylinders 4.5cm in diameter and 10cm tall (Plate 3.1). The glass cylinder contained a strip of dry filter paper to help prevent condensation and upon which the ticks could rest. The top and bottom ends of each glass cylinder were covered with fine nylon mesh secured by elastic bands. The glass cylinders were placed on trays of damp peat in an outdoor insectary. (Plate 3.2). The peat was watered as and when required to keep it damp.

The outdoor insectary consisted of a wooden framework to which was attached nylon gauze to form the walls and transparent PVC sheeting to form the roof (Plate 3.3). The insectary and its contents were protected from the wind by means of an artificial windbreak.

Larval and nymphal stages of ticks were collected by blanket dragging at weekly intervals from sites in woodland and on farms. Some unfed nymphs and larvae were placed directly into glass tubes in the insectary. The majority of nymphs and larvae were fed on female mice (NIH strain, Zoology Department, University of Glasgow). To

allow larval and nymphal ticks to attach to the mouse, the mouse was placed in a plastic cylinder which was corked at one end. Holes in the cylinder allowed ventilation and the introduction of ticks. Ticks were placed on the mouse around the face, neck and ears and the mouse was usually held in the cylinder for around 45 minutes until ticks were attached or not visibly unattached. The mouse was then removed from the cylinder and transferred to a wire-bottomed cage of 25 x 35 x 10cm which was placed above another cage base filled with water. The water-filled base was ringed with "Vaseline" to prevent the escape of any ticks, either fed or unfed. After ticks had engorged and dropped into the water they were washed in a fungicidal solution of nystatin, 500,000 units per litre in distilled water. Up to 10 of the engorged larvae or nymphs were then placed in glass tubes and transferred to the outside insectary.

RESULTS

Temperatures were recorded from inside the glass tubes with a thermometer and from inside the insectary and at the weather station at Auchincruive by thermohygrograph. Both thermohygrographs were calibrated in the laboratory prior to use, and were kept in Stevenson screens for recording of data.

Using Students t-test, the mean temperatures for 13 days were analysed and there was no significant difference between the temperature inside the glass tube and either the temperature in the insectary or at the weather station (Table 3.3 . and XI).

Ticks collected directly from the field and placed unfed into the insectary gradually died. A 50% mortality for batches of nymphs was found to occur 11 to 14 weeks from the time of field collection. Most larvae did not survive longer than 1 to 2 weeks although a small proportion, approximately 10% , survived for 13 weeks from the time of collection at the end of May.

Observed and predicted times for tick development in an outdoor insectary are given in Table 3.1.* Female ticks which engorged in April, May and June, laid eggs which developed into larvae in the autumn. Larvae which fed in May and June developed into nymphs in the autumn. Nymphs feeding in March, April, May and June developed into male and female adult ticks in the autumn. However, larvae and nymphs which engorged from July onwards entered developmental diapause. These larvae and nymphs overwintering in the engorged state suffered very high mortalities in the insectary (Table 3.2). Only nymphs engorging in September 1984 and October 1985 and larvae engorging in the last half of October 1985 emerged from diapause.

*Also Appendix Tables XII - XIV.

Predicted times for the pre-oviposition and egg development periods closely followed those observed in the insectary. The observed development times for the few larvae and nymphs which did not die over the winter in the insectary and emerged from diapause were close to those predicted by the computer model. Much longer development times were, however, predicted for larvae feeding in May and June and nymphs in April, May and June than were actually observed. Larvae engorging in May and June and nymphs in April, May and June developed more quickly in the insectary than predicted, actual development times being two thirds to three quarters of the predicted times.

DISCUSSION

The outdoor insectary allowed maximum accessibility to observe tick development and activity with very little disturbance to the ticks due to handling. It was a more natural environment than the laboratory in which to study the life cycle of the tick. It was found that the maximum and minimum temperatures in the tubes were very similar to those recorded by the thermometer in the Stevenson screen of the meteorological station, which showed the construction of the insectary allowed an adequate flow of air through it.

The insectary has proved particularly successful in maintaining ticks for the pre-oviposition and egg

development period. It has been used by Titchener and Smitherman (1987) to study the effects of flumethrin residues on the wool of sheep. In their study, ticks collected in the spring from sheep dipped in insecticide during the previous autumn were reared in the insectary. Subsequent egg production and larval hatch from these eggs were recorded. One advantage for this type of study is that it is far removed from the constraints of the laboratory and the presence of other insecticidal compounds.

The high mortality of some batches of ticks, especially those entering diapause, suggested that improvements could be made in the way that ticks were maintained in the insectary. The elastic bands securing the nylon mesh on the ends of the glass tubes perished and required replacement. In subsequent work plastic electrical cable ties proved to be satisfactory. It also proved difficult to maintain a satisfactory humidity level using moist peat even with the aid of a glasshouse capillary watering system. The peat tended to dry out too quickly in the summer. In recent work the glass tubes containing ticks were contained within a plastic box lined with kitchen towel which was kept moist.

The computer simulation model used in the present study had been modified to use soil maximum and minimum temperatures at a depth of 50mm (Gardiner and Gray, 1986). Whilst soil temperatures at a depth of 50mm could be

obtained from Irish meteorological stations, Scottish stations provide only soil temperatures at the soil surface.

However, the prediction times for tick development using soil surface temperatures correspond much better with the development observed in the insectary. This was found to be particularly true for egg development. The Gardiner and Gray computer model (1986) predicted that under normal conditions the majority of eggs laid by spring-fed female ticks would develop by early autumn. In the present study in 1985, and in the subsequent years 1986 and 1987, eggs laid by spring engorged female ticks kept in the insectary produced larvae in the autumn. The majority of these larvae were inactive in the autumn and only became active the following spring. However, any disturbance of the tubes containing larvae, by vibrations or breathing close to the tubes, caused the larvae to become active.

Gardiner and Gray (1986) pointed out that whilst all the predicted hatch dates for larvae occurred during the period July to October the observed peak of activity in the field occurs in May of the following year. Gardiner and Gray (1986) did not, however, examine tick infestation on small mammals that are considered to be the main host of the larvae. The insectary study would suggest that field activity could occur in the autumn in the presence of a host. In a concurrent study, a peak of larval

infestation of I. ricinus was observed on small mammals in September although this was smaller than the peak of infestation observed in June and July.

Plate 3.1. Open-ended glass tube used for maintaining ticks.

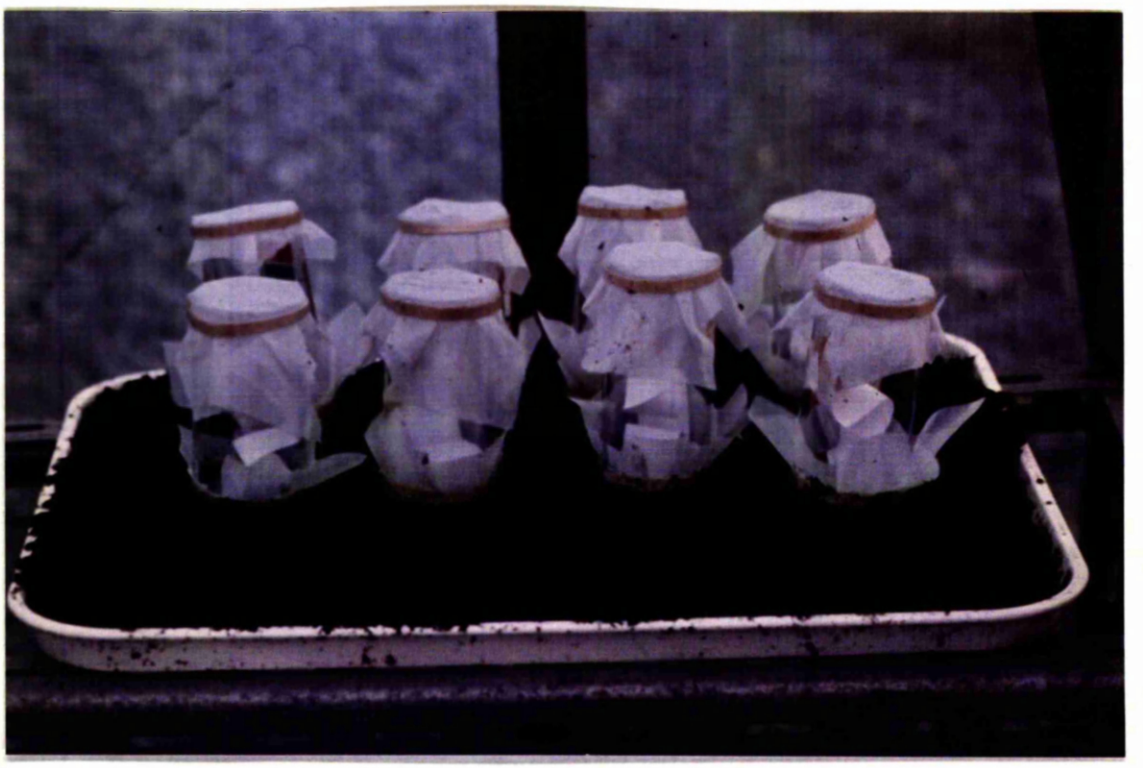


Plate 3.2. Glass tubes on tray of damp peat.

Plate 3.3. The outdoor insectary.

Table 3.1.

ACTUAL AND PREDICTED TIMES FOR TICK DEVELOPMENT IN AN OUTDOOR INSECTARY.

Pre-oviposition. Period from engorgement of female ticks to commencement of egg laying.

Engorgement Period	No. of ticks engorged	Days to egg laying Observed	Predicted
April 16-31, 1985	2	50	40
May 1-15	1	23	33
16-31	12	28	32
June 1-15	2	21	26

Egg development. Period from egg laying to larval hatch.

Period of egg laying	No. of females laying fertile eggs	Days to larval appearance Observed	Predicted
May 16-31, 1985	1	80	110
June 1-15	2	91	107
16-30	8	98	103
July 1-15	2	106	106

Larval development. Period from larval engorgement to appearance of nymphs.

Larval engorgement period	No. of larvae engorged	Days to nymphal appearance Observed	Predicted
May 1-15, 1985	16	92	144
16-31	18	89	146
June 1-15	4	77	276
16-30	13	84	331
October 16-31	17	292	293

Nymphal development. Period from nymphal engorgement to appearance of adults.

Nymphal engorgement period	No. of nymphs engorged	Days to adult appearance Observed	Predicted
September 16-30, 1984	6	324	387
March 1-15, 1985	9	186	197
April 16-30	29	124	158
May 1-15	26	111	143
16-31	54	91	140
June 1-15	21	85	218
16-30	34	86	320
October 1-15	14	313	312
16-31	2	293	297

Table 3.2.

TICK MORTALITY AFTER COMPLETION OF ENGORGEMENT.

Larval Mortality

Larval engorgement period			No. of ticks	% Mortality
May	1-15,	1985	18	22
	16-31		18	28
June	1-15		4	0
	16-30		13	38
July	1-15		3	100
	16-30		10	100
August	1-15		3	100
	16-31		6	100
September	1-15		7	100
	16-30		1	100
October	1-15		15	100
	16-31		17	88
November	1-15		4	100

Nymphal Mortality

Nymphal engorgement period			No. of ticks	% Mortality
August	16-31,	1984	8	100
September	1-15		2	100
	16-30		6	67
March	1-15,	1985	8	38
April	1-15		2	100
	16-31		29	48
May	1-15		16	81
	16-31		54	30
June	1-15		21	28
	16-30		32	34
July	1-15		11	100
	16-30		33	100
August	1-15		13	100
	16-31		23	100
September	1-15		26	100
	16-30		6	100
October	1-15		17	88
	16-31		14	86
November	1-15		10	100

Egg Mortality/Infertility

Female engorgement period			No. of ticks	% Mortality (% egg batches yielding larvae)
April	16-31,	1985	2	50
May	1-15		1	100
	16-31		12	83
June	1-15		2	50

Table 3.3.

TEMPERATURES RECORDED INSIDE & OUTSIDE THE INSECTARY.

TEMPERATURE DATA (DEGREES CENTIGRADE)

		THERMOMETER	THERMOHYGROGRAPH	
Date	Time	Temp. in tube	Temp. in insectary	Temp. at weather station
19.5.88	10.45	23	13.5	11
	13.30	13	15	14
	15.30	13	15.5	14
20.5.88	10.45	17	12	13
	13.30	15.5	15	14.5
	15.30	16	15.5	15
23.5.85	10.45	15	18	19
24.5.88	10.45	16	14	17
	15.30	13	14	16
25.5.88	11.00	13	15	16
	13.30	16	15	17
	15.45	13.5	16	16
26.5.88	09.30	15	15	16.5
	11.45	20	16	16.5
	17.00	16	13	16
27.5.88	09.15	20	14	15
	11.45	15	17	16.5
	14.15	17	17.5	18
	16.30	18	17	18
30.5.88	10.30	20.5	17	18
6.6.88	11.30	14	14	15.5
	14.00	16	16	17
	16.00	17	17	17
7.6.88	09.15	14	13	16
	12.30	20	19	20.5
	15.20	24	20	20
	16.30	21	20	20.5
8.6.88	09.30	14.5	12	15
	11.30	17	16.5	20
	14.00	19	20.5	21.5
	16.30	23	19.5	19.5
9.6.88	09.15	20.5	14	16.5
	11.45	18	17.5	18
	15.30	16	18	19.5
10.6.88	09.30	23	16	18
	Mean	17.2	15.9	16.9
	S.D.	3.2	2.2	2.3

CHAPTER 4

Heat and Hot Water Methods for Extraction of Ixodes ricinus from Turf Samples

INTRODUCTION

Blanket dragging and tick counts on animals are commonly used to assess the presence and population of ticks on a pasture, but these methods only sample questing ticks which are active for only part of the year.

There is, as yet, no direct method for estimating the ground population of ticks, i.e. those which are not actively seeking hosts. If autumn sampling for the quiescent tick stages were possible information could be provided for predicting the tick problem in the following spring. The areas of a farm where ticks were found to be present would be recognised and could be isolated from livestock or treated with insecticide.

Since ticks show avoiding responses to temperatures in excess of 42 degrees C (Lees, 1948) and most stages are photonegative to some extent, it should be possible to sample most tick stages by extraction from pasture samples using heat. Milne et al (1958) cited a previous attempt by Milne in 1939 to drive out ticks, Ixodes ricinus, from the bottom layer of a grass mat by heat using a light bulb fixed just above the mat surface (the Tullgren funnel

method). The results were unsatisfactory and this was thought to be a consequence of using dry heat which may have caused desiccation of the ticks initiating their retreat. It occurred to Milne (1958) that perhaps wet heat would be better as ticks would not be desiccated but would possibly be driven out by slowly rising hot water. However this idea was not tested.

Apparatus designed for extraction of tabanid larvae from turf samples was found to yield ticks (personal communication, K. Thomson, Edinburgh University, 1985).

The purpose of this study was to ascertain the efficiency of heat and hot water extractions of ticks from turves known to be infested with ticks.

MATERIALS AND METHODS

Turves of approximately 25cm square and 8cm depth (soil and vegetation mat) were cut from an area of rough grazing bordering a coniferous plantation. The vegetation of the turves was generally rough grasses, Nardus spp., Molinia spp., and rushes, Juncus spp.

Each turf was infested with a known number of unfed ticks recently collected from the field by blanket dragging. The turves were each placed on white instrument trays which were then placed in a shallow tray of water. The water completely surrounded the instrument tray and

prevented the escape of any ticks. Turves were regularly watered and kept in an outdoor insectary of type described by Berlyn (1979). Before extraction, any questing ticks were removed by forceps from the vegetation and the vegetation was trimmed down to 2cm above the vegetation mat layer. Therefore ticks to be extracted were not actively host seeking prior to extraction. Infestation of the turves took place between 1 - 79 days before extraction was attempted.

Dry Heat Extraction.

This was carried out in a special extractor (Plate 4.1). This consisted of a bottomless chipboard box within which 1" chicken netting had been placed so as to enclose the bottom of the box. Heat and light were supplied from 4 x 150W light bulbs placed on the underside of the lid and wired in parallel. A piece of metal was put around the bottom edge of the box so placed as to funnel any extracted fauna into a waterfilled collecting tray in which the extractor stood.

Trimmed infested turves were placed grass side down on the wire netting of the extractor and the bulbs switched on. The extractor was on from 0900-1630. The contents of the tray were examined for ticks twice a day, at 1630 and 0900.

Wet Heat Extraction.

Infested turves were placed in a white plastic container

of 40 x 25 x 11cm. Hot water at 60 degrees C was gradually added to the container at the rate of 350ml every 15 minutes over a period of 2 hours or until the water reached the lower layer of vegetation. Throughout the period the turves were observed continually to ensure that any ticks expelled were seen and removed immediately.

RESULTS

Dry Heat Extraction.

The results of the heat extraction are given in Table 4.1. The dry heat extractor varied in its efficiency of extraction from 0-100% for adult male ticks (mean 62%), 0-50% for adult females (mean 17%) and 10-67% for nymphs (mean 29%) recovered. Temperatures of 57 degrees C were recorded in the soil of the turves.

When 2 turves, infested with 4 engorged nymphs each, were extracted 9 days later, 3 nymphs were found at 24, 31 and 55 hours after being subjected to extraction giving 38% efficiency.

8 turf samples were collected from a woodland site at Kilkerran, Maybole, Ayrshire and from a rough farm grazing. Both areas were known to have tick populations. Only one unfed tick was extracted from a turf of surface area 324 square cm from the woodland site using the dry extraction technique.

Wet Heat Extraction.

The results of the hot water extraction are given in Table 4.2. Hot water extraction varied in its efficiency from 50-100% for adult males (mean 75%), 0-50% for adult females (mean 33%) and 0-50% for nymphs (mean 37%).

DISCUSSION

The results of this study show that ticks can be recovered from artificially infested turves using both dry heat (heat extractor) and wet heat (hot water extraction). Extraction efficiencies for unfed ticks were similar for both methods with males being most efficiently extracted followed by nymphs and then females. Extraction was dependent on the ability of the ticks to avoid unsuitable environmental conditions by moving away from harmful stimuli.

The true efficiency of extraction was difficult to judge because the survival of the ticks once placed on the turves was not known, therefore it was not possible to ascertain whether ticks were not extracted due to the extraction method not being totally effective or because the ticks were dead. Assuming ticks placed on turves 1 day before extraction were unlikely to die, the extractions of 24.4.85 (see Tables 4.1. and 4.2.) should give a guide to the extraction efficiencies possible. Nymphs were extracted with varying success from infested

turves, the most successful extractions occurred when the turves had been infested for the least time. This suggested that nymphs may become less available for extraction due to either death or a decreased ability for movement or decreased ability to avoid harmful stimuli.

The extractor did not seem to be particularly efficient for extraction of engorged stages judging by the results of the extraction of engorged nymphs from turves infested 9 days previous to the extraction. From the low mortality of engorged nymphs kept in similar conditions in the insectary (unpublished data) they would be very unlikely to die in such a short time.

Since nymphs are more numerous than adult females and males on a pasture it might be expected that nymphs would give the most reliable indication of the density of a tick population. There was reasonable success in the extraction of unfed ticks from artificially infested turves but the density of ticks in these turves is much higher than would be expected in the field. Milne (1943) deduced from repeatedly blanket dragging plots that there would be no more than 12 nymphs per square yard in the heaviest infested areas. This would suggest that large numbers of 25cm (9") square turves would be required to guarantee adequate sample size and due to the variable extraction efficiencies obtained these extraction methods would not be adequate as a method of tick sampling.

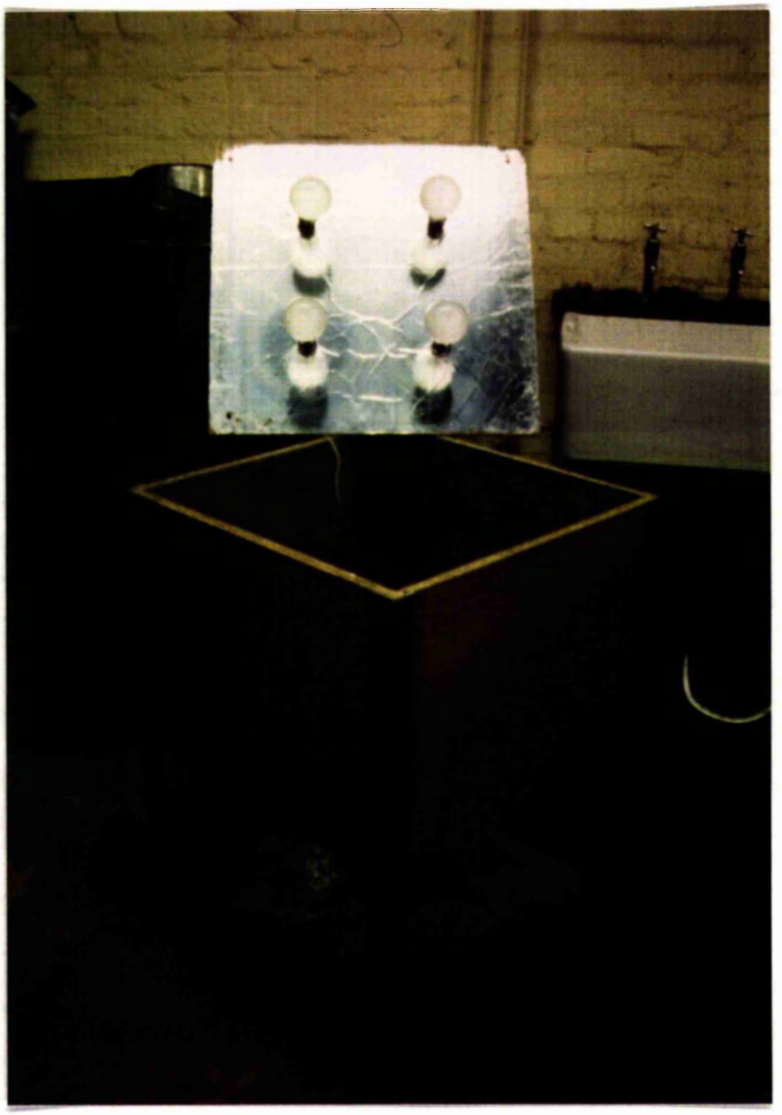


Plate 4.1. Dry heat extractor and collecting base.

Table 4.1.

Dry Heat Extraction of Ticks from Artificially Infested Turves

Date of infestation	Infestation of ticks			Date of extraction	Time infested	Possible ticks for extraction after hand removal			Ticks extracted			% age efficiency		
	♂	♀	N			♂	♀	N	♂	♀	N	♂	♀	N
5.3.85	2	2	10	12.3.85	7 days	2	2	10	2	1	5	100	50	50
22.3.85	1	1	10	16.4.85	25 days	1	1	10	1	0	1	100	0	10
23.4.85	2	2	12	24.4.85	1 day	2	2	12	2	1	8	100	50	67
15.4.85	4	4	10	3.7.85	79 days	4	3	10	3	0	1	75	0	10
8.8.85	4	4	20	19.8.85	11 days	3	0	8	0	0	1	0	0	12.5
8.8.85	4	4	20	2.9.85	25 days	3	2	8	0	0	2	0	0	25

Table 4.2.

Hot Water Extraction of Ticks from Artificially Infested Turves

Date of infestation	Infestation of ticks			Date of extraction	Time infested	Possible ticks for extraction after hand removal			Ticks extracted			% age efficiency		
	♂	♀	N			♂	♀	N	♂	♀	N	♂	♀	N
26.2.85	2	2	5	27.3.85	29 days	2	2	5	2	1	3	100	50	60
26.2.85	4	5	12	11.4.85	44 days	4	5	12	3	0	0	75	0	0
23.4.85	2	2	12	24.4.85	1 day	2	2	12	1	1	6	50	50	50

CHAPTER 5

Chemical Treatment of Stock to Control Tick Infestation

INTRODUCTION

The sheep tick, Ixodes ricinus, is an economically important ectoparasite of sheep and cattle in the British Isles. Ticks are important parasites not only because of their blood sucking activities but also because of the diseases which they transmit these being tick-borne fever, louping ill and tick pyaemia in sheep, and babesiosis in cattle.

Chemical treatment of sheep to control ticks has two aims: i) to prevent blood loss, irritation and lesion infection due to the tick's feeding activities and ii) to prevent the transmission of disease.

Recently, pour-on preparations containing the synthetic pyrethroid, cypermethrin, have been used to control several ectoparasites of sheep including lice (Henderson and McPhee, 1983), headfly (Titchener, 1984) and ticks (Henderson and Stevens, 1987).

The following tick trials were carried out in the spring and early summer of 1986 and 1987 with Border Research Ltd. using various synthetic pyrethroids in pour-on formulations and a dip formulation.

MATERIALS AND METHODS

The following insecticide preparations were used:

1) Cypor (Robert Young & Co.) - 2.5% w/v technical cypermethrin

2) HCC pour-on - 1.25% w/v high cis cypermethrin pour-on formulation

3) HCC dip - 10% w/v high cis cypermethrin dip formulation

4)Spoton (Coopers Animal Health) - 1% w/v deltamethrin

Treatments were applied according to the manufacturers instructions, as follows.

1) 30 ml of Cypor was applied to the sheep as a pinstream from the crown of the head to the top of the rump using a Young's applicator gun.

2) 30 ml of HCC pour-on was applied to the sheep as a pinstream from the crown of the head to the top of the rump using a Young's applicator gun.

3) The HCC dip formulation was used at an initial dilution rate of 1:1000 (ca. 100ppm) and a top-up rate of 1.5:1000 (ca.150ppm). Sheep were plunge dipped thoroughly in the dip bath with the head being submerged at least twice.

4) 5ml of Spoton was applied at the mid-point of the shoulders from a dispenser bottle.

The trials were carried out on three farms in the Borders and S.W. Scotland where sheep flocks were run on tick-infested hill pastures. The sheep breeds were Scottish Blackface and South Country Cheviot. The majority of the

sheep were treated between mid-March and mid-April but some ewes in each flock were left as untreated controls. In each trial, all the sheep being examined for ticks, both treated and controls, were run on the same pasture.

Tick counts were carried out on about 10 control and 10 treated sheep per visit. Live attached female ticks were counted on the head, neck, axillae and inguinal regions.

RESULTS

The results for each farm trial are shown in tables 5.1., 5.2. and 5.3. and in Appendix Tables XV - XXX.
Table 5.4. summarises the efficacies of the various treatments for the control of ticks.

Cypor gave good control of ticks (mean control of 74%) for at least 8 weeks post-treatment. HCC gave very good control (mean control of 85%) for up to 12 weeks post-treatment. HCC dip gave very good control (mean control of 88%) for up to 12 weeks post-dipping. It was not possible to examine the sheep at more than 12 weeks post-treatment so it is not known how much longer the treatments remained effective.
Spoton gave poor control (mean control of 37%) between 6 and 11 weeks post-treatment.

DISCUSSION

The main periods of tick feeding activity on sheep are in the spring and, to a lesser extent, the autumn. Ewes have traditionally been dipped before lambing and then the lambs have been dipped or smeared when about 1 to 3 weeks old.

It was found that the HCC dip gave slightly better control than the pour-ons. Dipping, which involves complete immersion of the sheep, ensures all areas of the animal come into contact with the insecticidal preparation. However pour-ons do have advantages over dipping at certain times of the year. Pour-on treatments are much less stressful than dipping ewes before lambing when sheep are fully fleeced and heavy in lamb (Titchener, 1985). Dipping of young lambs can lead to mis-mothering whereas the use of a pour-on does not usually lead to this problem.

Spoton was not found to be as effective as either Cypor or the HCC pour-on for controlling ticks in these trials. 64% of the total ticks found on the ewes treated with Spoton were found on the head compared to 38% found on the heads of untreated ewes. Mitchell et al (1986) found, on sheep treated with Spoton, that the majority of ticks were found on the head and that control dropped to approximately 43% by 41 days post-treatment. The lower application volume and limited site of application for

Spoton compared to the other pour-ons may account for its reduced efficacy. Probably, the larger the dose volume the better the spread of the insecticide from the area of application to the site of action, (Henderson and Stevens, 1987).

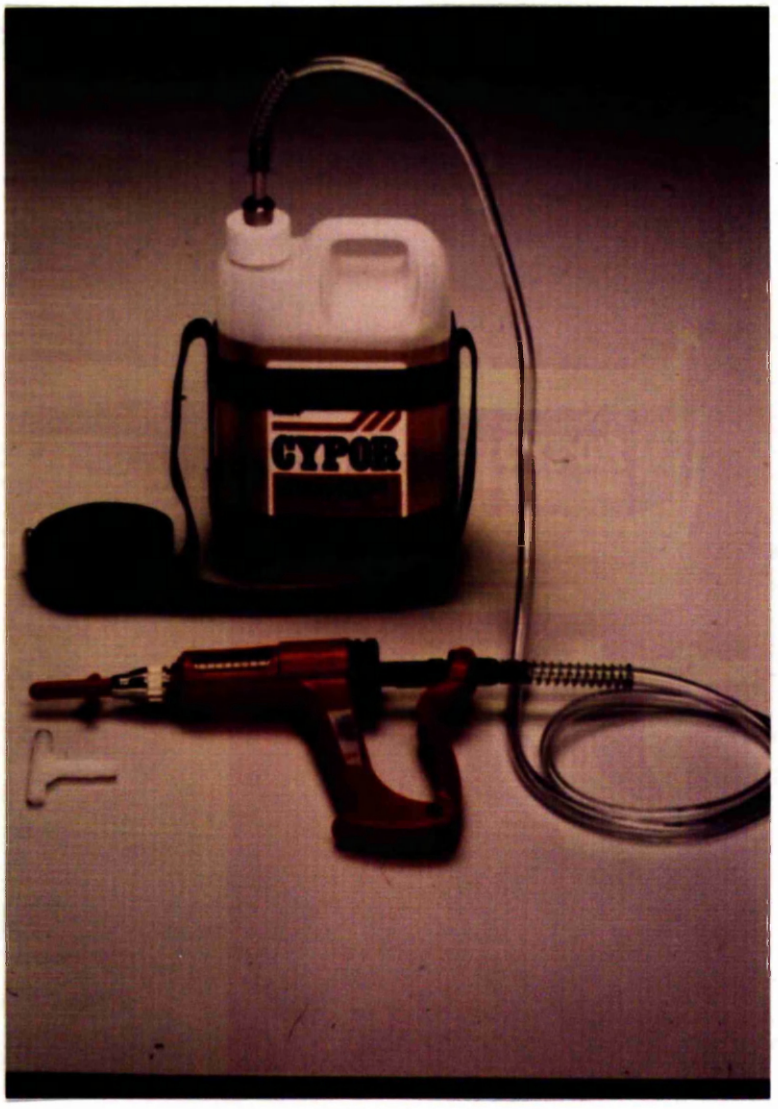


Plate 5.1. Container of Cypor, applicator gun and nozzles.

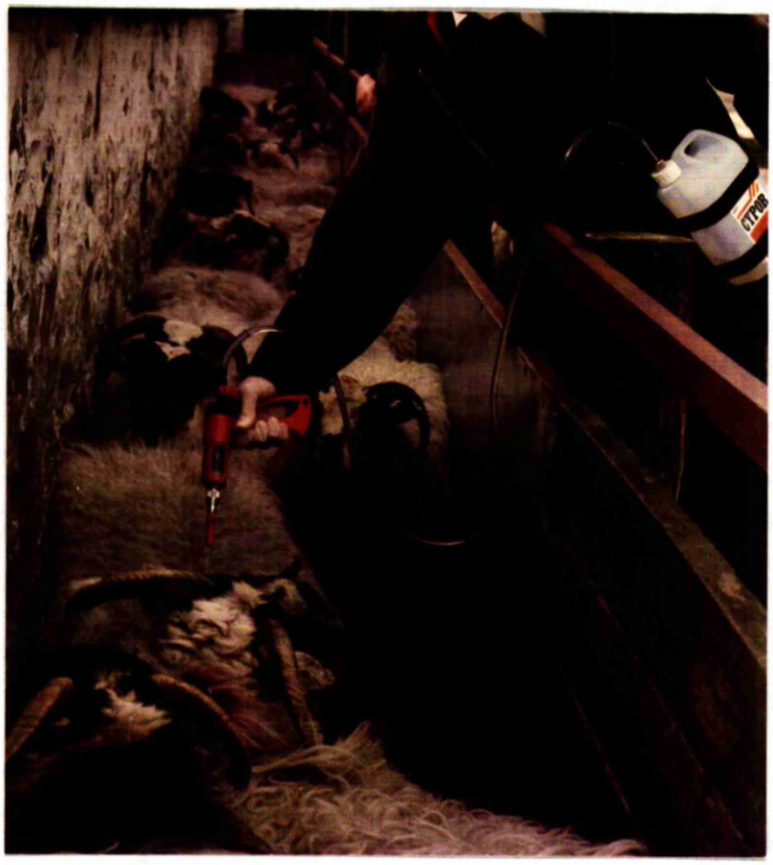


Plate 5.2. Cypor being applied to sheep for tick control.

TICK CONTROL TRIALS.

Table 5.1.

Site : Davidson, E. Deloraine, Ettrick.

Days Post-treatment		13			27	
Treatment	1	2	3	1	2	3
No. of sheep	4	11	3	8	10	7
No. with ticks	4	8	3	8	8	4
Mean ticks/sheep	5.2	1.7	4	8.1	3.2	1
S.D.	3.3	1.7	2	7.7	4.2	1.5
% CONTROL	-	67	23		60	88

Days Post-treatment		41			55	
Treatment	1	2	3	1	2	3
No. of sheep	6	10	8	8	11	8
No. with ticks	5	4	0	5	4	2
Mean ticks/sheep	2.8	0.4	0	2.6	0.5	0.2
S.D.	2.3	0.5	0	4.3	0.7	0.5
% CONTROL	-	86	100		81	90

Key to treatments: 1 = Untreated
2 = HCC pour-on
3 = Cypor

Table 5.2.

Site : McMorran, Miefield, Twynholm.

Days Post-treatment	45				63			
Treatment	1	2	3	4	1	2	3	4
No. of sheep	5	5	8	10	7	5	8	12
No. with ticks	5	4	6	8	5	0	1	9
Mean ticks/sheep	6	0.8	1.1	2.4	1.7	0	0.1	2.3
S.D.	2.5	0.8	1.2	1.9	1.6	0	0.4	1.6
% CONTROL	-	87	82	60	-	100	93	0

Days Post-treatment	77			
Treatment	1	2	3	4
No. of sheep	10	10	10	10
No. with ticks	9	1	10	8
Mean ticks/sheep	2.9	0.1	0	1.4
S.D.	1.7	0.3	0	1
% CONTROL	-	96	100	52

Key to treatments: 1 = Untreated
2 = Cypor
3 = HCC pour-on
4 = Spoton

Table 5.3.

Site : Cavers, Sorbie, Langholm.

Days Post-treatment	14			28			42		
Treatment	1	2	3	1	2	3	1	2	3
No. of sheep	10	10	9	11	11	11	10	10	10
No. with ticks	6	0	1	10	5	0	10	6	1
Mean ticks/sheep	1.8	0	0.2	5	0.8	0	15.9	2.6	0.3
S.D.	2.5	0	0.7	3.6	1.2	0	11.6	4	0.9
% CONTROL	-	100	89	-	84	100	-	84	98

Days Post-treatment	56			71			91		
Treatment	1	2	3	1	2	3	1	2	3
No. of sheep	9	10	10	10	10	10	11	10	10
No. with ticks	8	3	3	9	4	4	8	3	3
Mean ticks/sheep	5.2	0.6	0.4	4.4	0.7	0.4	4	0.4	0.4
S.D.	5.9	1.1	0.7	3.3	1	0.5	3.5	0.7	0.7
% CONTROL	-	89	92	-	84	91	-	90	90

Key to treatments: 1 = Untreated
2 = HCC pour-on
3 = HCC dip

Table 5.4

Efficacy of the treatments for the control of Ixodes ricinus on ewes

	Percentage Control at Week								
	2	4	6	8	9	10	11	12	$\bar{x}$
Trial 1									
HCC pouron	67	60	86	81					73.5
Cypor	23	88	100	90					75.0
Trial 2									
HCC pouron			82		93		100		92.0
Cypor			87		100		96		94.0
Spoton			60		0		52		37.0
Trial 3									
HCC pouron	100	84	84	89		84		90	88.0
HCC dip	89	100	98	92		91		90	93.0

CHAPTER 6

ENVIRONMENTAL FACTORS

There are 2 major environmental factors governing the spatial distribution of Ixodes ricinus:-

(i) ground cover, the most important factor, which may be described as "the amount of protection from adverse conditions of humidity and temperature and from predators".

and

(ii) host potential, the "supply of hosts for feeding and mating purposes" (Milne, 1950b).

GROUND COVER

Since the majority of the lifecycle of I. ricinus is spent on the ground, the condition of this environment will determine whether the species is likely to survive and develop in that area. The survival of the unfed stages of I. ricinus is dependent on a persistently high relative humidity in the microhabitat and this is only possible where the grazings are rough (Arthur, 1963). Rough grazings tend to be associated with decaying and rank vegetation which forms a mat over the soil (Milne, 1944). The availability of moisture on the ground during the

summer months has been shown to be the physical factor controlling the distribution of the tick as a species. Very low temperatures during severe winters may also be a controlling factor. During the summer the saturated air required for development on the ground surface and for survival of the unfed stages in the herbage is only found in rough pasture over peat or acid soils where there is moss and a mat of rank or old vegetation. The mat of dead vegetation also protects the tick from extreme cold (MacLeod, 1941).

The absence of ticks in lowland areas is because cover is too poor for their survival in sufficient numbers to maintain permanent populations. Hill and moorland pastures are characterised by deep, dense layers of vegetation over much of their area. Tick populations are denser on a pasture (within limits) the more universal the distribution of adequate cover. This is because the tick is more or less restricted to the spot where it drops from the host, therefore any patch of poorer cover limits the total population because some of the ticks from the better cover are dropped here and are unlikely to survive. More ticks probably drop off at night due to increased friction when the sheep is lying down, aiding the process of detachment. Thus the sheep's habit of lying overnight on poorer cover may be a severe checking factor to multiplication (Milne, 1950b).

The vegetation of the mat is made up of an accumulation of

undecomposed and semi-decomposed root fibres and is mostly found on wet and acid soils where bacterial decomposition of organic matter is hindered thereby encouraging the formation of the mat (Arthur, 1949). The pH values of soil are important in determining the suitability of a habitat for ticks since the mat develops quicker under acid conditions and tick survival in grassland is correlated with the establishment of the mat.

Evans (1951b), who studied I. ricinus in Wales and the Welsh border counties, found that infested grazings are always badly managed or poorly drained land where one of the following plants is dominant: Festuca spp., fescues; Agrostis spp., bents; Molinia caerulea, moor grass; Nardus stricta, mat grass; Pteris aquilina, bracken or Juncus spp., rushes. One explanation for this is that when these plants wither they form a layer of moisture-bearing debris over the soil and provide the permanent moist microclimate essential for the survival of the tick (Milne, 1944)

Arthur (1949) compared the tick populations of 4 adjoining areas of land in the county of Glamorgan in South Wales. These 4 tracts of land were equally accessible to stock and most ticks were found by blanket dragging in rush-type vegetation. Heather (Erica tetralix) and bracken were found to have similar populations with lower bracken slopes yielding more ticks than higher bracken slopes. No ticks were recovered from ley pasture. Heather, being evergreen, produces very little underlying vegetation and

tends to grow more openly than either bracken, rushes or rough grasses. This would provide a less damp habitat for ticks but mosses and occasionally peat are found at the base of heather so compensating for the lack of mat (Milne, 1944).

On one farm, Arthur (1949) investigated 4 fields for the presence of ticks by the blanket method. Here "islands" of suitable vegetation where ticks were found were of bracken, moor grass and copse where sphagnum moss was abundant. These potential areas of livestock infestation were adjoining well-grazed pasture where ticks were unlikely to survive.

Conditions in the herbage are such that during the day the humidity at the vegetation tips is relatively low while near the vegetation base very high humidities prevail continuously. During the night the humidity near the tips rises and usually approaches saturation but the gradient is rarely reversed. During the spring period of activity ticks usually climb on the dead stems of last year's growth and not on vegetation that is actively transpiring so it can be assumed that the humidity the tick encounters is similar to that of the surrounding air (Lees, 1948).

From observations by Lees and Milne (1951) it can be seen that active ticks do not remain continuously near the vegetation tips. After coming to rest near the vegetation tips, ticks are exposed to normal atmospheric conditions

and so will gradually lose water by evaporation. Ticks will be aroused before desiccation becomes critical and by walking down the stem will come to rest in the moist microclimate near the vegetation base. Once here they will take up water from the humid atmosphere and restore their water balance to normal. Thus during periods of "activity" ticks, after an unsuccessful period of waiting, disappear from view often reappearing several days later near the tips of the same stems.

Ticks at rest on exposed vegetation may be able to gain a little water at night when humidities rise but this is usually insufficient under normal meteorological conditions to replace completely water lost during the day.

Humidity, Water Balance, Temperature and Light.

Water Balance and Humidity

Lees (1946) studied the water balance in Ixodes ricinus and other tick species. Exchange of water in I. ricinus takes place almost exclusively through the cuticle which consists of 2 principal layers, the epicuticle and the endocuticle. The epicuticle lies to the outside of the endocuticle and is overlaid by a lipoid possessing waterproofing properties and this probably allows the retention of water at low humidities. In the female, the epicuticle covering the legs, scutum and capitulum is flat

and difficult to detect and the endocuticle of these body areas is rigid, pigmented and highly sclerotised. Over the alloscutum the epicuticle is deeply folded and the endocuticle is soft, colourless and extensible to allow for expansion in the replete female. In the male almost the entire body surface is hard and pigmented with the only unsclerotised endocuticle lying between the plates of the conscutum (alloscutum and scutum) and this is linked with males rarely feeding. The darkening of the cuticle after moulting is probably due to a tanning process similar to that which occurs in insects.

Regulation of the water balance of ticks is brought about by the activity of the epidermal cells. The cuticle is traversed by ducts of the dermal glands which have a complicated structure and are continuous with the epicuticle. The ducts open freely onto the surface of the cuticle while at the base of the endocuticle their open ends lie next to the epidermal cells. Pore canals, which traverse the endocuticle but do not penetrate the epicuticle, are occupied by cytoplasm and may play an important role in the active transfer of water through the cuticle.

Because of the tick's ability to secrete water, a state of equilibrium in its water balance is reached at approximately 92% RH. At lower relative humidities the tick loses water by evaporation and at higher humidities the tick takes up water. Close to the equilibrium point

the loss or gain of water over a wide range of temperatures is determined by the relative humidity. Uptake of water from humid air occurs when the tick is desiccated but ceases as the normal water content is restored. After previous exposure to saturated air, the tick at first loses water at relative humidities above the equilibrium point but later comes to retain water completely. Both fed and unfed ticks can prevent or limit temporarily the entry of water in contact with cuticle. When feeding, excess water gained from blood is excreted by the tick in its excrement. Engorged ticks usually lack the ability to take up water from their environment (Lees, 1946).

The range of humidities within which survival is possible is narrow, at 10 degrees C the lower humidity level for survival lies between 70 and 75% RH and at 15-30 degrees C it is between 75 and 80% RH. At 35 degrees C, the upper temperature limit for survival, both larvae and nymphs die at 100% RH while surviving at 95% RH.

Nymphs seemed more tolerant of dry conditions than larvae, therefore they would appear to have some mechanism by which they can reduce their rate of water loss under unfavourable humidities which is absent in the larvae. Larvae, being non-tracheate, must lose water over their body surface whereas in nymphs water loss is probably mainly from the tracheal tree and they may conserve moisture by closing their spiracles.

Temperature

MacLeod (1935) studied the resistance of I. ricinus to unfavourable conditions. By gradual lowering of the temperature by a few degrees each successive day the tick's resistance to cold was ascertained. It was found that all stages can survive exposure at -8 degree C for 4 days whereas one day of exposure at -15 degrees C kills all stages. Recently hatched larvae, i.e. of 1-7 days old, were less resistant to cold than older larvae of 7 weeks old which were able to survive lower temperatures for longer times. Ticks showed resistance to freezing if allowed to develop cold hardiness.

The temperatures to which the ticks were exposed was gradually increased to determine the thermal death point for each stage. Larvae were found to be less resistant than nymphs to a temperature of 35 degrees C at humidities below saturation but were equally resistant at 100% RH. Regardless of humidity both larvae and nymphs were killed by 1 hour's exposure at 45 degrees C. The differential resistances of larvae and nymphs at humidities below saturation may be related to nymphs being tracheate whereas larvae are non-tracheate therefore there will be differences in their mechanisms for water exchange with surrounding air. The thermal death point was concluded to be around 40 degrees C.

Light

Ticks in the upper mat are probably exposed to very low intensities of light during daylight and they will be subjected to rapidly increasing light intensities as they move up the vegetation. Ticks are never attracted to light and may be repelled by direct illumination especially when newly moulted. Ticks become indifferent to light as they age, i.e.the longer the time after moulting. MacLeod (1935a) was unable to confirm the work of Totze (1933, cited in MacLeod, 1935a) which indicated that all unfed stages are positively phototropic and that there is an optimum intensity of light above and below which ticks are less marked in their response.

HOSTS

Where I. ricinus occurs, it is by far the most important tick parasite of wild and domestic animals on hill and moorland grazings in Scotland and in northern and western England. Milne (1948b) concluded that no host occurs below the reptilian level among vertebrates and, of British vertebrates, only rarely has the lizard been found as a host. The range of alternative hosts is large, therefore the geographical distribution of the species is not likely to be dependent on host distribution. The range of this tick does not extend as far as the distribution limits of its possible hosts, therefore it

would seem that physical factors are more important than potential hosts in governing the world distribution of this species (MacLeod, 1939b).

Generally speaking birds are only parasitised by the immature stages of this tick, i.e. larvae and nymphs, whereas mammals are hosts to all three stages (Cameron, 1939, cited in Milne, 1948a). Mammals which are smaller in size than a stoat are rarely parasitised by females (Arthur, 1963).

Milne (1948b) attempted to assess the importance of farmstock and wild fauna as tick hosts. Only larger wild mammals and birds are hosts to female ticks with proportionally more mammal than bird species being hosts because of their larger size in general. All the recorded British hosts are hosts to larvae and all except for the shrew, and possibly the mole, are hosts to nymphs. Larvae are seasonally more numerous on hosts than nymphs and nymphs more numerous than females. The smaller the host the fewer the number and the lower the average infestation weight of female ticks, the same also being true for nymphs and larvae as regards numbers of individuals per host. In general smaller hosts are likely to cover less ground than larger hosts and so come into contact with and pick up fewer ticks.

The sheep was considered to be the main farm animal host by Milne (1948b) probably feeding 94-99% of the female

ticks on hill grazings. Proportionately more of the nymphal and larval populations feed on wild hosts compared with farm livestock. However the sheep still probably feeds the majority of the nymphal and a large proportion of the larval population. MacLeod (1939a) states that on typical tick infested areas in Britain the average incidence of ticks per sheep may range from 15 to over 100 females. Individual sheep may have more than 300 female ticks plus immature stages. The prevalence of larvae and nymphs has not been as thoroughly studied as that for females but for the greater part of the tick season, nymphal incidence is approximately 2 times that of females. Since larvae hatch from egg clusters they tend to be picked up in large numbers or not at all.

Breeds of sheep vary in their susceptibility to ticks, Blackface sheep being more susceptible to tick infestation than Cheviots and within a breed the condition of the sheep is also important, milk ewes being most susceptible followed by geld ewes followed by hoggs (MacLeod, 1932). Sheep tend to have lower tick infestations when they are in good condition. This may be because the better their condition, the more greasy the wool and the better the covering of wool. The activity of the individual animal is probably the most important factor in individual differences in infestation, i.e. more ticks are picked up the more ground is covered (Milne, 1947). From six weeks old, lambs were found to be more heavily infested than

ewes. If both ewes and lambs were picking up a similar number of ticks from the vegetation in their foraging, the longer fleece of the ewe compared to the lamb in the spring, may be preventing as many ticks from reaching their attachment sites on the ewes thus leading to the lambs being more heavily infested (Evans, 1951c).

MacLeod (1934) showed by a study of the role of alternative hosts that sheep are not necessary to the continued existence of a tick population. In a 10-acre area, a tick population of appreciable extent was maintained where the only available hosts were birds, hares and other small mammals such as field mice, voles, weasels and stoats. Sheep were excluded for 18 months before the tick population density was measured to assess the effect of alternative hosts on the tick population. It was found that removal of the chief host, i.e. sheep from a particular area for a number of years would not eradicate the tick from that area even when the alternative host population was also much reduced.

Evans (1951a) found that the degree of tick infestation of cattle in the region of Wales studied depended on the proportion of tick-infested pasture to total available grazing land. A small proportion of infested pasture to total grazing land resulted in a light infestation whereas cattle practically confined to infested grazing recorded heavy infestations.

Self de-ticking by hosts will also reduce tick numbers especially in birds and small mammals where the mouthparts are better suited for removal of ticks. On small mammals, which are thorough in their grooming, ticks only survive on the inaccessible areas such as the head and ears. On larger mammals the mouthparts are not so effective at removing relatively small ticks though death of ticks may occur due to rubbing of infested body areas. On birds, ticks are rarely found within reach of the beak suggesting that de-ticking by birds keeps these areas free from ticks (Milne, 1948b).

Parasites and Predators

I. ricinus seems fortunate in not suffering from either intraspecific or interspecific competition in its ecological niche. It is also comparatively free from parasitism, the only known parasite is Hunterellus hookeri, a chalcid wasp, which is recorded from I. ricinus in France. It has since been found parasitising other species of ticks but has not yet been found in the British Isles. Factors against the effective control of ticks by parasites in cooler climates would be the inadequate co-ordination of tick and parasite generations.

An important biotic environmental factor on the ground may be predator activity. Predators probably exert some degree of limitation on the numbers of ticks surviving.

The most susceptible stages would be newly engorged ticks which had not yet managed to get down into the vegetation mat (Barnett, 1961) and questing ticks at the tips of the vegetation. The main predators are thought to be the common shrew and, to a lesser extent, birds. Milne (1948b) suggests that the greater the amount of cover, the more difficult it would be for birds and shrews to find ticks. Therefore predator activity may be another factor linked to the importance of good cover for the tick's survival and development.

BEHAVIOUR OF TICKS

A variety of sensory perceptions are of value in promoting survival and host finding by I. ricinus. These may be grouped as follows:-

i) those bringing the tick into a position where it is likely to meet a host - orientation,

ii) those giving warning of approach of a host,

iii) those leading to attachment once the tick is transferred to the host.

i) The most frequent and important orientation by ticks on vegetation is a gravity response involving both taxis and kinesis (Lees and Milne, 1951). The majority of adults, nymphs and larvae are found in the top third of the vegetation layer and this shows the significance of

the orienting movements in bringing the tick close to the vegetation tips and to a position suitable for obtaining a host. Ticks may repeatedly ascend and descend a grass stem before finally coming to rest near the tip where they may remain for varying periods from a few minutes to several days.

A reaction to humidity may also be partly responsible for the tick's position in the vegetation as the lower vegetation layer generally has a higher humidity than the upper layer. Undesiccated ticks have been observed to avoid moist air and this would be sufficient to halt the descent to an active tick and cause it to ascend the vegetation. Very slight desiccation will cause the tick to enter a humid environment if possible.

Lees and Milne (1951) also showed from observations of ticks in the wild that ticks tend to avoid both sun and wind when finally coming to rest on a stem. Avoidance of wind is the most marked of these 2 responses and may possibly be linked with preservation of water, i.e. ticks in a less exposed position to both sun and wind will lose water more slowly than ticks in exposed positions.

Temperature fluctuations may be important in rousing the tick from quiescence at the roots and so initiating a phase of activity but temperature gradients within the vegetation are probably too small to influence orientation.

ii) Active ticks, i.e. ticks at rest in a position to obtain a host, respond to a drop in light intensity and to mechanical disturbance of the vegetation by questing. The response of questing to shading is not essential to obtaining a host since ticks will attach to a blanket dragged at night in darkness (Lees, 1948).

iii) The time taken to attach is critical because the environment of the host's skin will be lower in humidity and of a higher temperature than the conditions required for the tick's survival if not attached (MacLeod, 1935). Inducement to attach to the host to feed is determined by the interaction of groups of sense organs, these being Haller's organ, temperature sensilli, tactile bristles, and the palpal organ. Haller's organ is situated on the dorsal surface of the tarsus of the fore leg and consists of an anterior pit, the sensilli of which are humidity receptors, and a posterior capsule, of which the peg-like receptors have an olfactory function. Sensory receptors for the sex pheromone produced by female ticks are also located in Haller's organ. The long tactile setae are mainly found on the ventral surface of the distal segments of the 1st pair of legs and when stimulated by vibrations set up a questing response. The palpal organ, consisting of sensilli found on the apical segments of the palps, appears to function as a contact chemoreceptor. In an experiment to show the importance of the forelegs in sensory perception, Hindle and Merrimen (1912, cited in

Lees, 1948) found that specimens of Argas persicus from which the forelegs had been removed would attach to artificial membranes of rat diaphragm when the latter were placed over sodium chloride or gelatine solutions at a temperature of 42 degrees C. Normal ticks failed to attach under similar conditions. Totze (1933, cited in Lees, 1948) found similar results with Ixodes ricinus which, since the forelegs bear the sense organs of olfaction, is indicative of the role of odour as a prerequisite for attachment to the host.

Odour alone is not enough to elicit a response in the tick. The attractiveness of sheep's wool for attachment increases as the temperature rises from 20 degrees C to 37 degrees C, at the latter temperature sheep's wool being highly attractive to the tick. When both temperature and odour are present a high percentage of ticks attach to artificial membranes compared to only 10% when just one of the stimuli is present. Lack of chemical stimulation inhibits the tick from testing the surface membrane (Lees, 1948).

The response of ticks to temperature is linked with the nutritional condition of the tick (Lees, 1948). Hungry ticks will orientate to an odourless tube at 37 degrees C by responding to a gradient of air temperature and not to radiant heat. Fully engorged ticks are repelled by the same tube at 37 degrees C. Newly moulted ticks, i.e. within 2 months of moulting to adults, are not hungry and

refuse to approach a warm tube at 37 degrees C until reserves are sufficiently depleted.

Lees (1948) has shown that male behaviour is identical to that of female ticks and that temperature is of relatively greater importance for immature stages in orientation to the host. Experiments with ticks and objects so treated as not to emit much heat have indicated that ticks are attracted to or repelled by air temperatures and not radiant heat. Objects warmer than the surroundings may be attractive but avoiding responses are always shown to temperatures higher than 42 degrees C.

TICKS AND DISEASE

The effects of tick infestation have been summarised by MacLeod (1939a) as follows:-

Effects

Direct	Indirect
Specific	
Skin reaction to salivary secretion: - man, horse	Red water (babesiosis)
	Louping ill
	Tick-borne fever
Tick paralysis	Pyaemia
Non-specific	
Anaemia	Pre-disposition to blowfly strike
Tick worry	
Loss of wool from rubbing	Septicaemia in lambs from tick bite sores
Grouse mortality	
Accidental	
Burying beneath the skin	Anaplasmosis - not important in Great Britain

Louping Ill

This is an acute disease of the central nervous system, caused by an arbovirus, affecting sheep although other domestic livestock and man may be affected. Louping ill is restricted to the British Isles and is transmitted by *I. ricinus*. Much of the sheep mortality on tick infested hill sheep farms in Scotland and Northern England is due to this disease although not all tick-infested areas have louping ill present. The occurrence of the disease is seasonal and losses coincide with periods of maximum tick activity with the heaviest mortality tending to be in spring and early summer and smaller losses occurring in autumn. Chronic cases, lasting for some weeks, are associated with paralysis of one or more limbs and the most severe form of the disease is characterised by cerebellar ataxia and disorder of the brain and spinal cord function (Gordon et al, 1962).

Ticks become infected when they ingest blood with a high titre of virus. The virus then multiplies within the tick and is injected into the vertebrate when the tick next feeds. Transmission is transstadial but not transovarial therefore only infected nymphs and adults can transmit the disease when they feed. The only hosts so far found with the relatively high level of virus in the blood necessary for transmission are the sheep and red grouse. The appearance of serum antibody is associated with a decline in the viraemia and animals which recover are immune for

life. Colostral antibody from the ewe protects lambs during the first tick season but these lambs will be susceptible in the following year. This helps to explain why louping ill is a disease problem associated with replacement breeding stock on the second year on the grazing. Also when susceptible stock are introduced to infected pastures or when louping ill appears on premises for the first time serious losses may occur in all ages of stock.

As regards red grouse and the problem of louping ill, it has been shown that viable grouse populations cannot exist in louping ill endemic areas. A heavy mortality can occur in grouse present on infected moors exerting a profound limiting effect on grouse numbers (Reid and Martin, 1982). The virus has also been isolated from the wood mouse, Apodemus sylvaticus; the common shrew, Sorex araneus and the bank vole, Clethrionomys glareolus and antibodies to the virus have been found in red deer, Cervus elaphus and hares, Lepus spp. (Hoogstraal, 1966; Smith, Varma and McMahon, 1964).

Tick-borne fever

The rickettsial parasite,Cytocoetes phagocytophila is the causal organism of tick-borne fever (TBF) in sheep and cattle in Great Britain and Europe. The febrile disease is usually mild with relatively low mortality although the importance of this condition lies in its apparent ability

to increase the animal's susceptibility to other diseases such as pasteurellosis, louping ill and especially tick pyaemia. TBF can also cause abortion in pregnant ewes exposed to tick infestation for the 1st. time (Reid and Martin, 1982). The possible mechanisms of immunosuppression have been investigated and TBF was found to effectively suppress the CMI (cell-mediated immunity) response. TBF may also impair the phagocytic and migratory abilities of neutrophils (Brodie et al, 1982).

The rickettsia involved C. phagocytophila is probably present in all tick populations (Reid and Martin, 1982) and in laboratory maintained ticks the infection persists for at least a year (MacLeod, 1936). Compared to louping ill, a higher proportion of ticks carry the organism due to the frequently prolonged period that animals have the organism in their blood. This may be from a few months to several years and transmission of the organism is through the tick's saliva at the time of feeding. Infection in the tick is transstadial but not transovarial.

Immunity appears to be dependent on constant sub-clinical re-infection as animals eliminating the parasite become susceptible to the disease. Sheep removed from infected pasture for prolonged periods may be fully susceptible when returned and although protection from a strain may be solid, challenge from strains from different localities or even different areas of the same farm may result in infection (Reid and Martin, 1982).

Tick pyaemia

Tick pyaemia, also known as cripples, is caused by a natural skin bacterium, Staphylococcus aureus, and is characterised by a systemic infection producing abscesses in joints and other tissues. Lambs of 2-6 weeks of age are mainly affected (Soulsby, 1982).

The natural resistance of lambs is weakened by tick-borne fever allowing invasion by bacteria which do not cause disease in healthy lambs. Abscesses forming in the joints may cause severe crippling and varying degrees of paralysis may result from abscesses in the spinal cord. Where abscesses form in vital organs the resulting malfunction may result in ill-thriving lambs which are often regarded by farmers as the major cause of economic loss (Reid and Martin, 1982). Evans (1951b) stated that in Wales lambs which recover from tick pyaemia are always unthrifty with the result the farmer has fewer saleable lambs than if the farm was disease-free.

The annual incidence of this disease on sheep farms in tick-infested areas is usually about 5% of the lamb crop with mortality occurring in not more than 50% of those affected with survivors recovering slowly and usually in poor condition for autumn lamb sales (Foggie, 1961).

Babesiosis

Babesiosis or redwater fever is the main tick-borne disease of cattle in Great Britain and is caused by protozoan parasites of the order Piroplasmida, genus Babesia. B.divergens is transmitted by Ixodes ricinus and is responsible for clinical redwater fever which occurs regularly in S.W. England and also for the disease in Scotland which occurs sporadically (Adam and Blewett, 1978). Cases of redwater are associated with tick activity, for example where I. ricinus shows biannual activity cases are to be expected in late spring and autumn (Soulsby, 1982). In S.E. England B. major also occurs, transmitted by the tick Haemaphysalis punctata.

Within the life-cycle of I. ricinus, the tick vector of B. divergens, both transstadial and transovarial transmission occurs. Infected ticks inject the parasite into the bloodstream when feeding. The parasite enters erythrocytes causing them to break down releasing haemoglobin, some of which is passed out in the urine giving the urine a reddish colour. Severe anaemia may result from the breakdown of large numbers of erythrocytes and this is responsible for the clinical signs and often death (Kavanagh and Purcell, 1972). There is an incubation period of 4-10 days which may be followed by an increase in body temperature up to 41 degrees C. Within 48 hours of the peak of fever, haemoglobinuria is observed followed by jaundice of the mucous membranes, increased

respiration and heart rates and also loss of appetite, weakness and occasional diarrhoea (Soulsby, 1982; Kavanagh and Purcell, 1972).

A serological survey was carried out to determine the extent of infection in cattle in Scotland by the IFA (indirect fluorescent antibody) test. The herd incidence of babesial antibody varied from 0-100% and the proportion of positive sera for individual countries varied from 0.4-39.8% (Adam and Blewett, 1978). Usually little appreciable loss is associated with the presence of this disease, many affected animals show no signs of infection, the disease running a sub-clinical course which leaves the animals resistant to further attack (MacLeod, 1939a). Babesiosis is a problem where mature, unacclimatised cattle (older than 9 months) are introduced to infested pasture. The infection in young animals is usually mild and subsequent immunity is complete (Reid and Martin 1982). Younger animals, although rarely showing clinical signs of infection, may serve as a source of infection for ticks. When infected cattle are brought onto tick infested land which is free from the disease, this can introduce redwater on to that farm.

Wild deer are commonly infected with Babesia sp. with the infection being benign. Evidence from transmission experiments by Blewett and Adam (1978) suggest that since cattle will not support the babesia of red deer, the red deer parasite and B. divergens are probably separate

species. At the moment that is insufficient evidence to separate the babesia of red deer and that of roe deer, B. capreoli. Since the deer babesias and B. divergens share a common vector, i.e. I. ricinus, this suggests a common ancestry for these parasites (Blewett and Adam, 1978).

Tick paralysis

This is a severe and often fatal disease of tick-infested animals and man. Mostly females, but sometimes nymphs, of the genus Ixodes are generally responsible with the degree of paralysis being proportional to the length of time the tick has been feeding and to the number of ticks attached. Removal of the ticks is usually followed by almost complete recovery provided heart and respiratory centres have not been affected.

The nature of the toxin causing tick paralysis is unknown and it would seem that it is produced in the salivary glands of the ticks and acts on motor and sensory nerves and on neuromuscular transmission. Animals recovering from tick paralysis develop an immunity to the toxin and in the absence of reinfection this lasts for up to several months (Soulsby, 1982; MacLeod, 1939a).

Tick worry

Tick worry is a combination of several entities including irritation from tick bites, local skin infection, blood loss and secondary attack by flies. It is characterised by loss of condition, restlessness and interference with grazing and is caused by heavy tick infestation. Systematic control of ticks almost always results in improved weight gains and yields.

In an attempt to get rid of irritation infested sheep rub and scratch themselves thereby decreasing the wool clip. The blood from burst ticks causes staining of the wool and due to absorption of water from rain and the warmth of the animal's body, this forms a suitable environment for bacterial activity for weeks afterwards. This fouled wool also predisposes sheep to secondary attack by blowflies and is a common cause of neck and shoulder 'strike' by maggots in early summer. Local skin infection due to tick bites may produce suppurative lesions, e.g. on ears and legs, and in lambs may lead to tick pyaemia (MacLeod, 1939a; Soulsby, 1982).

Skin reaction

A skin reaction in man to the salivary secretion of I. ricinus has been known for 60 years to be relatively common in Europe. This reaction in man is known as erythema chronicum migrans (ECM) and is characterised by a

persistent elevated annular erythematous ring with advancing indurated borders and central blanching radiating on the skin from the site of the bite. Often this condition is accompanied by fever, headache and a general feeling of illness (Hoogstraal, 1981).

Lyme disease, which is caused by the bacteria Borrelia burgdorferi and transmitted by ticks of the genus Ixodes, is characterised by ECM. Patients may develop other symptoms including arthritic, neurological and cardiological abnormalities within weeks or months of ECM occurring (Burgdorfer et al, 1982).

Anaemia

This condition rarely occurs as a result of tick infestation, although the blood loss from a heavy and prolonged infestation must be appreciable. A single adult female may ingest 0.5-2.0ml of blood but the blood ingested by the tick is only a proportion of the total blood lost. The rest is lost as a clot around the puncture after detachment of the tick particularly because of an anti-coagulant injected by the tick as it feeds. In a larval infestation the blood loss is greater after tick detachment than the amount ingested (MacLeod, 1939a; Evans, 1951b; Soulsby, 1982).

The red grouse and ticks

Densities of red grouse populations vary from area to area and this may be due to the quantity and quality of food available. Gamekeepers are of the opinion that grouse are scarce on moors with large tick populations. The ticks' role as vectors of louping ill may be more important than the harm done by removing blood and causing inflammation (Duncan et al, 1978). Both experimental and field studies indicate that viable grouse populations cannot exist in louping ill endemic areas and that a heavy mortality can occur in grouse present on infested moors (Reid and Martin, 1978).

Game birds, especially young grouse are often heavily infested by the sheep tick in its immature stages (MacLeod, 1939a). A study carried out by Duncan et al (1978) in N.E. Scotland showed a close association between tick burdens, the presence of louping ill virus and antibody, and the disappearance and presumed death of grouse chicks in the wild. The evidence suggested that ticks themselves may kill very young chicks but that louping ill is more important in killing bigger chicks and adults. Observations on broods of grouse chicks in Moray showed that only 7% of chicks survived on areas where ticks were abundant. Chicks in which louping ill virus or antibody was detected were significantly ($P<0.005$) more likely to die than other chicks. Where ticks are abundant, antibody to the louping ill virus was present in

84% of 73 adult birds and the breeding success was at best 0.6 full grown young per adult. Where ticks were scarce, approximately 10% of adult birds had antibody to louping ill, and the breeding success was at least 2.3 young per bird.

The incidence of louping ill has increased both in sheep and in red grouse and grouse stocks have decreased particularly in some parts of Scotland (Hudson and Watson, 1985). Prior to the introduction of extensive sheep farming on hill pastures, louping ill was probably absent or rare and red grouse probably did not encounter the virus and this would explain the extreme susceptibility of red grouse to infection (Reid, 1978).

The consequence of a reduction in grouse numbers has been the sale of once productive grouse moors to forestry companies for turning into coniferous plantations. This has long term implications in that forestry tends to be the only activity that can be carried out on a moor whereas hill grazing, grouse management and conservation can be carried out together and to the benefit of each other if managed properly (Hudson and Watson, 1985).

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APPENDIX

APPENDIX

TABLE I.

BLANKET DRAGGING RESULTS

CHAPELTON WOOD, KILKERRAN - 1984

Date	IXODES RICINUS Adults male	female	Nymphs	Larvae	Mean Weekly Max. Air Temp. (°C)	Daily Max. Air Temp. (°C)	Total Weekly Rainfall (mm)	Daily Sunshine (hours)
12.4.84	2	0	24	0	8.6	9.3	7.7	0.2
24.4.84	0	4	39	0	15.1	20.7	6.7	13.9
4.5.84	3	0	83	0	17.4	16.6	0.0	8.1
9.5.84	6	6	189	26	14.4	11.6	10.5	3.7
16.5.84	8	6	231	19	14.5	11.2	1.9	0.0
25.5.84	8	5	97	42	15.7	10.1	6.3	0.0
29.5.84	4	0	147	13	15.2	16.6	3.6	4.8
7.6.84	5	2	99	44	17.6	23.9	19.2	15.3
13.6.84	1	4	29	0	18.5	14.6	7.9	0.4
28.6.84	2	1	76	3	13.9	15.3	10.5	7.3
4.7.84	3	2	99	13	17.2	20.3	0.0	14.9
11.7.84	3	0	82	0	22.0	19.5	1.5	4.0
18.7.84	9	3	43	0	19.8	22.6	1.9	8.4
25.7.84	4	6	85	5	22.1	24.9	0.0	14.2
1.8.84	7	11	75	0	19.2	21.0	30.2	10.0
7.8.84	2	2	22	2	17.0	19.0	10.1	7.1
15.8.84	5	2	61	0	21.0	20.1	0.0	11.2
22.8.84	1	1	23	65	25.1	27.2	1.2	10.3
29.8.84	3	2	36	1	21.6	17.2	11.7	2.4
3.9.84	1	2	36	16	17.8	16.5	35.4	2.0
10.9.84	5	3	34	2	14.4	13.1	23.5	0.9
17.9.84	1	0	13	0	15.9	13.0	23.1	0.8
26.9.84	1	2	21	4	12.7	15.2	14.7	5.2
10.10.84	0	2	3	0	13.8	14.2	17.3	3.9
23.10.84	0	0	1	0	11.9	10.6	85.3	5.9
31.10.84	0	1	2	0	12.8	13.9	27.1	7.0
8.11.84	0	0	2	0	8.2	12.1	38.1	0.0
19.11.84	0	0	0	0	8.0	6.6	1.1	0.5
12.12.84	0	0	0	0	9.4	8.8	15.0	2.5

TABLE II.

BLANKET DRAGGING RESULTS

BARONY HILL, KILKERRAN - 1984

Date	IXODES RICINUS Adults male	female	Nymphs	Larvae	Mean Weekly Max. Air Temp. (°C)	Daily Max. Air Temp. (°C)	Total Weekly Rainfall (mm)	Daily Sunshine (hours)
12.4.84	2	0	82	0	8.6	9.3	7.7	0.2
24.4.84	0	0	18	0	15.1	20.7	6.7	13.9
4.5.84	0	0	49	0	17.4	16.6	0.0	8.1
9.5.84	0	0	60	9	14.4	11.6	10.5	3.7
16.5.84	0	0	64	0	14.5	11.2	1.9	0.0
25.5.84	0	0	14	5	15.7	10.1	6.3	0.0
29.5.84	0	0	65	0	15.2	16.6	3.6	4.8
7.6.84	0	0	26	84	17.6	23.9	19.2	15.3
15.6.84	0	0	54	31	16.3	12.4	7.9	0.3
28.6.84	0	0	20	6	13.9	15.3	10.5	7.3
4.7.84	0	0	32	15	17.2	20.3	0.0	14.9
11.7.84	0	0	4	0	22.0	19.5	1.5	4.0
18.7.84	0	0	18	0	19.8	22.6	1.9	8.4
25.7.84	0	0	4	0	22.1	24.9	0.0	14.2
1.8.84	0	0	5	0	19.2	21.0	30.2	10.0
7.8.84	0	0	0	0	17.0	19.0	10.1	7.1
15.8.84	0	0	2	0	21.0	20.1	0.0	11.2
22.8.84	0	0	3	0	25.1	27.2	1.2	10.3
29.8.84	0	0	0	0	21.6	17.2	11.7	2.4
3.9.84	0	0	2	0	17.8	16.5	35.4	2.0
10.9.84	0	0	3	0	14.4	13.1	23.5	0.9
17.9.84	1	0	4	3	15.9	13.0	23.1	0.8
26.9.84	0	0	1	0	12.7	15.2	14.7	5.2
10.10.84	0	0	0	0	13.8	14.2	17.3	3.9
23.10.84	0	0	0	0	11.9	10.6	85.3	5.9
31.10.84	0	0	1	0	12.8	13.9	27.1	7.0
8.11.84	0	0	0	0	8.2	12.1	38.1	0.0
19.11.84	0	0	0	0	8.0	6.6	1.1	0.5

TABLE III.

BLANKET DRAGGING RESULTS

CHAPELTON WOOD, KILKERRAN - 1985

Date	IXODES RICINUS Adults male	female	Nymphs	Larvae	Mean Weekly Max. Air Temp. (°C)	Daily Max. Air Temp. (°C)	Total Weekly Rainfall (mm)	Daily Sunshine (hours)
4.2.85	0	0	1	0	7.9	7.8	24.5	0.0
25.2.85	1	0	2	0	9.0	10.1	7.1	2.5
4.3.85	0	0	3	0	7.6	6.1	6.8	0.0
11.3.85	1	0	1	0	9.8	10.9	5.2	9.7
18.3.85	0	1	0	0	6.2	6.2	2.2	9.6
25.3.85	0	0	7	0	5.7	8.3	7.5	1.2
3.4.85	0	2	6	0	10.7	14.4	48.4	1.5
10.4.85	0	4	33	0	9.6	7.5	15.0	0.0
16.4.85	0	0	25	0	10.0	15.5	22.2	10.6
22.4.85	1	7	125	0	12.9	14.8	3.8	10.3
30.4.85	0	1	40	0	9.6	12.2	20.9	1.6
7.5.85	1	0	93	0	11.6	16.0	3.0	14.0
14.5.85	1	2	211	7	13.6	11.8	8.1	0.0
20.5.85	2	4	129	46	14.5	15.2	13.7	12.3
27.5.85	4	4	156	17	14.8	15.8	22.4	1.2
3.6.85	3	3	129	132	19.5	23.7	0.1	15.3
10.6.85	3	2	132	5	13.9	14.2	12.7	7.0
17.6.85	3	2	44	0	13.9	15.4	14.8	0.0
24.6.85	0	5	105	5	16.4	14.3	29.9	3.8
2.7.85	3	3	75	9	16.2	22.0	4.1	6.4
9.7.85	6	4	353	176	18.4	16.2	22.2	8.7
15.7.85	3	2	118	3	20.0	22.0	32.9	0.0
23.7.85	0	2	63	1	15.9	17.7	46.4	0.0
30.7.85	3	3	100	11	19.5	19.7	18.2	0.0
6.8.85	3	2	67	2	15.8	15.9	28.1	0.3
14.8.85	2	3	19	3	15.8	16.3	47.0	0.0
20.8.85	3	5	79	5	16.7	16.8	58.6	0.0
26.8.85	2	1	38	6	14.9	15.3	40.4	0.0
2.9.85	0	1	7	3	16.0	11.2	35.6	0.0
9.9.85	2	1	74	6	14.4	19.8	33.5	0.3
17.9.85	1	1	5	4	15.0	14.4	49.1	8.1
27.9.85	2	0	20	1	15.7	21.1	24.5	3.5
1.10.85	1	2	26	2	16.4	19.2	18.2	4.0
7.10.85	1	1	8	3	13.4	13.6	36.7	8.0
15.10.85	1	2	15	14	16.1	13.0	8.3	0.0
21.10.85	4	1	17	1	13.8	14.4	0.0	4.1
28.10.85	1	0	4	3	17.2	11.2	0.0	3.2
5.11.85	0	0	1	0	17.1	6.8	24.9	0.8
12.11.85	0	0	0	0	13.4	4.9	22.5	3.5
18.11.85	0	0	0	0	14.2	6.7	13.9	1.0
25.11.85	0	0	0	0	12.7	4.0	1.9	1.9
2.12.85	1	1	0	0	10.4	13.6	20.2	0.0
9.12.85	0	0	1	0	9.4	3.2	12.8	4.3
16.12.85	0	0	1	0	6.0	11.0	16.0	0.0

TABLE IV

BLANKET DRAGGING RESULTS

BARONY HILL, KILKERRAN - 1985

Date	IXODES RICINUS Adults male	female	Nymphs	Larvae	Mean Weekly Max. Air Temp. (°C)	Daily Max. Air Temp. (°C)	Total Weekly Rainfall (mm)	Daily Sunshine (hours)
25.2.85	0	0	0	0	9.0	10.1	7.1	2.5
4.3.85	0	0	0	0	7.6	6.1	6.8	0.0
11.3.85	0	0	0	0	9.8	10.9	5.2	9.7
18.3.85	0	0	0	0	6.2	6.2	2.2	9.6
25.3.85	0	0	1	0	5.7	8.3	7.5	1.2
3.4.85	0	0	0	0	10.7	14.4	48.4	1.5
10.4.85	8	0	5	0	9.6	7.5	15.0	0.0
16.4.85	3	2	27	0	10.0	15.5	22.2	10.6
22.4.85	1	0	3	0	12.9	14.8	3.8	10.3
29.4.85	1	2	16	0	9.2	9.8	16.1	0.0
7.5.85	1	1	19	33	11.6	16.0	3.0	14.0
14.5.85	4	1	16	103	13.6	11.8	8.1	0.0
20.5.85	4	0	10	389	14.5	15.2	13.7	12.3
30.5.85	3	0	16	33	15.4	18.1	11.2	10.6
3.6.85	4	0	5	116	19.5	23.7	0.1	15.3
17.6.85	0	0	1	0	13.9	15.4	14.8	0.0
24.6.85	1	6	7	10	16.4	14.3	29.9	3.8
2.7.85	1	1	1	35	16.2	22.0	4.1	6.4
9.7.85	3	2	3	6	18.4	16.2	22.2	8.7
15.7.85	0	0	0	2	20.0	22.0	32.9	0.0
23.7.85	0	0	1	5	15.9	17.7	46.4	0.0
30.7.85	0	0	1	0	19.5	19.7	18.2	0.0
6.8.85	0	0	0	9	15.8	15.9	28.1	0.3
15.8.85	0	0	0	0	15.7	14.3	63.9	0.0
22.8.85	0	0	0	0	16.5	14.6	26.3	0.0
26.8.85	0	0	1	27	14.9	15.3	40.4	0.0
2.9.85	0	0	4	36	16.0	11.2	35.6	0.0
9.9.85	0	0	0	60	14.4	19.8	33.5	0.3
17.9.85	0	0	3	1	15.0	14.4	49.1	8.1
27.9.85	0	0	8	23	15.7	21.1	24.5	3.5
7.10.85	0	0	1	19	13.4	13.6	36.7	8.0
15.10.85	0	0	0	32	16.1	13.0	8.3	0.0
21.10.85	0	0	3	8	13.8	14.4	0.0	4.1
28.10.85	0	0	3	12	17.2	11.2	0.0	3.2
12.11.85	0	0	0	0	13.4	4.9	22.5	3.5
18.11.85	0	0	0	0	14.2	6.7	13.9	1.0

TABLE V

Correlation Co-efficients for Total Tick Activity with Weather Conditions.

	d.f.	Mean Weekly Max. Air Temp. (°C)	"P" VALUE	Daily Max. Air Temp. (°C)	"P" VALUE	Total Weekly Rainfall (mm)	"P" VALUE	Daily Sunshine (hours)	"P" VALUE
1984									
Chapelton Wood	27	0.291	NS	0.175	NS	-0.367	NS	0.146	NS
Barony Hill	26	-0.133	NS	-0.077	NS	-0.261	NS	0.043	NS
1985									
Chapelton Wood	42	0.467	<0.01	0.442	<0.01	-0.052	NS	0.339	<0.05
Barony Hill	34	0.138	NS	0.203	NS	-0.160	NS	0.390	<0.05

TABLE VI

Correlation Co-efficients for the Activity of Each Tick Stage with Weather Conditions.

		d.f.	Mean Weekly Max. Air Temp. (°C)	"P" VALUE	Daily Max. Air Temp. (°C)	"P" VALUE	Total Weekly Rainfall (mm)	"P" VALUE	Daily Sunshine (hours)	"P" VALUE
1984										
Chapelton Wood	adult	27	0.380	<0.05	0.256	NS	-0.235	NS	0.167	NS
	nymph		0.220	NS	0.099	NS	-0.369	NS	0.108	NS
	larva		0.331	NS	0.306	NS	-0.167	NS	0.183	NS
Barony Hill	adult	26	-0.316	NS	-0.297	NS	-0.020	NS	-0.295	NS
	nymph		-0.213	NS	-0.240	NS	-0.337	NS	-0.150	NS
	larva		-0.066	NS	0.215	NS	-0.006	NS	0.315	NS
1985										
Chapelton Wood	adult	42	0.564	<0.001	0.607	<0.001	0.080	NS	0.160	NS
	nymph		0.453	< 0.01	0.448	< 0.01	-0.027	NS	0.268	NS
	larva		0.378	< 0.05	0.311	< 0.05	-0.104	NS	0.427	<0.01
Barony Hill	adult	34	0.009	NS	0.050	NS	-0.181	NS	0.299	NS
	nymph		-0.138	NS	0.114	NS	-0.194	NS	0.410	<0.05
	larva		0.156	NS	0.198	NS	-0.142	NS	0.356	<0.05

TABLE VII

Correlation Co-efficients for the Activity of each Tick Stage with Weather Conditions for April-May and for June-December.

1984		d.f.	Mean Weekly Max. Air Temp. (°C)	"P" VALUE	Daily Max. Air Temp. (°C)	"P" VALUE	Total Weekly Rainfall (mm)	"P" VALUE	Daily Sunshine (hours)	"P" VALUE
April-May										
Chapelton	adult	5	0.380	NS	0.256	NS	-0.235	NS	0.167	NS
Wood	nymph		0.220	NS	0.099	NS	-0.369	NS	0.108	NS
	larva		0.331	NS	0.306	NS	-0.167	NS	0.183	NS
Barony	adult	5	-0.931	<0.01	-0.459	NS	0.300	NS	-0.369	NS
Hill	nymph		-0.583	NS	-0.387	NS	-0.036	NS	-0.445	NS
	larva		0.106	NS	-0.405	NS	0.673	NS	-0.246	NS
June-Dec.										
Chapelton	adult	20	0.519	<0.05	0.587	<0.01	-0.212	NS	0.477	<0.05
Wood	nymph		0.575	<0.01	0.682	<0.001	-0.384	NS	0.706	<0.001
	larva		0.414	NS	0.582	<0.01	-0.149	NS	0.451	<0.05
Barony	adult	19	-0.035	NS	-0.18	NS	0.069	NS	-0.252	NS
Hill	nymph		-0.088	NS	0.106	NS	-0.263	NS	0.190	NS
	larva		0.039	NS	0.227	NS	-0.051	NS	0.364	NS

TABLE VIII

Correlation Co-efficients for the Activity of each Tick Stage with Weather Conditions for February-May and for June-December.

1985		d.f.	Mean Weekly Max. Air Temp. (°C)	"P" VALUE	Daily Max. Air Temp. (°C)	"P" VALUE	Total Weekly Rainfall (mm)	"P" VALUE	Daily Sunshine (hours)	"P" VALUE
Feb.-May										
Chapelton	adult	13	0.717	<0.01	0.437	NS	-0.150	NS	0.127	NS
Wood	nymph		0.856	<0.001	0.565	<0.05	-0.141	NS	0.115	NS
	larva		0.611	<0.05	0.387	NS	0.040	NS	0.260	NS
Barony	adult	12	0.410	NS	0.178	NS	0.104	NS	-0.055	NS
Hill	nymph		0.466	NS	0.581	<0.05	0.056	NS	0.327	NS
	larva		0.532	<0.05	0.317	NS	0.010	NS	0.311	NS
June-Dec.										
Chapelton	adult	27	0.552	<0.01	0.669	<0.001	0.117	NS	0.264	NS
Wood	nymph		0.489	<0.01	0.450	<0.05	0.023	NS	0.382	<0.05
	larva		0.383	<0.05	0.287	NS	-0.178	NS	0.630	<0.001
Barony	adult	20	0.370	NS	0.211	NS	-0.176	NS	0.541	<0.01
Hill	nymph		0.178	NS	0.227	NS	-0.155	NS	0.455	<0.05
	larva		0.232	NS	0.463	<0.05	0.306	NS	0.525	<0.05

TABLE IX

SMALL MAMMALS TRAPPED IN KILKERRAN WOOD, 1985 GRID REF. NS 318 032

Date	Host Species	Sex of host male	Sex of host female	Ixodes ricinus larvae	Ixodes ricinus nymphs	I.triangulliceps larvae	I.triangulliceps nymphs	TOTAL
20.3.85	Apodemus sylvaticus	0	5	0	0	0	0	0
20.3.85	A.sylvaticus	4	0	0	0	0	0	0
21.3.85	A.sylvaticus	0	2	0	0	0	0	0
21.3.85	A.sylvaticus	1	0	0	0	0	0	0
21.3.85	Clethrionomys glareolus	0	1	0	0	0	0	0
16.4.85	A.sylvaticus	0	1	0	0	0	0	0
16.4.85	A.sylvaticus	2	0	0	0	0	0	0
16.4.85	A.sylvaticus	1	0	1	0	0	0	1
16.4.85	C.glareolus	0	3	0	0	0	0	0
17.4.85	A.sylvaticus	0	1	1	0	0	0	1
17.4.85	A.sylvaticus	2	0	0	0	0	0	0
17.4.85	A.sylvaticus	0	1	2	0	0	0	2
8.5.85	A.sylvaticus	0	1	3	0	0	0	3
9.5.85	A.sylvaticus	0	1	5	0	0	0	5
9.5.85	A.sylvaticus	1	0	3	0	0	0	3
9.5.85	A.sylvaticus	1	0	2	0	0	0	2
9.5.85	A.sylvaticus	1	0	2	0	0	0	2
29.5.85	A.sylvaticus	0	1	14	0	0	0	14
25.6.85	A.sylvaticus	1	0	22	0	0	0	22
25.6.85	A.sylvaticus	1	0	8	0	0	0	8
25.6.85	A.sylvaticus	0	1	13	1	0	0	14
25.6.85	C.glareolus	1	0	25	0	1	1	27
26.6.85	A.sylvaticus	0	1	9	0	0	0	9
16.7.85	A.sylvaticus	1	0	5	0	0	0	5
17.7.85	A.sylvaticus	1	0	20	2	0	0	22
7.8.85	Sorex araneus	-		0	0	0	0	0
8.8.85	A.sylvaticus	0	1	6	0	0	0	6
27.8.85	A.sylvaticus	0	1	0	0	0	0	0
27.8.85	C.glareolus	0	1	1	0	0	0	1
16.9.85	A.sylvaticus	0	1	5	1	0	0	6
16.9.85	A.sylvaticus	1	0	0	0	0	0	0
17.9.85	A.sylvaticus	1	0	6	0	0	0	6
18.9.85	C.glareolus	0	1	0	0	3	0	3
8.10.85	A.sylvaticus	1	0	1	0	0	0	1
9.10.85	C.glareolus	1	0	1	0	0	1	2
9.10.85	A.sylvaticus	1	0	2	0	2	0	4
10.10.85	A.sylvaticus	0	1	2	0	1	0	3
10.10.85	A.sylvaticus	1	0	1	0	0	0	1

TABLE IX

SMALL MAMMALS TRAPPED IN KILKERRAN WOOD, 1985 GRID REF. NS 318 032 (cont.)

Date	Host Species	Sex of host male	Sex of host female	Ixodes ricinus larvae	Ixodes ricinus nymphs	I.trianguliceps larvae	I.trianguliceps nymphs	TOTAL
29.10.85	A.sylvaticus	0	1	0	0	2	0	2
29.10.85	A.sylvaticus	0	1	1	0	0	0	1
29.10.85	A.sylvaticus	1	0	0	0	2	0	2
1.11.85	A.sylvaticus	0	1	2	0	2	0	4
1.11.85	A.sylvaticus	0	1	2	0	2	0	4
1.11.85	A.sylvaticus	1	0	0	1	1	0	2
1.11.85	A.sylvaticus	0	1	0	0	1	0	1
1.11.85	A.sylvaticus	0	1	2	1	0	0	3
1.11.85	A.sylvaticus	1	0	1	0	2	0	3
1.11.85	A.sylvaticus	1	0	0	0	2	0	2
1.11.85	A.sylvaticus	0	1	0	0	1	0	1
1.11.85	A.sylvaticus	1	0	0	1	2	0	3
19.11.85	A.sylvaticus	0	1	0	0	2	0	2
19.11.85	A.sylvaticus	1	0	0	0	1	0	1
22.11.85	A.sylvaticus	1	0	1	0	0	0	1
22.11.85	A.sylvaticus	1	0	0	0	0	0	0
22.11.85	C.glareolus	0	1	0	0	0	0	0
22.11.85	C.glareolus	0	1	0	0	0	0	0
10.12.85	C.glareolus	1	0	0	0	0	0	0
11.12.85	C.glareolus	1	0	0	0	0	0	0

TABLE X

Students T-test - Larval data from small mammal trapping.

		P
Apodemus sylvaticus - infested by *I. ricinus* vs. *I. trianguliceps*,	t=3.279, 112d.f.,	<0.01
Clethrionomys glareolus - infested by *I. ricinus* vs. *I. trianguliceps*,	t=0.881, 22d.f.,	NS
I. ricinus larvae infesting *A. sylvaticus* vs. *C. glareolus*,	t=0.280, 67d.f.,	NS
I. trianguliceps larvae infesting *A. sylvaticus* vs. *C. glareolus*,	t=0.142, 67d.f.,	NS
Total larvae infesting *A. sylvaticus* vs. *C. glareolus*,	t=0.184, 67d.f.,	NS

TABLE XI

Temperature Data From The Insectary

Students T-test

		P
Inside tube vs. inside insectary	t=1.933, 69d.f.,	NS
Inside tube vs. weather station	t=0.446, 69d.f.,	NS
Inside insectary vs. weather station	t=1.793, 68d.f.,	NS

TABLE XII

INSECTARY DEVELOPMENT RESULTS

FEMALE to LARVAE

Date of Female Engorgement	Eggs Present From	Larvae Hatched From
24.4.85	4.6.85	-
24.4.85	13.6.85	18.9.85
8.5.85	31.5.85	19.8.85
16.5.85	14.6.85	18.9.85
16.5.85	14.6.85	-
16.5.85	21.6.85	18.9.85
22.5.85	5.6.85	-
22.5.85	21.6.85	30.9.85
22.5.85	21.6.85	30.9.85
22.5.85	27.6.85	30.9.85
28.5.85	21.6.85	30.9.85
28.5.85	21.6.85	30.9.85
28.5.85	24.6.85	30.9.85
28.5.85	24.6.85	2.10.85
28.5.85	1.7.85	30.10.85
11.6.85	2.7.85	2.10.85
11.6.85	5.7.85	-

TABLE XIII

INSECTARY DEVELOPMENT RESULTS

LARVAE to NYMPHS

Date of Engorgement	Nos. of Larvae Engorged	Period of Moulting	Nos. of Nymphs Moulted
13.5.85	12	8 - 19.8.85	11
14.5.85	4	14.8.85	3
17.5.85	2	12.8.85	2
20.5.85	5	9 - 21.8.85	5
23.5.85	2	12.8.85	1
27.5.85	5	19.8.- 3.9.85	4
28.5.85	4	14.8.85	1
3.6.85	4	19.8.- 3.9.85	4
19.6.85	4	3 - 13.9.85	3
24.6.85	8	13 - 27.8.85	5
30.6.85	1	10.9.85	1
8.7.85	4	-	-
15.7.85	6	-	-
22.7.85	3	-	-
29.7.85	4	-	-
12.8.85	3	-	-
20.8.85	3	-	-
27.8.85	3	-	-
3.9.85	3	-	-
10.9.85	4	-	-
7.10.85	7	-	-
14.10.85	8	-	-
22.10.85	8	14.8.86	1
28.10.85	9	14.8.86	1
8.11.85	4	-	-

TABLE XIV

INSECTARY DEVELOPMENT RESULTS

NYMPHS to ADULTS

Date of Engorgement	Nos. of Nymphs Engorged	Period of Moulting	Nos. of Adults Moulted
21.8.84	6	-	-
31.8.84	2	-	-
8.9.84	2	-	-
17.9.84	4	19.8.85	1
26.9.84	1	-	-
29.9.84	1	6.8.85	1
11.3.85	9	28.8.- 26.9.85	5
3.4.85	2	-	-
16.4.85	8	-	-
18.4.85	6	20.9.- 26.9.85	2
23.4.85	6	19 - 28.8.85	5
29.4.85	9	14.8.- 9.9.85	8
7.5.85	14	12 - 19.8.85	2
8.5.85	10	19.8.- 3.9.85	10
14.5.85	2	28.8.85	1
17.5.85	6	21 - 27.8.85	2
20.5.85	14	9 - 27.8.85	9
23.5.85	7	23.8.85	4
27.5.85	19	19.8.- 13.9.85	15
28.5.85	8	28.8.- 3.9.85	6
3.6.85	9	19.8.- 3.9.85	6
7.6.85	12	19.8.- 9.9.85	11
19.6.85	15	3 - 28.9.85	9
24.6.85	7	13 - 16.9.85	5
30.6.85	12	15 - 16.9.85	5
8.7.85	11	-	-
15.7.85	10	-	-
22.7.85	11	-	-
29.7.85	7	-	-
6.8.85	5	-	-
12.8.85	13	-	-
20.8.85	11	-	-
27.8.85	12	-	-
3.9.85	15	-	-
10.9.85	10	-	-
17.9.85	6	-	-
30.9.85	3	-	-
7.10.85	7	14.8.86	2
14.10.85	7	-	-
22.10.85	9	14.8.86	2
28.10.85	5	-	-
8.11.85	10	-	-

TABLE XV

Tick Control Trials - Students T-test
Site : Davidson, E. Deloraine, Ettrick.

Days Post-treatment	Treatment	t	d.f.	P
13	Control vs. HCC	2.490	13	<0.05
	Control vs. Cypor	4.713	5	<0.01
	HCC vs. Cypor	1.848	12	NS
27	Control vs. HCC	1.620	16	NS
	Control vs. Cypor	2.234	13	<0.05
	HCC vs. Cypor	1.247	15	NS
41	Control vs. HCC	2.972	14	<0.02
	Control vs. Cypor	3.189	12	<0.01
	HCC vs. Cypor	2.133	16	<0.05
55	Control vs. HCC	1.505	17	NS
	Control vs. Cypor	1.467	14	NS
	HCC vs. Cypor	0.979	17	NS

TABLE XVI

Tick Control Trials - Students T-test
Site : McMorran, Miefield, Twynholm.

Days Post-treatment	Treatment	t	d.f.	P
45	Control vs. Cypor	3.962	8	<0.01
	Control vs. HCC	4.359	11	<0.002
	Control vs. Spoton	2.887	13	<0.02
	Cypor vs. HCC	0.455	11	NS
	Cypor vs. Spoton	1.680	13	NS
	HCC vs. Spoton	1.589	16	NS
63	Control vs. Cypor	2.169	10	NS
	Control vs. HCC	2.544	13	<0.05
	Control vs. Spoton	0.746	17	NS
	Cypor vs. HCC	0.514	11	NS
	Cypor vs. Spoton	3.019	15	<0.01
	HCC vs. Spoton	3.615	18	<0.002
77	Control vs. Cypor	4.866	18	<0.001
	Control vs. HCC	5.118	18	<0.001
	Control vs. Spoton	2.282	18	<0.05
	Cypor vs. HCC	1.000	18	NS
	Cypor vs. Spoton	3.736	18	<0.002
	HCC vs. Spoton	4.200	18	<0.001

TABLE XVII

Tick Control Trials - Students T-test
Site : Cavers, Sorbie, Langholm.

Days Post-treatment	Treatment	t	d.f.	P
14	Control vs. HCC pour-on	2.160	18	<0.05
	Control vs. HCC dip	1.755	17	NS
	HCC pour-on vs. HCC dip	0.855	17	NS
28	Control vs. HCC pour-on	3.500	20	<0.01
	Control vs. HCC dip	4.392	20	<0.001
	HCC pour-on vs. HCC dip	2.108	20	<0.05
42	Control vs. HCC pour-on	3.252	18	<0.01
	Control vs. HCC dip	4.022	18	<0.001
	HCC pour-on vs. HCC dip	1.683	18	NS
56	Control vs. HCC pour-on	2.288	17	<0.05
	Control vs. HCC dip	2.415	17	<0.05
	HCC pour-on vs. HCC dip	0.460	18	NS
71	Control vs. HCC pour-on	3.219	18	<0.01
	Control vs. HCC dip	3.595	18	<0.01
	HCC pour-on vs. HCC dip	0.805	18	NS
91	Control vs. HCC pour-on	3.039	19	<0.01
	Control vs. HCC dip	3.039	19	<0.01
	HCC pour-on vs. HCC dip	-	-	-

In Tables XVIII - XXX, H= numbers of ticks found on head,
B= numbers of ticks found on body.

TABLE XVIII

Tick counts, ewes - 24/4/86 - 13 days post-treatment
Davidson, E. Deloraine, Ettrick

	Untreated		HCC pour-on		Cypor	
	H	B	H	B	H	B
	0	3	0	2	0	4
	1	4	0	1	0	2
	0	3	0	1	0	6
	0	10	0	0		
			0	2		
			0	3		
			0	5		
			0	1		
			0	0		
			0	0		
			1	3		
Totals	1	20	1	18	0	12
Total	21		19		12	
n	4		11		3	
x	5.2		1.7		4	
s.d.	3.3		1.7		2	

TABLE XIX

Tick counts, ewes - 8/5/86 - 27 days post-treatment
Davidson, E. Deloraine

	Untreated		HCC pour-on		Cypor	
	H	B	H	B	H	B
	1	1	1	1	1	1
	5	20	0	3	0	0
	0	9	3	0	0	1
	0	2	0	0	0	0
	3	1	0	0	2	2
	3	9	5	3	0	0
	1	2	0	1	1	1
	0	8	1	0		
			2	11		
			1	0		
Totals	13	52	13	19	3	4
Total	65		32		7	
n	8		10		7	
x	8.1		3.2		1	
s.d.	7.7		4.2		1.5	

TABLE XX

Tick counts, ewes - 22/5/86 - 41 days post-treatment
Davidson, E. Deloraine

	Untreated		HCC pour-on		Cypor	
	H	B	H	B	H	B
	0	3	0	1	0	0
	2	4	0	0	0	0
	0	0	1	0	0	0
	1	1	0	0	0	0
	0	1	0	0	0	0
	2	3	0	1	0	0
			0	0		
			0	0		
			0	0		
			1	0		
Totals	5	12	2	2	0	0
Total	17		4		0	
n	6		10		8	
x	2.8		0.4		0	
s.d.	2.3		0.5		0	

TABLE XXI

Tick counts, ewes - 5/6/86 - 55 days post-treatment
Davidson, E. Deloraine

	Untreated		HCC pour-on		Cypor	
	H	B	H	B	H	B
	0	0	0	0	0	0
	5	8	0	0	0	0
	0	0	0	1	0	1
	2	0	1	0	0	0
	0	1	0	0	0	0
	2	1	0	1	0	0
	0	0	0	0	0	0
	0	2	0	0	1	0
			0	0		
			0	1		
			0	0		
Totals	9	12	2	4	1	1
Total	21		6		2	
n	8		11		8	
x	2.6		0.5		0.25	
s.d.	4.3		0.7		0.5	

TABLE XXII

Tick counts, ewes - 8/5/87 - 45 days post-treatment
McMorran, Miefield, Twynholm

Untreated		Cypor		HCC pour-on		Spoton	
H	B	H	B	H	B	H	B
0	5	0	0	2	2	0	0
0	3	2	0	0	1	1	2
2	8	0	1	1	0	1	0
2	4	0	1	0	1	2	4
2	4	0	0	0	0	4	0
				0	0	1	3
				1	0	1	1
				1	0	1	1
						0	0
						0	2
Totals	6 24	2	2	5	4	11	13
Total	30	4		9		24	
n	5	5		8		10	
x	6	0.8		1.1		2.4	
s.d.	2.5	0.8		1.2		1.9	

TABLE XXIII

Tick counts, ewes - 26/5/87 - 63 days post-treatment
McMorran, Miefield, Twynholm

	Untreated		Cypor		HCC pour-on		Spoton	
	H	B	H	B	H	B	H	B
	2	2	0	0	0	0	3	0
	1	0	0	0	0	0	1	3
	0	0	0	0	1	0	0	0
	0	1	0	0	0	0	1	1
	0	3	0	0	0	0	3	1
	2	1			0	0	0	0
	0	0			0	0	0	0
					0	0	2	1
							1	1
							3	1
							2	0
							2	2
Totals	5	7	0	0	1	0	18	10
Total	12		0		1		28	
n	7		5		8		12	
x	1.7		0		0.1		2.3	
s.d.	1.6		0		0.4		1.6	

TABLE XXIV

Tick counts, ewes - 9/6/87 - 77 days post-treatment
McMorran, Miefield, Twynholm

	Untreated		Cypor		HCC pour-on		Spoton	
	H	B	H	B	H	B	H	B
	1	2	0	0	0	0	1	0
	1	1	0	0	0	0	0	0
	3	0	0	0	0	0	2	0
	0	0	0	0	0	0	1	0
	3	1	0	0	0	0	2	0
	1	3	0	0	0	0	1	1
	4	2	0	0	0	0	0	0
	2	2	1	0	0	0	1	0
	1	1	0	0	0	0	2	0
	0	1	0	0	0	0	3	0
Totals	16	13	1	0	0	0	13	1
Total	29		1		0		14	
n	10		10		10		10	
x	2.9		0.1		0		1.4	
s.d.	1.7		0.3		0		1.0	

TABLE XXV

Tick counts, ewes - 31/3/87 - 14 days post-treatment
Cavers, Sorbie, Langholm

	Untreated		HCC pour-on		HCC dip	
	H	B	H	B	H	B
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	1	0	0	0	0
	5	3	0	0	0	0
	0	2	0	0	0	0
	2	1	0	0	0	0
	0	0	0	0	0	0
	0	1	0	0	0	2
	2	1	0	0		
Totals	9	9	0	0	0	2
Total	18		0		2	
n	10		10		9	
x	1.8		0		0.2	
s.d.	2.5		0		0.7	

TABLE XXVI

Tick Counts, ewes - -14/4/87 - 28 days post-treatment
Cavers, Sorbie, Langholm

	Untreated		HCC pour-on		HCC dip	
	H	B	H	B	H	B
	0	0	0	1	0	0
	0	9	0	0	0	0
	3	8	0	0	0	0
	0	3	0	1	0	0
	2	3	0	0	0	0
	2	2	0	3	0	0
	1	7	0	0	0	0
	0	1	0	0	0	0
	1	7	0	0	0	0
	2	2	0	3	0	0
	0	2	0	1	0	0
Totals	11	44	0	9	0	0
Total	55		9		0	
n	11		11		11	
x	5		0.8		0	
s.d.	3.6		1.2		0	

TABLE XXVII

Tick counts, ewes - 28/4/87 - 42 days post-treatment
Cavers, Sorbie, Langholm

	Untreated		HCC pour-on		HCC dip	
	H	B	H	B	H	B
	4	2	3	2	0	0
	9	22	0	3	0	0
	5	24	0	0	0	0
	2	10	0	3	0	0
	2	9	1	12	0	0
	3	17	0	0	0	0
	4	14	0	1	3	0
	2	8	0	0	0	0
	2	1	0	0	0	0
	4	5	0	1	0	0
Totals	47	112	4	22	3	0
Total	159		26		3	
n	10		10		10	
x	15.9		2.6		0.3	
s.d.	11.6		4.0		0.9	

TABLE XXVIII

Tick counts, ewes - 12/5/87 - 56 days post treatment
Cavers, Sorbie, Langholm

	Untreated		HCC pour-on		HCC dip	
	H	B	H	B	H	B
	1	0	0	2	0	0
	0	0	0	1	0	0
	7	13	0	0	1	0
	5	0	0	0	0	0
	3	4	0	0	1	0
	3	1	0	0	2	0
	1	1	0	0	0	0
	4	1	0	3	0	0
	1	2	0	0	0	0
			0	0		
Totals	25	22	0	6	4	0
Total	47		6		4	
n	9		10		10	
x	5.2		0.6		0.4	
s.d.	5.9		1.1		0.7	

TABLE XXIX

Tick counts, ewes - 27/5/87 - 71 days post-treatment
Cavers, Sorbie, Langholm

	Untreated		HCH pour-on		HCC dip	
	H	B	H	B	H	B
	3	1	0	0	0	0
	4	2	0	0	1	0
	0	3	0	0	0	0
	1	0	1	1	0	1
	2	2	0	0	0	0
	0	0	1	2	0	0
	5	0	1	0	1	0
	2	10	0	0	0	0
	3	0	0	0	0	0
	4	2	0	1	1	0
Totals	24	40	3	4	3	1
Total	44		7		4	
n	10		10		10	
x	4.4		0.7		0.4	
s.d.	3.3		1.0		0.5	

TABLE XXX

Tick counts, ewes - 16/6/87 - 91 days post-treatment
Cavers, Sorbie, Langholm

	Untreated		HCC pour-on		HCC dip	
	H	B	H	B	H	B
	0	0	0	1	0	0
	3	5	0	0	0	0
	0	0	0	1	0	0
	2	0	0	0	1	0
	3	2	0	0	0	0
	2	0	2	0	0	0
	4	0	0	0	2	0
	0	0	0	0	1	0
	3	2	0	0	0	0
	6	4	0	0	0	0
	7	1				
Totals	30	14	2	2	4	0
Total	44		4		4	
n	11		10		10	
x	4.0		0.4		0.4	
s.d.	3.5		0.7		0.7	