# HOSTS AND DISTRIBUTION OF ROCKY MOUNTAIN WOOD TICKS *(DERMACENTOR ANDERSONI)* AT A TICK FOCUS IN BRITISH COLUMBIA RANGELAND

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## ABSTRACT

In a study of a Rocky Mountain wood tick (RMWT) population, *Eutamias amoenus* and *Peromyscus maniculatus* were the hosts most frequently trapped. Of these *E. amoenus* carried the greater number of immature RMWT. RMWT were also found in decreasing order of abundance on the following larger rodents: *Marmota flaviventris*, *Neotoma cinerea*, and *Tamiasciurus hudsonicus*. Of 3 areas sampled in and near the tick focus in 1967, most of the ticks were found on the uppermost steep and rocky, shrubby area, while the fewest were taken on a less steep grassy slope with few rocks. Sherman traps were the most efficient of 7 types tested in 1967 for capturing small mammals.

In both 1967 and 1968, larvae were most abundant on rodents in July, and scarce or absent from September to June. In 1968, trapping rodents from March to October revealed a major increase in nymph numbers in April and May, and a smaller rise in August and early September. In 1967, $CO_2$ as dry ice attracted only a few adult and nymphal ticks, when placed on and near the trap lines and rodent burrows. The number of unfed adult ticks/100 $m^2$, recorded by flagging on and near the trap lines, declined each year in 1968 to 1970.

In addition to RMWT, a few *Ixodes kingi* and *I. marmotae* were collected from mustelids and rodents.

## INTRODUCTION

The prospects for management of Rocky Mountain Wood Tick *(Dermacentor andersoni)* populations by alteration of their environment (Wilkinson, 1979a) would be greatly improved if life tables of the tick, including relevant information on its mammal hosts, could be compiled at several localities in each of the bioclimatic zones in which it is of major importance. The present exploratory study on the hosts and distribution of various instars of this tick was carried out in the *Pinus ponderosa - Agropyron spicatum* zone of British Columbia (Wilkinson, 1967). In this zone, the tick causes paralysis of man and livestock (Gregson, 1966) in springtime when the livestock are on open grassland ranges, i.e., between the valley bottoms used in winter and the higher forest ranges used in summer. 'Tick' in this paper refers to Rocky Mountain Wood Tick (RMWT) unless specified otherwise.

Gregson (1956) published lists of hosts of *D. andersoni* in Canada, but this is the first published account of quantitative RMWT — host relations on a study area in Canada. Some of the 1967 work was reported in an unpublished thesis (Maynard, 1968). Sonenshine *et al.* (1976) studied RMWT in Montana in relation to host numbers and the ecology of Colorado tick fever virus. In this paper, an attempt is made to relate numbers of adult ticks, obtained by flagging, to numbers of nymphs on hosts in the previous year. Some comments on problems in compiling life-tables for this tick are included in the discussion.

## METHODS

The study area is located about 1.5 km west of Stump Lake, British Columbia, at approximately 50°23'N and 120°22'W and its aspect is southeasterly. The main features are the rocky outcrops and associated trees *(P. ponderosa* and *Pseudotsuga menziesi)* and rosaceous shrubs (Fig. 1). This site is typical of many isolated tick foci in the area, surrounded by grassland with relatively few ticks (Wilkinson, 1967). The grassland is part of a large field used intermittently for cattle grazing. No cattle were seen on the experimental plots during my observations there, and no attempt was made to record the number or movements of cattle.

### Ticks on small mammals in 1967, and captures of free living RMWT in 1967 and 1968

**Layout of small mammal traps in 1967.** Two parallel trap lines each 40 m long were laid out in each of three areas differing in vegetation and topography, to gain infomation on distribution of instars of the ticks and their hosts. The first and second trap lines were 20 m apart, the uppermost commencing 10 m below a rock cliff (Fig. 2, upper area). The third and fourth trap lines were 60 m and 80 m below the second trap line, on a gentler slope amid grass, shrubs, and large rocks (intermediate area). The fifth and sixth lines were 60 and 80 m below the fourth lines, on gently sloping open grassland (lower area). Each pair of trap lines could be considered as sampling an area 40 m x 40 m, separated from the other areas by a gap of 40 m.

Fig. 1. General view of *D. andersoni* focus near Stump Lake, looking southwest. Note extensive grassland around focus.

**Trapping procedures 1967.** Four differnt types of traps, Sherman, Longworth, Utah, and Hav-a-hart (HH) (Table 1), were set out 5 m apart on each 40 m trap line, in randomized sets of 4 traps each, with 2 sets per line commencing 2.5 m from the end of the line. This variety of traps was to provide information on the best traps for small mammals for the 1968 studies. The Utah traps tended to wound the captured mammals and were removed after the June 8 trapping. Half were replaced by Burt (1940) traps, and half by HH traps; the Burt traps were later replaced by the *Rattus* type (Table 1). After July 28, only Sherman (Mosby, 1963) and Longworth (Chitty and Kempson, 1949) traps were used for small rodents. There was also one 'large box' trap in the center of each trap line able to accommodate squirrel-size rodents or *Mustela*. In each area, one of these was baited for rodents, and one was baited with fish for *Mustela*.

Traps were set on two consecutive days and emptied on the day after setting, in alternate weeks between May 24 and August 31. Between setting, the traps were left baited but with egress possible, to encourage regular visiting of the traps (pre-baiting, see Chitty and Kempson, 1949). Traps for rodents were baited with prunes rubbed with peanut butter except the 'Utah' traps, which were baited with peanut butter only because of the small treadle. All these small mammal traps, except the *Rattus* traps, were provided with cotton wool to reduce deaths by chilling and shock, and with plywood covers to reduce exposure to wind and sun. Captured mammals were shaken into a plastic bag containing an ether-soaked pad and lightly anaesthetised, or unaesthetised animals were grasped at the nape of the neck after shaking into the bag. They were removed from the plastic bag and examined for ticks at the site of capture by running a tweezer blade through the pelage. Any ticks found were placed in labelled tubes for return to the laboratory. The trap number and tag number of the mammal were recorded; any animals not already tagged were tagged in one ear with numbered stainless steel fingerling tags*. The majority of these mammals were then released at the site of capture.

Some of the rodents were returned to the laboratory in cages inside cloth bags and held there for 10 days, to obtain a comparison of the count of ticks found in the field and the number falling off in the bags. These rodents were returned to the site of capture 13-14 days after capture. Ticks were identified, stored in a refrigerator, and later released near the site of capture.

In addition to the traps on the lines, four size 1½ leg-hold traps, with padded jaws, were set near the burrows of a small colony of yellow-bellied marmots (*Marmota flaviventris* Audubon and

*Salt Lake Stamp Co., 380 W, 2S, Salt Lake City, Utah 84101.

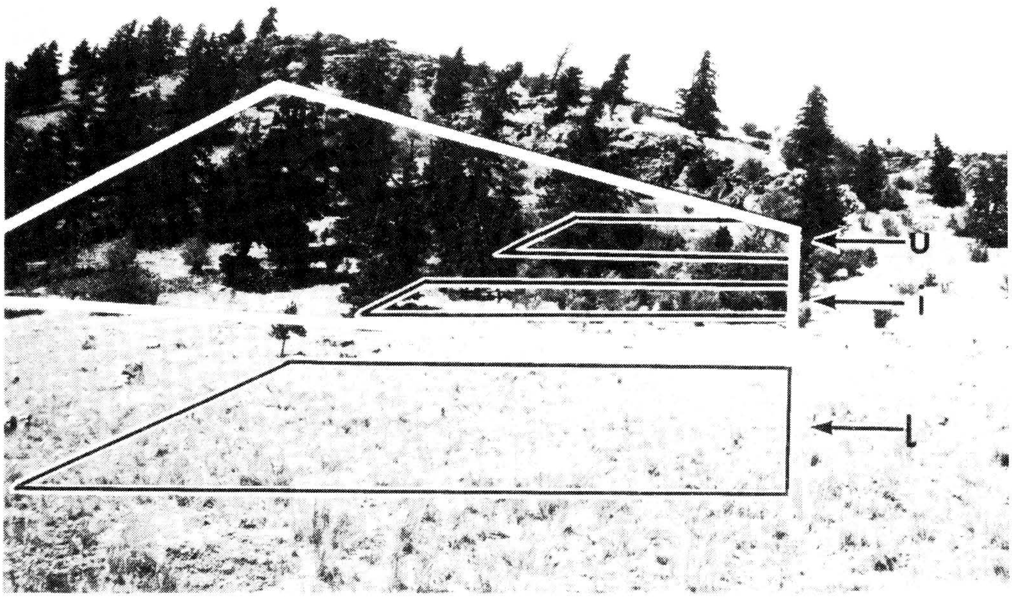


Fig. 2. Black-white lines indicate approximate extent of upper (u), intermediate (i), and lower (l) areas of 1967 study. White lines indicate 150 x 150 m trapping area in 1968, looking northwest. All areas were rectangular, asymmetry is due to camera angle.

Bachman) situated between the upper and intermediate zones, for one day only (August 17).

**Tests with $CO_2$ as 'dry ice' to attract ticks in 1967.** On May 17 and 31 and June 21 and 28, one 0.9 x 0.9 m white flannelette cloth was placed on the ground in the center of each of the 6 trap lines and one was placed 10 m southeast of each of these centers and in line with them (i.e., four cloths on each of the three areas). A $CO_2$ block was placed in the center of each alternate cloth to evaluate this method of collecting ticks (Garcia, 1965).

The blocks weighed about ⅓ kg and were contained in 250-ml freezer cartons with a 4-mm hole at 90° intervals around the base. The cloths were examined for ticks two hours after they were put out. The ticks were then counted and returned to the ground nearby, and the cloths were removed. On August 9, one cloth with $CO_2$ and one blank cloth were put out in each area, either at the center of a trap line or southeast of them as before, determined at random within each area. In addition, one $CO_2$ cloth and one blank cloth were placed near each of four separate burrows in the upper area and similarly in the lower area. In the intermediate area, one cloth with $CO_2$ was placed in a former cattle loafing area under a ponderosa pine (Hafez, 1969); one $CO_2$ cloth was also placed near each of two burrows, but no blank cloths were used in this area. On August 23, two cloths, each with a 1-kg block without carton, and two with ⅓-kg blocks as before, were placed in each of the three areas, all cloths being near separate burrows.

**Flagging for host-seeking adult ticks.** Transects 40 m long x 3 m wide, along the 1967 traps lines, were 'flagged' (Wilkinson, 1976) on March 12, 19, and 26 and April 8 and 23, 1968, the season of activity of host-seeking adults. Forward and return traverses were made on each line and the highest number of ticks of each sex was recorded for each traverse. Ticks were replaced close to the place of capture.

**Ticks on trapped animals in 1968, and flagging for adult ticks in 1969 and 1970**

**Sampling ticks and their hosts on a 150 m x 150 m trap grid at the tick focus in 1968.** The 1967 studies had provided information on the most effective type of trap, the area of highest tick density, and the distances travelled by deer mice (*Peromyscus maniculatus* [Wagner]) and yellow-pine chipmunks (*Eutamias amoenus* [Allen]). Based on this information, 36 Sherman traps were placed 25 m apart on a 150 x 150 m grid which extended from the base of the rock wall to beyond the lower edge of the treed area (Figs. 2 and 5). This area included some marmot burrows and most of the area favourable to *Eutamias*. To improve trapping capabilities for bushy-tailed wood rats, *Neotoma cinerea* (Ord) and American red squirrels, *Tamiasciurus hudsonicus* (Erxleben), one single-door and one double-door plywood-clad wire mesh trap with 15 x 15 cm doors

(National Live Trap Corp., P.O. Box 302, Tomahawk, Wisc. 54487) were placed in each quarter of the grid. The traps were set for two consecutive days every other week from March to October to provide information on numbers of immature RMWT in the spring and summer, and the gradual reduction of tick activity in the fall; very few RMWT are active in November-February (Wilkinson, 1968).

Procedures for processing the mammals and ticks were the same as in 1967. Movements of some of the farther-travelling chipmunks and deer mice were mapped to provide information on desirable grid size in future work.

**Marmot and porcupine traps, 1968.** In the weeks between setting the Sherman and National traps, four single-door cage traps as described by Trump and Hendricksen (1943) and 4 to 6 leg-hold traps were set around the marmot burrows within the 150 x 150 m grid. When using leg-hold traps, the operator remained at the site for about two hours to release the marmots. The cage traps were left set overnight. In the western corner of the grid, a double-door wire-mesh trap (doors 38 x 38 cm) was placed near a rock crevice containing old porcupine (*Erethizon dorsatum* [Linnaeus]) droppings. This trap was set and baited with carrots at the same intervals as the marmot traps to trap porcupine.

**Flagging of 1968 trap lines in 1969 and 1970.** Transects 150 m long and 3 m wide were flagged on March 27, 1969, in one direction only on each trap line, on a line halfway between each trap line, and 12.5 m below the lowest trap line, i.e., 12 transects at 12.5 m intervals. Flagging was resumed in 1970 because some *D. andersoni* have a 2-year life cycle (Wilkinson, 1968). On April 2, 1970, only the trap lines were flagged, i.e., six 150 x 3 m transects, since by that time the field had been overgrazed, and the number of ticks was so low that more extensive flagging was considered unproductive.

## RESULTS

### 1967 trapping and $CO_2$ attractant results

**Efficiency of mammal traps.** The Sherman trap caught the greatest number of chipmunks and almost as many deer mice as the more elaborate Longworth trap (Table 1). Removal of rodents from the Longworth trap was slightly easier than from the Sherman, but chipmunks occasionally chewed holes in the soft aluminum of the Longworth trap.

The Utah, HH, and Burt's traps were also intended for these mouse- and rat-sized rodents. The HH

**TABLE 1.** Efficacy of live traps tested at Stump Lake tick focus in 1967.

| Type | No. of trap-days[1] (No. of traps) | No. of rodents captured | | Rodents per trap-day | |
|---|---|---|---|---|---|
| | | Chipmunks | Deer mice | Chipmunks | Deer mice |
| Sherman | 192(12) | 29 | 65 | 0.15 | 0.34 |
| Longworth | 192(12) | 11 | 75 | 0.06 | 0.39 |
| Large box[2] | 144(12) | 7 | 6 | 0.05 | 0.04 |
| 'Utah'[2] | 48(12) | 1 | 4 | 0.02 | 0.08 |
| Hav-a-hart (HH)[2] | 36(6) | 3 | 12 | 0.08 | 0.33 |
| *Rattus*, wire[2] | 18(6)[3] | 0 | 0 | 0 | 0 |
| Burt (large size) | 18(6)[3] | 0 | 0 | 0 | 0 |

[1]Number of traps x days set.

[2]Hav-a-hart manufactured by Allcock Manufacturing Co., Box 551, Ossining, N.Y. 10562, size about 8 x 8 x 25 cm. 'Utah' made from 1 litre oilcan, with hardware cloth closure secured to snap of 'museum special' snap trap. 'Large box' was a locally made wooden box trap about 15 x 15 x 35 cm. *Rattus* trap was a woven wire mesh trap with treadle entry, overall size about 20 x 35 cm.

[3]Approximate figure. Exact number of days not recorded.

TABLE 2. Comparison of captures of rodents and their **D. andersoni** ticks on three areas in 1967[1]. The numbers of larvae and nymphs are derived from counts on the rodents in the field.

| Area | No. of captures of Chipmunks | Tick nymphs | Tick larvae | No. of captures of Deer mice | Tick nymphs | Tick larvae |
|---|---|---|---|---|---|---|
| Lower grassland | 1 | 0 | 3 | 46 | 4 | 1 |
| Intermediate | 20 | 6 | 12 | 60 | 0 | 1 |
| Upper | 30 | 21 | 25 | 63 | 3 | 14 |

[1] In addition, the following animals and D. andersoni were captured in the upper area:

1 vole probably Microtus montanus on August 17: no ticks (Longworth trap).

1 American red squirrel on July 5: 4 larvae (large wooden trap).

1 muskrat on July 20: no D. andersoni (Longworth trap).

Also 1 marmot on August 17: 14 nymphs and 1 engorged larva (jaw trap); between upper and intermediate areas.

traps performed about as well as the Sherman for deer mice but less well for chipmunks. They tended to close unpredictably, and their open mesh did not protect small rodents from cold, windy weather. The plywood Burt trap and wire *Rattus* traps caught nothing. The 'Utah' trap caught few rodents and those caught were usually injured or killed.

**Differences in numbers of hosts and ticks between areas.** Chipmunks were more numerous and more heavily infested with ticks on the upper slope than on the grassland. Deer mice were captured frequently in the grassland, but were less infested with tick larvae than on the upper slope. Other hosts, with the exception of the marmots, apparently fed very few immature *D. andersoni* on or near the 1967 areas (Table 2). Larvae commenced feeding on rodents in early July and persisted until the end of August (Fig. 3).

**Travel of rodents between captures, and numbers of recaptures.** Of 27 deer mice recaptured a total of 103 times, the maximum straight line distance between any two points of capture for any one mouse varied from 0 to 160 m, with a mean of 35 m. Eight chipmunks were recaptured a total of 28 times. The maximum distances, on the same basis as above, were 0-105 m, with a mean of 59 m.

**Carbon dioxide as a tick attractant.** The only ticks captured were on the cloths in the upper area. Two nymphs and one female were taken from one cloth with $CO_2$, and one male from the other $CO_2$ cloth on May 31. One nymph was taken on May 17 on a cloth with no $CO_2$. On August 9, one nymph was taken on a cloth with $CO_2$ near a rodent burrow. On August 23, one female tick was taken on cloth with a 1-kg $CO_2$ block, and a nymph was found on a cloth with a ⅓-kg block near a burrow. These captures showed a low yield of ticks for the expenditure of approximately 16 kg of $CO_2$.

**Efficiency of field examination and correction factor in 1967 and 1968.**

In 1967, field counts on 5 chipmunks yielded 15 larvae and 5 nymphs which were removed, then the same chipmunks kept in the laboratory yielded a further 25 larvae and 5 nymphs. The unengorged larvae were minute and hard to find in the pelage of the neck. Only one deer mouse, with two nymphs visible in the field, was observed in the laboratory in 1967 — no additional larvae or nymphs were recorded. Comparisons for 1968 are shown in Table 3.

**Ticks other than RMWT in 1967 and 1968**

A few nymphs and larvae of *Ixodes kingi* Bishopp (see Gregson, 1971) and *Ixodes marmotae* Cooley and Kohls were taken on rodents and mustelids. Details are given in Table 4.

**1968 trapping results and results of flagging in 1968-70**

**Numbers of chipmunks and deer mice and their tick infestation, 1968.** Tick infestations and minimum numbers of rodents are shown in Fig. 4. Rodent populations were estimated from the calendar of captures (Mermod, 1969) and these estimates were multiplied by mean tick infestation.

These mean tick infestations were calculated from field counts of ticks on the rodents during each two-day trapping period, not counting recaptured

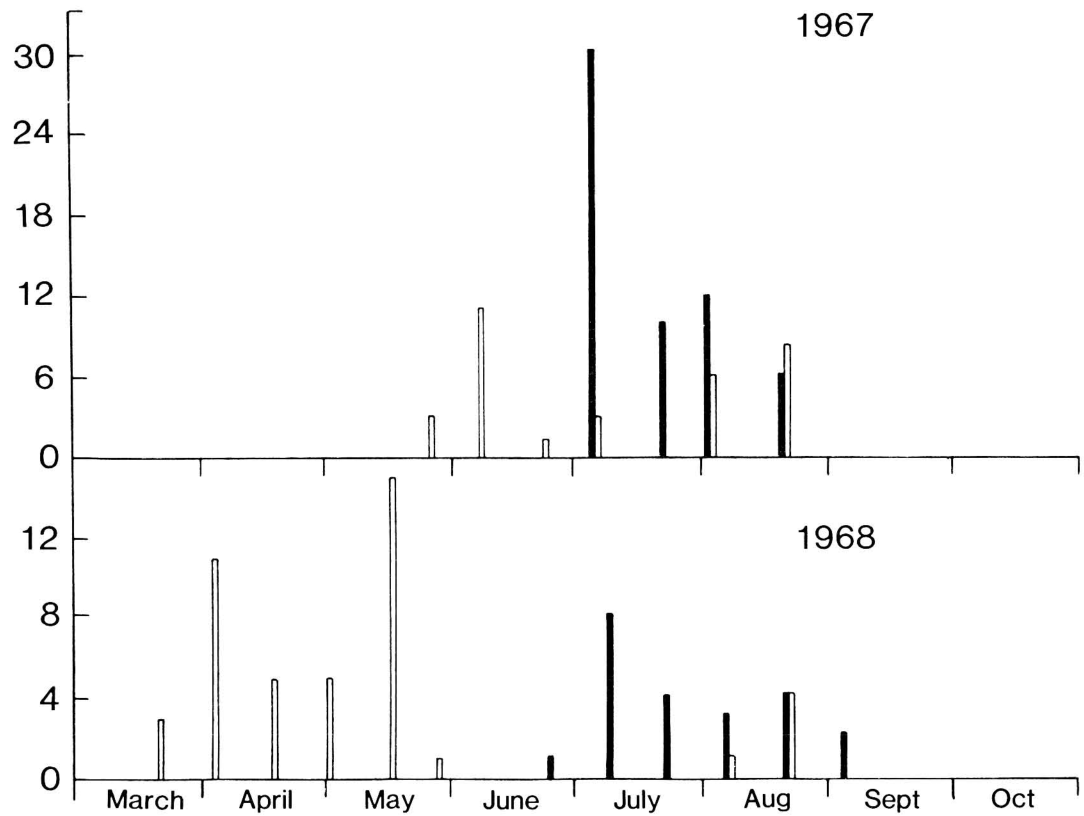


Fig. 3. Seasonal incidence of larvae (black bars) and nymphs (white bars) of *D. andersoni*, on *Eutamias* and *Peromyscus* combined, in 1967 and 1968. 1967 figures are actual captures as reported in Table 2. 1968 figures are populations calculated as in Fig. 4. Both are based on field examinations of rodents, not adjusted for subsequent laboratory yield of ticks.

**TABLE 3.** Comparison of field counts of **D. andersoni** with ticks that subsequently dropped from rodents when they were placed in bagged cages and taken to the laboratory for 10-14 days, in 1968.

| Species of rodent | No. animals taken to laboratory | Field counts | | Additional counts (in laboratory) | | Rounded correction factor for field counts | |
|---|---|---|---|---|---|---|---|
| | | L[1] | N[2] | L | N | L | N |
| Eutamias | 12 | 3 | 7 | 3 | 8 | x 2 | x 2.1 |
| Peromyscus | 14 | 0 | 2 | 0 | 2 | - | x 2 |
| Neotoma | 4 | 0 | 3 | 0 | 8 | - | x 3.7 |
| Marmota | 3 | 0 | 11 | 0 | 3 | - | x 1.3 |

[1]L = Larva

[2]N = Nymph

**TABLE 4.** Ticks other than **D. andersoni** from mammals captured on trap grids at the Stump Lake site in 1967-1968.

| Date | Host | Tick | Tick stage |
|---|---|---|---|
| March 20, 1968 | Peromyscus maniculatus | Ixodes sp.[1] | 1 larva |
| May 21, 1968 | Marmota flaviventris | Ixodes marmotae | 4 nymphs |
| August 7, 1968 | Mustela frenata | Ixodes kingi | 30 nymphs |
| July 20, 1967 | Mustela erminea | Ixodes kingi | 2 nymphs |
| August 16, 1967 | P. maniculatus | Ixodes kingi | 1 nymph[2] |
| August 17, 1967 | Marmota flaviventris | Ixodes marmotae | 4 nymphs |
| | | Ixodes marmotae | 1 larva |
| August 30, 1967 | P. maniculatus | Ixodes sp.[1] | 1 larva |

[1]No adequate key for Canadian Ixodes larvae exists.

[2]Abnormal specimen. 3 legs on one side, 4 on the other.

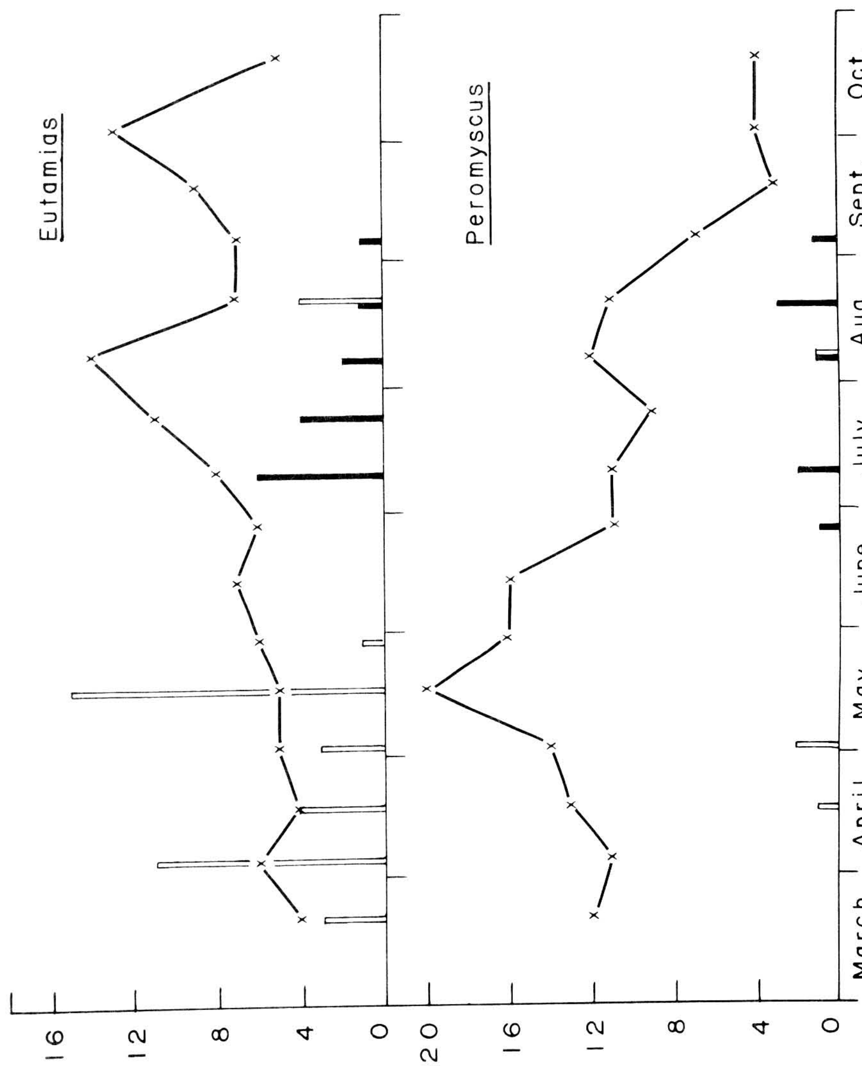


Fig. 4. Minimum numbers of *Eutamias* and *Peromyscus* on the trapping grid, and the numbers of larvae (black bars) and nymphs (white bars) feeding on them, in 1968. (See Results for methods of calculation.)

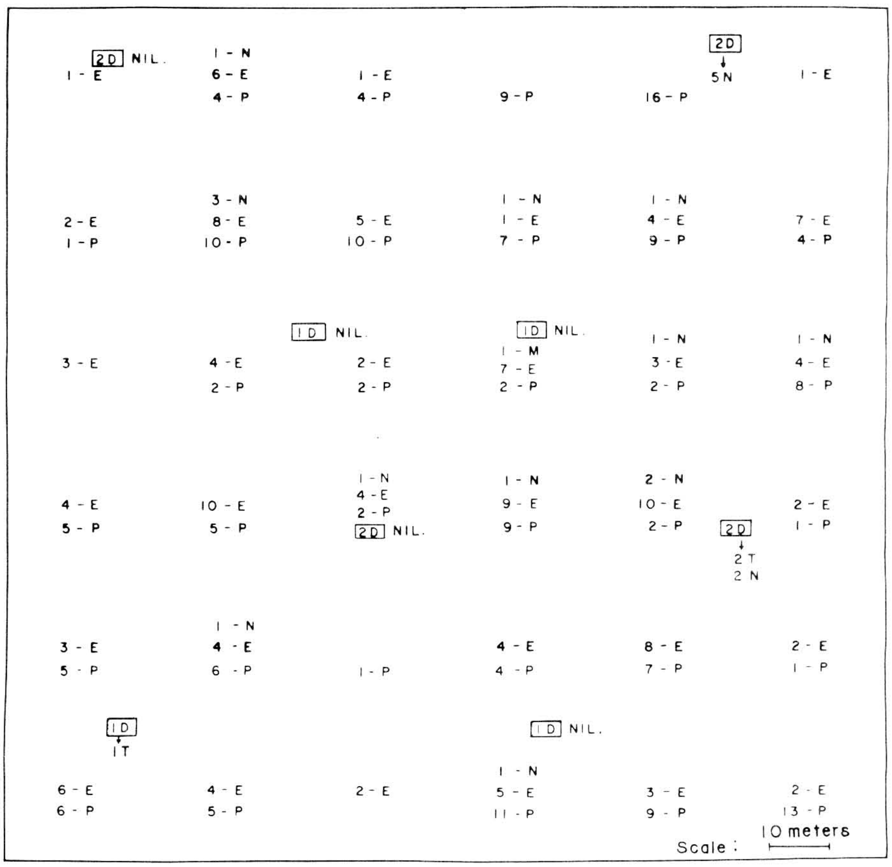


Fig. 5. Numbers of captures of mammals in individual traps during 1968 to illustrate their distribution on the grid. N = *Neotoma*, E = *Eutamias*, P = *Peromyscus*, M = *Mustela*, T = *Tamiasciurus*. 1D and 2D show locations of one and two-door National traps. Remainder were Sherman traps.

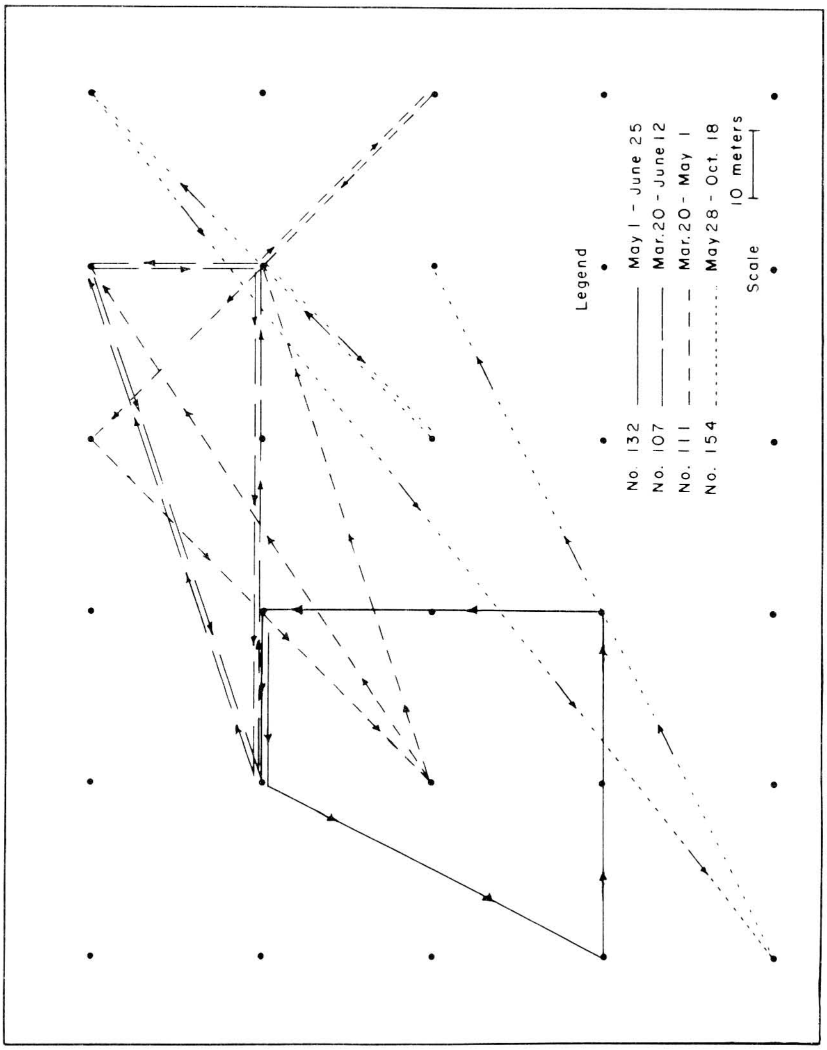


Fig. 6. Travels of some individual *Peromyscus*, as recorded by recaptures on trap grids in 1968. The lowest row of traps was not used by these *Peromyscus* and is omitted.

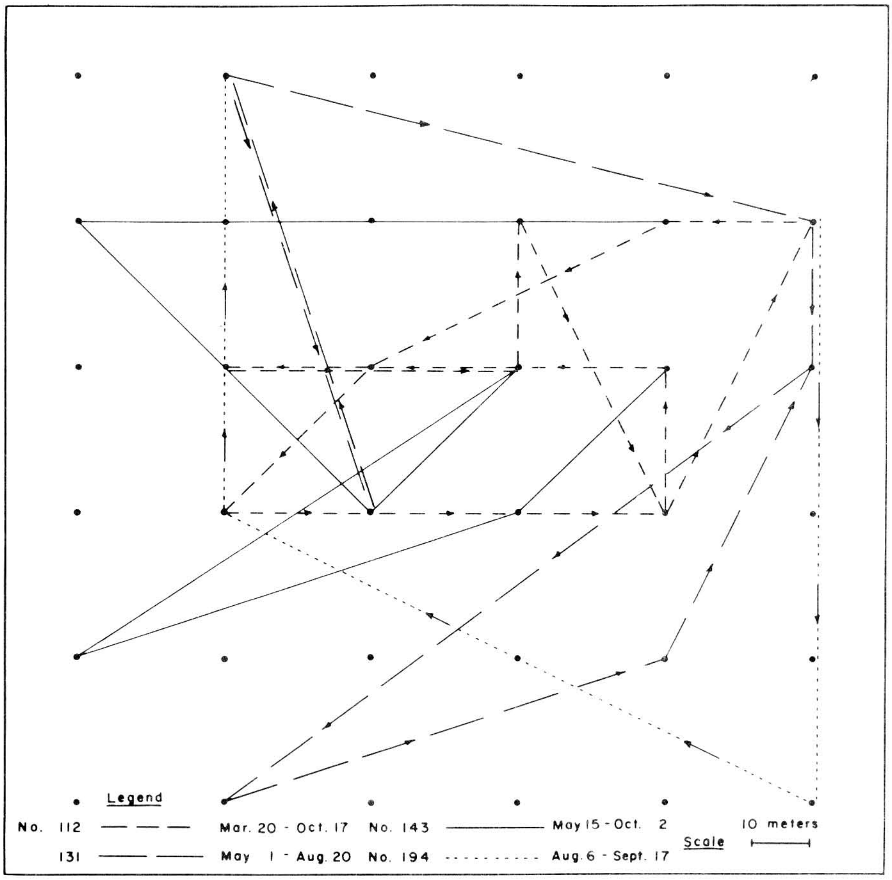


Fig. 7. Travels of some individual *Eutamias*, as recorded by recaptures on trap grid in 1968.

rodents from which ticks had been removed on the previous day. Based on the mean infestations x number of rodents, chipmunks carried 1.7 times more larvae than deer mice, and 9.5 times more nymphs. Seasonal incidence of immature ticks is shown diagrammatically in Fig. 3. Sites of capture of rodents in Fig. 5 and the movements of some of the farther-travelling rodents, derived from recapture records, are shown in Figs. 6 and 7.

**Captures of rodents other than chipmunks and deer mice, and their RMWT infestations in 1968.** RMWT on rodents other than chipmunks and deer mice are shown in Table 5. Captures in the National traps are included in Fig. 5. Three marmots were caught in Trump and Hendricksen type traps and four in leg-hold traps.

Ticks other than *D. andersoni* in 1968 are listed in Table 4. The lack of *D. andersoni* on mustelids was further investigated by Wilkinson (1970b).

**Potential hosts not sampled or inadequately sampled.** One vole, probably *Microtus montanus* (Peale), was trapped on August 17, 1967. It died on the way to the laboratory and a search revealed no ticks. A coyote *(Canis latrans* Say) was seen crossing the grid on May 2, 1968. Mule deer *(Odocoileus hemionus* [Refinesque]) droppings were seen on the grid, but it was not possible to examine these animals for ticks. No porcupine was captured.

**Flagging in 1968.** The highest counts of free-living adult ticks were in the upper area on March 12, 1968, when 5 and 6 adult ticks were taken on the two transects. In the intermediate area, 1 adult was taken on 1 transect on March 19 and 1 on the other transect on April 23. No ticks were taken in the lowest area. Thus, the total peak counts on 6 transects, each 40 m long x 3 m wide, was 13 ticks; adjusting this to the total size of the three 40 x 40 m areas gives 87 adult ticks of 1.8 tick/ 100 m². This

**TABLE 5.** Numbers of captures of **Neotoma**, **Tamiasciurus**, and **Marmota** at Stump Lake bluff in 1968, and infestations with **D. andersoni** in brackets. Figures joined by + indicate field + laboratory counts.

| Date | Neotoma cinerea | Tamiasciurus hudsonicus | Marmota flaviventris |
|---|---|---|---|
| Mar. 20-21 | | 2(3 N[1]) | |
| Apr. 4 | 1(2 + 3 N) | | |
| Apr. 17-18 | 1(0) | 1(0) | |
| Apr. 25 | | | 1(0 + 1 N) |
| May 21 | | | 1(5 + 2 N) |
| May 29 | 1(escaped) | | |
| June 5 | | | 1(0) |
| June 12 | 1(1 + 3 N) | | |
| June 18 | | | 1(6 + 0 N) |
| June 26 | 1(0 + 2 N) | | |
| July 4 | | | 1(1 N) |
| July 15 | | | 1(2 L[2]) |
| July 17 | | | 1(escaped) |
| July 24 | 1(1 L) | | |
| Aug. 6-7 | 5(0) | | |
| Sep. 4-5 | 2(2 L) | | |
| Sep. 17-18 | 3(0) | | |
| Oct. 2-3 | 2(0) | | |
| Sep. 17-18 | 4(0 + 0) | | |
| Total | 22(3 L, 11 N) | 3(3 N) | 7 (2 L, 15 N) |

[1]Nymph

[2]Larva

figure can be compared with the 34 nymphs collected on the areas in 1967 (Table 2, see Discussion for suggested adjustments to nymph numbers).

**Estimation of adult tick population of 1968 trapping area by flagging in 1969.** In 1969, sums of males plus females for each of the 12 lines sampled, starting at the lowest line, were 2, 1, 0, 0, 1, 1, 2, 1, 3, 5, 14, and 13. Each flag swath was approximately 3 m wide so the total number of host-seeking ticks was estimated at $43 \times \frac{150}{12 \times 3} = 179$, or 0.8 ticks/100 $m^2$.

Counts in the 6 trap lines in 1970 were 0, 0, 0, 1, 2, 1. This would be equivalent to $4 \times \frac{150}{6 \times 3} = 33$, or 0.15 ticks/100 $m^2$. In all three years of this study, adult ticks were more abundant near the upper edges of the areas sampled than in the lower areas toward the grassland.

## DISCUSSION

**Trap efficiency**

In 1967 the Sherman trap was almost as effective as the Longworth for deer mice and more effective than the Longworth for chipmunks. Morris (1968) reached a similar conclusion and attributed it to the larger opening of the Sherman trap (7.5 cm wide compared with 6 cm on the Longworth trap). The Sherman trap also caught wood rats on 12 occasions in 1968. The cost of the Sherman was $1.25 compared with about $5.00 for the Longworth.

Brown *et al.* (1969) had better success with Burt traps than I had, they used a suitably placed nail to prevent escape through the entry door (E. B. Brown, personal communication). These traps provide good protection in either cold or warm weather.

In future studies, sticky traps (Southwood, 1966) might be tested for sampling free-living ticks, and pitfall traps for sampling rodents (Nellis *et al.* 1974).

**Distribution of rodents and ticks in 1967**

The concentration of chipmunks in the upper and intermediate zones was expected, since this rodent is associated with rocky and wooded terrain. It was considered possible that the ubiquitous deer mice (Cowan and Guiguet, 1965) would carry appreciable numbers of larvae arising from eggs of engorged ticks which dropped from cattle or other large animals outside the main focus, e.g., in the lower grassland, but there were few larvae on deer mice in the grassland areas (Table 2). More information is needed on the pattern of dropping of the engorged females, e.g., in relation to habits of cattle. The records on which Table 2 is based did not show a large infestation of larvae on rodents near the cattle loafing area under the ponderosa pine in the intermediate zone. The concentration of feeding nymphs in the upper zone corresponded with the presence of most host-seeking adults.

**Hosts of immature ticks in 1968**

Deer mice were estimated to be more adundant than chipmunks for most of the season, and the reversal at the end of the season may have been due to chipmunks pre-empting the traps. They supported more larvae and nymphs than did deer mice over the trapping season (Fig. 4). Sonenshine *et al.* (1976) found that deer mice were rarely infested with nymphs in a canyon in Montana, and wood rats were the most important host, but their area also differed in the absence of *Marmota flaviventris* and the presence of *Citellus lateralis*. It is probable that porcupines made an important contribution in both the Stump Lake and Montana areas, but they were not captured in either study (cf. Wilkinson, 1979b).

The 'calendar of captures' method (Mermod, 1969) may underestimate the population because it does not allow for the 'never-captured' element. However, Mermod found it agreed well with the simple Lincoln index, and for a small number of captures it has the advantage of simplicity and of concrete evidence of existence of rodents rather than deductions based on mathematical assumptions. Wilkinson (1979b) briefly reviewed the merits of several methods.

**Correction for larvae and nymphs missed during field examination**

The results presented for 1967 and 1968 (Tables 2 and 3) suggest that the figures for larvae and nymphs, based on field examinations, in Table 2 and Fig. 3 and 4 may need to be doubled, at least, to equal actual tick numbers. However, removal of rodents to the laboratory to await dropping of ticks cannot be recommended as a routine measure in future studies, since it would cause major disruption of the rodent population, e.g., to females suckling young.

**Factors in planning trapping grid size and spacing, in relation to disturbance due to trapping**

The travel distances given for chipmunks and deer mice can be used to indicate the sizes of home ranges. A grid should contain several home ranges, otherwise population estimates are confused by 'edge effects', e.g., by a high proportion of transient rodents from adjacent areas. In an undisturbed area, home ranges may be smaller, since Sheppe (1967) found that animals released from live traps travelled farther than untrapped animals. Other unavoidable abnormalities introduced by trapping include some separation of lactating mothers from young, trap deaths, path formation by the trappers due to regular visits, increase of food supply in the area due to regular baiting, and development of 'trap shy' and 'trap happy' sub-populations. The apparent displacement of deer mice by chipmunks would indicate the need for more traps, e.g., 10-m spacing or 2 traps together at 20-m spacing.

**Seasonal incidence of immature ticks in 1967-68**

In Fig. 3 the paucity of nymphs in July, when the larvae are most abundant, and their presence on hosts in spring and August, is explainable if 1-year and 2-year life cycles occur concurrently at this focus. Most of the nymphs feed during the spring after over-wintering (2-year life cycle, Wilkinson, 1968), but some feed in the fall of the same year that their preceding larvae feed, and produce adults that feed the next spring (1 year life-cycle).

**Relation of counts of adults by flagging to numbers of nymphs and larvae**

Although larvae, nymphs and adults may not have been sampled with equal efficiency (i.e., numbers enumerated/numbers present) and the numbers of hosts and ticks and the area sampled were small, the number of nymphs feeding can be compared with number of adults subsequently flagged as part of a tentative life-table. Figure 3 indicates a cumulative total of 45 nymphs feeding on chipmunks and deer mice during 1968, and this figure can be doubled as discussed earlier. In addition, Table 5 records 29 nymphs on other rodents to which 4 should be added to adjust for 1 red squirrel (*Tamiasciurus*) and 1 marmot hosting nymphs but not taken to the laboratory. The total, 123, can be multiplied by 3, since the rodents were examined every 14 days, whereas the nymphs remain on the rodents for 4-6 days (Wilkinson, 1981). This gives 369 nymphs. The 1969 flagging gave an estimate of 179 host-seeking adult ticks in the area, which is not inconsistent with 369 preceding nymphs.

The corresponding mortality or disappearance between the larvae and the nymphs cannot be calculated since an unknown fraction of the nymphs feed the same year as they are produced, and the remainder feed in the following spring.

Pre-1967 unpublished laboratory records showed that as many as 1000 unfed adult ticks were collected at this focus in one spring visit. There was progressively less grass cover in and around the focus in the period 1967-1970, and this may have been responsible for a reduction in numbers of adult ticks produced (Wilkinson, 1979a).

**Prospects for life-table studies**

The following comments draw attention to some of the difficulties and potential for further studies on RMWT life tables (cf. Harcourt, 1969).

After dropping, engorged female ticks tend to be scattered and their egg masses concealed. The unfed larvae do not respond predictably to $CO_2$ (Garcia 1965) and further work is needed on the relation of $CO_2$ catches to population present. Feeding larvae and nymphs and host-seeking adults can be sampled by the methods outlined in this paper. The feeding adult ticks can be counted on cattle, if facilities are available for round-ups, preferably at 5-day intervals. Only indirect evidence may be available for numbers of adult ticks on deer, coyotes, porcupines (Wilkinson, 1970a, b), and bears (Doss *et al.* 1974) unless methods for repeated live trapping improve. Sonenshine (1972) has published tentative life tables for *D. variabilis* in Virginia, using flagging, trapping, and release of isotope-tagged larvae, but the larger hosts such as deer were not examined (cf. Montgomery, 1968) and he makes no mention of predation on the engorged stages by rodents, shrews, birds or insects (cf. Pelinenchenko, 1957; Wilkinson, 1970a). Sonenshine's experience suggests that a grid of at least 500 Sherman traps may be needed for calculation of a life table, e.g., an area 230 x 230 m with 10-m trap spacing. This would be larger than many of the tick foci in the British Columbia tick paralysis area, and could be advantageously spread over more than one focus. If some foci subjected to controlled overgrazing or burning were studied, this would assist in planning control of tick paralysis of cattle by range management (Wilkinson, 1979a). These studies would necessitate a multi-disciplinary team, and probably computerized handling of data (cf. Gendron and Bergeron, 1975).

## ACKNOWLEDGEMENTS

Professor D. Chitty, Department of Zoology, University of British Columbia, visited the site and his advice on small-mammal trapping was much appreciated.

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