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SEASONAL ACTIVITY AND COLORADO TICK FEVER VIRUS INFECTION RATES IN ROCKY MOUNTAIN WOOD TICKS, *DERMACENTOR ANDERSONI* (ACARI: IXODIDAE), IN NORTH-CENTRAL COLORADO, USA[1]

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Abstract. Studies of the seasonal activities of adult *Dermacentor andersoni* ticks were conducted in Larimer Co., Colorado, USA, during the summers of 1979–1980. Twenty-five CO_2 platform traps were used in an 80 × 80-m grid to monitor host-seeking activities. Ticks were marked with a spot of fluorescent paint as they were captured in 1979, with a different color used for each month. Eleven percent of the marked ticks were recaptured the following summer. Using the Lincoln Index to determine population density by the mark-recapture method, we obtained an estimate of 1139 ticks per hectare for May 1979. In both years tick activity began in early March, peaked in late April, and virtually ceased by the end of June. The actual CTF infection rate of painted ticks surviving at least 2 winters in hibernation was 129 per 1000, indicating that ticks infected as larvae or nymphs retain the infection for extended periods.

Colorado tick fever (CTF) is an acute viral disease of public health importance in the mountainous regions of the western United States. Goodpasture et al. (1978) detailed the clinical, epidemiological, and laboratory aspects of 228 cases occurring in Colorado in 1973–1974. Effects of the illness may persist for several weeks, as one of us (RBE) who contracted the disease during the course of this study can attest. Fortunately, fatalities are rare.

For several years, J.D. Poland (unpubl. data, Vector-Borne Diseases Division Annual Reports 1975–1979) has been monitoring clinical illness due to CTF virus among the youth at the Cherokee Christian Ranch in north-central Larimer Co., Colorado. A total of 344 young people (9–18 years old) spent 1-wk sessions at the camp during June and July, 1975. While still in camp, the youths submitted 25 adult *Dermacentor andersoni* Stiles ticks removed from their persons, attached or unattached, to be tested individually for CTF virus. Six (24%) were positive. After returning home, 304 of the youths were contacted by telephone. Sixty-one individuals reported ticks crawling on their persons or attached during the camping period; 18 had 1 tick attached and 2 had 2 attached. There were 6 clinical cases of CTF, 1 of which was confirmed in the laboratory.

When the camp area was shown to be a continuing focus of CTF virus transmission, we selected it as the site for seasonal activity and density studies of unfed *D. andersoni* adults in 1979–1980, which we report here.

STUDY AREA

Cherokee Christian Ranch is within the Cache La Poudre River drainage system in the Roosevelt National Forest, along the east slope of the front range of the Rocky Mountains. The Cache La Poudre River originates along the Continental Divide and runs generally easterly through the rugged and precipitous terrain. Elevations range from about 1675 m to over 3660 m. Soils are derived mainly from granite, schist-gneiss, and undivided metamorphic and igneous rocks, with occasional sedimentary formations at lower elevations (Lovering & Goddard 1950). Marr (1961) has described front range ecosystems, and Marr et al. (1968) have characterized the climate.

Cherokee Christian Ranch is within the lower montane forest climax region, about 32 km NW of Livermore off U.S. highway 287. Buildings consist of a main lodge and satellite cabins located in a valley on the north fork of the Cache La Poudre River. Elevation at camp headquarters is 2152 m (7060 ft), although the camp is immediately surrounded by much higher hills. Hills to the north of the camp are treeless, while ponderosa pine (*Pinus ponderosa*) occurs on those to the south and west.

This environment is subject to sudden and extreme changes in atmospheric conditions at any season of the year. The summers are relatively hot and dry. Prevailing winds are usually from the west

[1] Use of trade names is for identification only and does not constitute endorsement by the Public Health Service or by the U.S. Department of Health and Human Services.

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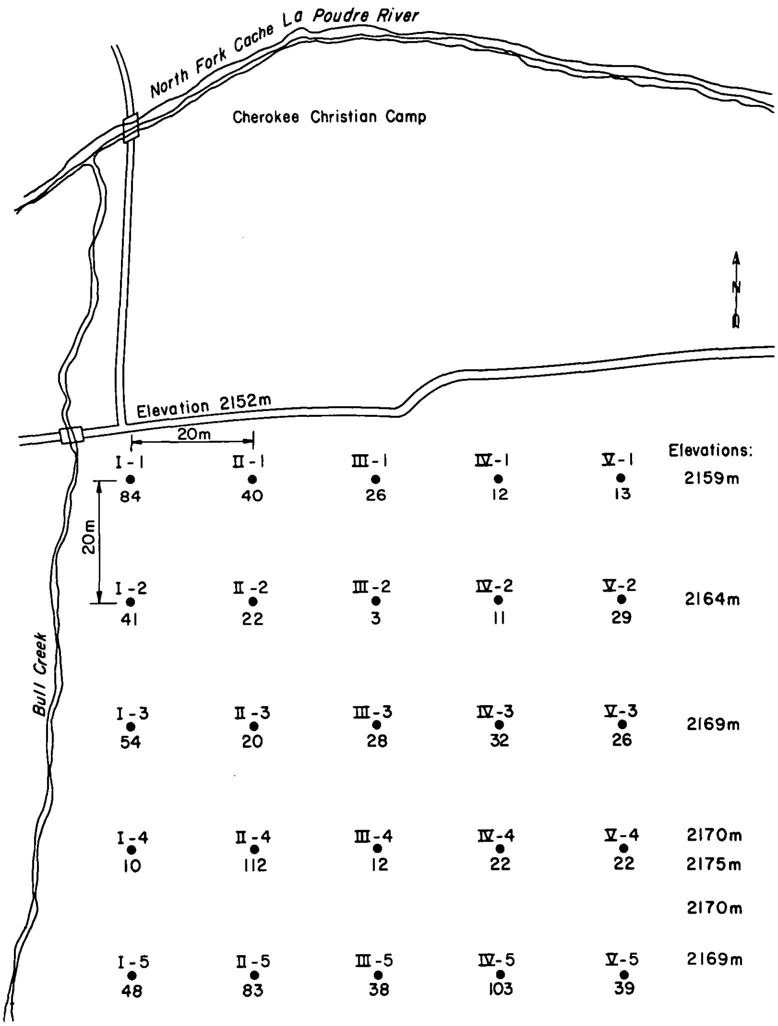

FIG. 1. Tick grid, with numbers of *Dermacentor andersoni* adults collected at each of the 25 trapping stations in 1979.

at all seasons; strong winds are almost always from this direction. In the spring, cool and warm intervals alternate, and wet snow or rainstorms are common. Winters may become very cold, with snowstorms depositing a foot or more of snow. The amount varies greatly from year to year. In years of light to moderate snowfall, snow remains on the ground in patches on north-facing slopes most of the winter, but it usually melts off south exposures within a few days after each storm.

Soil water content is low much of the year on the slopes, especially during the fall and winter months. The coarse, rocky soil does not retain water efficiently. Free water is seldom in evidence at ground level in appreciable amounts except in the spring.

An 80 × 80-m tick grid was established in an area covered by scattered ponderosa pine, including about 275 trees with basal diameters of 6 cm or more. In recent years a fairly dense stand of these trees has been thinned by beetle-fungus kill. Other trees sparsely represented on the grid include Douglas fir, *Pseudotsuga menziesii*; Rocky Mountain juniper, *Juniperus scopulorum*; common juniper, *J. communis*; limber pine, *Pinus flexilis*; and aspen, *Populus tremuloides*. Dominant shrubs are mountain mahogany, *Cercocarpus montanus*; bitter brush, *Purshia tridentata*; and fringed sage, *Artemisia frigida*. Others include thimbleberry, *Rubus deliciosus*; wax currant, *Ribes cereum*; and waxflower, *Jamesia americana*.

Principal hosts for immature *D. andersoni* in the vicinity of the tick grid are the Golden-mantled Ground Squirrel, *Spermophilus lateralis*; Least Chip-

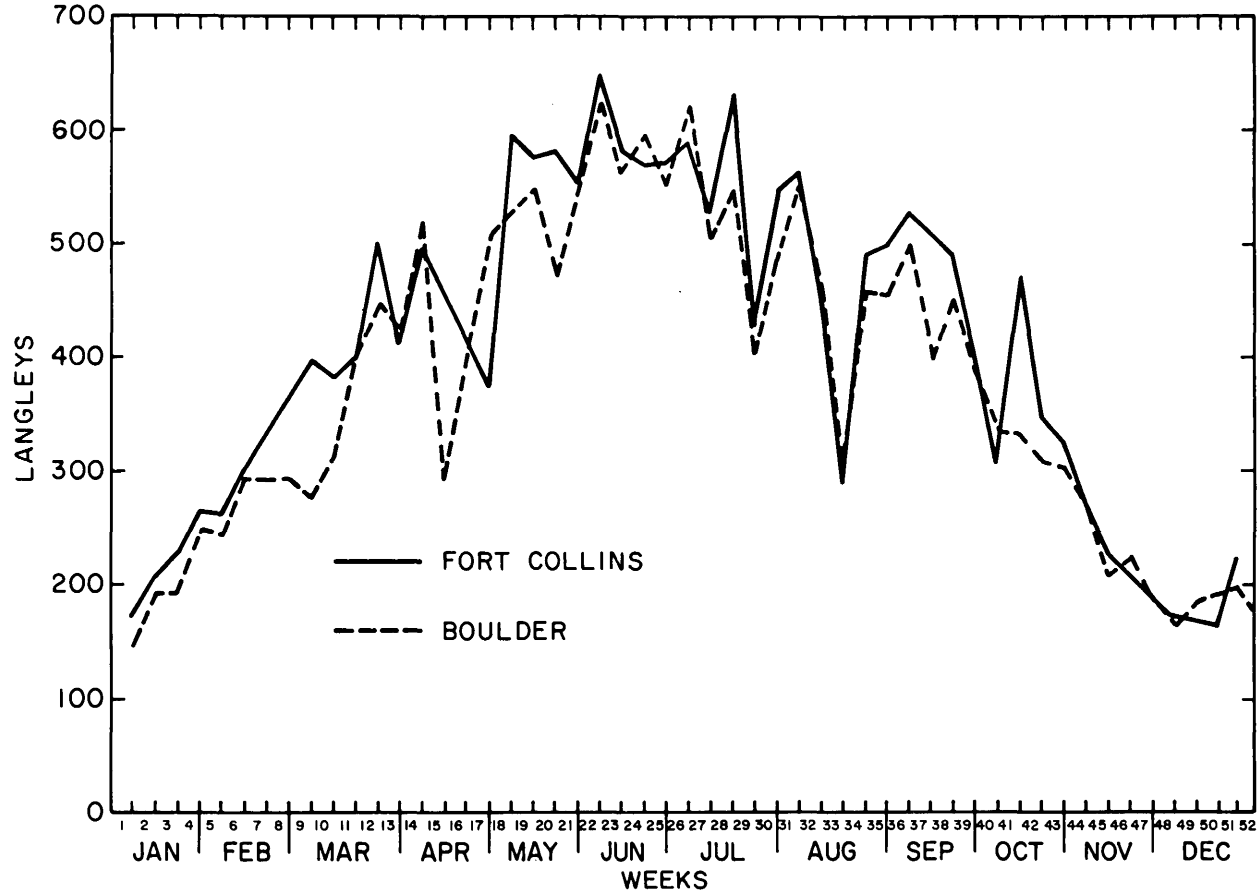

FIG. 2. Weekly averages of daily solar irradiance in 2 Colorado localities, 1977.

munk, *Eutamias minimus*; and Deer Mouse, *Peromyscus maniculatus*. During the study period, diurnal rodents were not abundant. Animals were not fed or interfered with by campers and thus represented a natural population.

Large numbers of Mule Deer, *Odocoileus hemionus,* range the Cherokee Christian Ranch during the winter and spring months, moving to higher elevations in the summer and fall. These animals, as well as the Porcupine, *Erethizon dorsatum*; Black Bear, *Ursus americanus*; Coyote, *Canis latrans,* and a variety of small carnivores, serve as hosts for adult *D. andersoni.*

MATERIALS AND METHODS

A modification of the Wilson et al. (1972) CO_2 platform trap was used in these studies. The trap, described and evaluated by Eads et al. (1982), consists of a fiber-glass shell platform with sloping sides and a central octagonal opening in which an 0.95-l container of molded styrene foam filled with small chunks of dry ice is inserted. Masking tape (5 cm), ½ of which is attached to the trap base and ½ left free, entangles ticks crawling up the sloping sides of the basal platform. The trap was quite effective in attracting adult *D. andersoni* at a distance of 6 m in 24 h, moderately effective at 9 m in 24 h, and ineffective at 12 m for up to 72 h.

In 1979 the tick grid (Fig. 1) was laid out in the area previously characterized in Cherokee Christian Ranch. Five rows of trapping stations 20 m apart were established in 5 parallel lines (also 20 m apart), resulting in an 80 × 80-m grid. Weather permitting, a CO_2 platform trap was operated for one or two 24-h periods at each of the 25 stations from 7 March through 23 October. Ticks taken in the traps were marked with a small spot of HiGlo® fluorescent paint (Pactra Industries, Inc., Los Angeles, CA 90028) when initially captured and were released at the appropriate station. Colors used were red in March, green in April, yellow in May, orange in June, and blue in July and September. The ticks were marked only once, at the time of their original capture. Data on captured ticks pre-

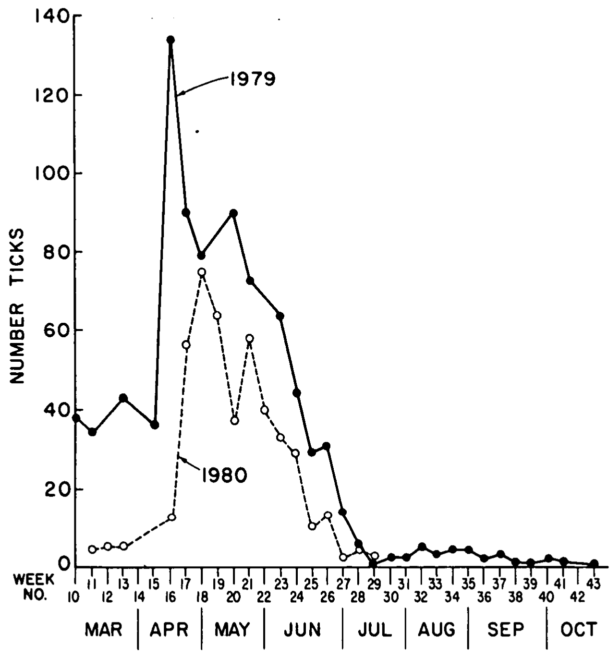

FIG. 3. Adult *Dermacentor andersoni* collected in CO_2 platform traps (25) on grid at Cherokee Christian Ranch, 1979–1980.

viously marked were recorded and the ticks released at the station at which they were captured.

A similar CO_2 trapping regime was followed in 1980 from 12 March through 15 July on the original grid. Unmarked ticks were released at the station where they were captured. Ticks marked the previous summer and taken on the traps in 1980 were brought into the laboratory and tested individually for CTF virus. Ticks were triturated in 1 ml of diluent consisting of 20% fetal bovine serum in medium 199 with antibiotics. Suspensions were clarified by centrifugation and inoculated intracranially into suckling mice aged 1–3 days. Brain suspensions from dead or moribund mice were used as complement-fixing antigens for virus identification.

Temperature and humidity at the tick grid were recorded continuously during the study periods on 7-day charts with a Belfort Hygro-thermograph® (Belfort Instrument Co., 4 N. Central Ave., Baltimore, MD 21202) housed in a weather station. A 20-cm diam rain gauge was used to measure precipitation.

Equipment was not available to obtain solar radiation data at the study site. However, data collected by Colorado State University (CSU) in Fort Collins and the University of Colorado in Boulder in 1977 are given in Fig. 2. The Atmospheric Science Department at CSU is at an elevation of 1609 m and is about 57 km SE of the tick study area.

RESULTS

The 25 CO_2 traps were operated on the grid at regular intervals, weather permitting, from 9 March–12 October 1979 and 12 March–15 July 1980. Trapping results are given in Table 1 and 2 and in Fig. 1 and 3.

The standard trapping period in both years was one 24-h period per week. In 1979 on 4 occasions the traps were recharged with CO_2 after 1 day and operated a 2nd consecutive day. On 28 and 29 March, 71 ticks were taken, 61% of them the 1st day and 39% the 2nd day. On 18 and 19 April, 173 ticks were trapped, 77% of them the 1st day and 23% the 2nd day. On 5 and 6 June, 73 ticks were taken, 88% the 1st day and 12% the 2nd. On 12 and 13 June, 44 ticks were trapped, 91% the 1st day and 9% the 2nd day.

The seasonal host-seeking activities are depicted in Fig. 3. When there were 2 consecutive 24-h trapping periods, only the 1st 24-h trapping results are included.

The CO_2 traps are less effective in taking nymphal *D. andersoni* than adults. Nymphs first appeared on the traps 1–2 months after the adults; none were taken after 21 June. As with the adults, the lack of appreciable host-seeking activity in mid- or late summer supports the thesis that newly molted nymphs hibernate through the winter before host seeking.

Some dispersal of the marked ticks within the 80 × 80-m grid was noted during the summer of 1979. On several occasions marked ticks were taken at stations at which no ticks of the color in question had been painted. In these cases the nearest stations at which these colors had been used were 20 m or more distant.

Dispersal by marked ticks outside the grid was monitored by flagging and CO_2 traps in both 1979 and 1980. Three of 294 ticks marked in 1979 were recovered off the grid in the same year. Two ticks painted red in March were taken 4 May. One was 23 m west of station I-5, and the other was 400 m south of I-5. The latter may have been picked up by a deer or other animal and carried to the capture point. A tick painted green in April was taken 23 m west of I-5 on 17 May.

Of the 291 painted ticks available for overwintering, 22 (8%) were recovered from the grid and 10 (3%) off the grid in 1980. Gregson (1951) recovered almost 8% of the *D. andersoni* marked in

TABLE 1. Monthly *D. andersoni* collections on grid by CO_2 traps, Cherokee Christian Ranch, 1979.

Month	Unmarked adult ticks recovered and marked	Color*	Marked tick recoveries: R	G	Y	O	B	Total collected	No. nymphs taken	No. traps operated	No. 24-h trapping periods
Mar.	86	R	20					106	2	75	3
Apr.	156	G	75	69				300	5	100	4
May	35	Y	48	134	25			242	7	75	3
June	13	O	50	74	41	14		192	6	150	6
July	3	B	5	7	5	3		24		100	4
Aug.	0		3	4	1	6	4	18		125	5
Sep.	1	B		5		1		7		100	4
Oct.	0			3				3		75	3
Totals	294		201	296	72	24	4	891	20	800	32

* See text for colors used.

the spring of 1949 in British Columbia the following spring.

Thirty-two ticks painted in 1979 were recovered during the summer of 1980. Thirty-one were tested individually for CTF virus. Four of these ticks, infected as larvae or nymphs, that had hibernated for at least 2 winters were positive, for an infection rate of 129 per 1000. Also in 1980, 90 unmarked adult *D. andersoni* taken along the creek bordering the grid in CO_2 traps and by flagging were tested in 47 pools, 10 of which were positive. This is a minimum infection rate (MIR) of 111 per 1000. The same season, 18 adult *D. andersoni* attached or crawling on campers were tested individually for CTF virus. The infection rate was 167 per 1000. In 1979, 42 *D. andersoni* attached or crawling on campers were tested individually, and the infection rate was also 167 per 1000. A higher CTF infection rate was obtained in unfed *D. andersoni* flagged or taken in CO_2 traps along the creek bordering the tick grid in 1979. Twenty-one ticks tested individually showed an infection rate of 381 per 1000.

The mark-recapture method of determining population density devised by Lincoln (1930) was used to estimate the number of adult *D. andersoni* per hectare on the study grid. According to May 1979 data, 242 ticks were marked in March and April and 242 were captured in May, 182 of them marked recaptures. The effective range of the CO_2 traps for 24-h periods has been shown to be ca. 6 m (Eads et al. 1982). Thus, 322 ticks (95% confidence limit extremes, 300 and 347) were estimated to be present on 0.28 ha, or 1139/ha.

The estimated 1139 ticks/ha in May 1979 in the study area is predicated on no tick movement into or out of the grid, random mix of marked and unmarked ticks, and an equal probability of marked and unmarked ticks being trapped.

DISCUSSION

In 1979 the tick traps on the grid were first operated on 9 March, when 39 ticks were trapped; however, they were released unmarked and are not included in Table 1. Flagging in the vicinity of

TABLE 2. Monthly *D. andersoni* collections on grid by CO_2 traps, Cherokee Christian Ranch, 1980.

Month	Unmarked adult tick recoveries	1979 marked tick recoveries*: R**	G	Y	O	B	Total collected	No. nymphs taken	No. traps operated	No. 24-h trapping periods
Mar.	11	1	1		1		14		75	3
Apr.	129	2	9		2	1	143	9	75	3
May	197		2				199	15	100	4
June	82	1	1		1		85	5	100	4
July	8						8		75	3
Totals	427	4	13		4	1	449	29	425	17

* Marked ticks were removed for virus testing as captured.

** See text for colors used.

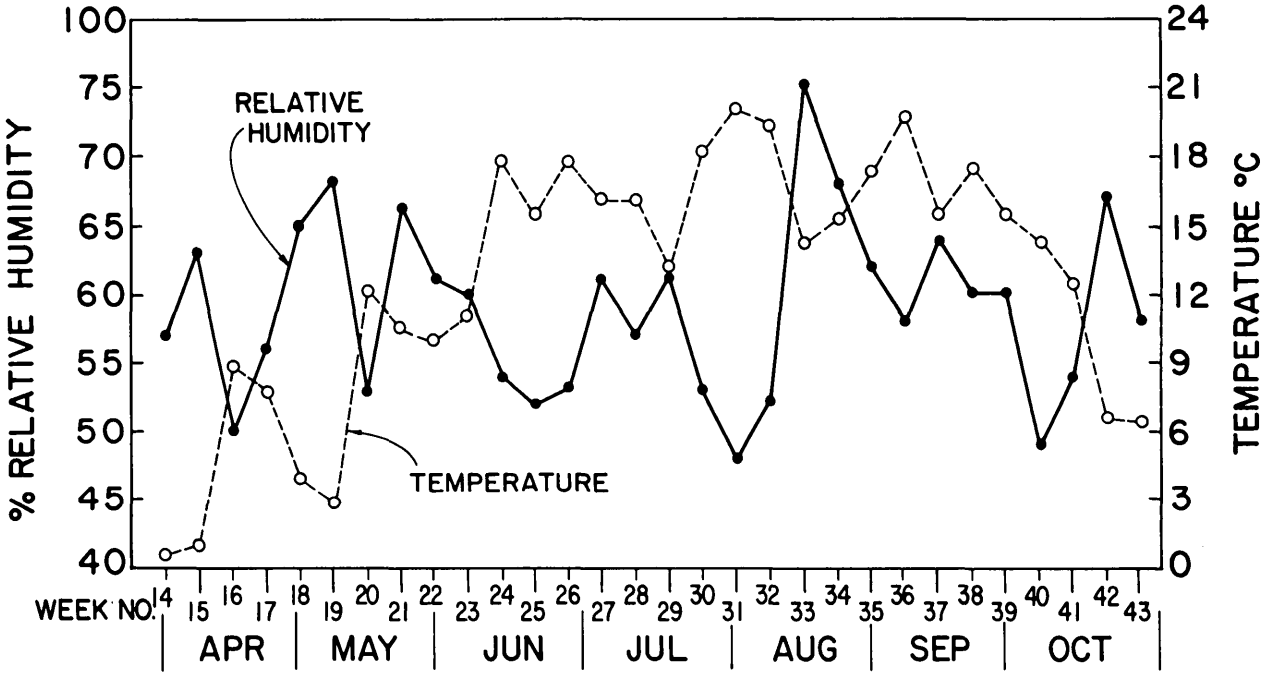

FIG. 4. Weekly average temperature and humidity in study area, 1979.

the grid in February and the 1st week in March was unproductive, except for a single male taken the last week in February. A few earlier records are available of adult *D. andersoni* host seeking in February in Larimer Co. For example, 5 males were taken in CO_2 traps on 11 February 1976 (Maupin & Eads, unpubl. data, VBDD Annu. Rep. 1976).

Seasonal host-seeking activity in 1979 peaked 18 April, and dropped rapidly in June; few ticks were taken from July through October. Ticks recovered after June consisted almost entirely of specimens marked earlier in the year. Only 4 of the 79 ticks trapped from 27 June–23 October were unmarked. The lack of activity of unmarked adults or nymphs in mid- or late summer indicates that 1-year life cycles seldom, if ever, occur. Similar results were obtained during CTF studies in the Rocky Mountain National Park, which is also in Larimer Co. (unpubl. VBDD data). Both adult and nymphal activity, as measured by CO_2 trap and host examination, virtually disappeared by mid- and late summer

Adult *D. andersoni* host-seeking activity followed similar seasonal patterns on the grid in 1980, with the largest number (75) recorded 29 April. This is only 56% of the 134 ticks taken during the peak 24-h trapping period 18 April 1979 and probably represents an actual decline in adult population density on the grid in 1980. Removal of ticks trapped in 1980 (painted in 1979) for virus testing would have little effect on total numbers captured, since only 22 marked ticks were removed from the grid. Results obtained from flagging and CO_2 traps in the vicinity of the grid suggested a lower adult *D. andersoni* population in 1980 than in 1979.

Seasonal activity patterns of adult *D. andersoni* in Larimer Co. are similar to those demonstrated by Philip (1937) in the Bitterroot Valley of Montana from 1930–1935. Using the flagging technique, he found that adult activity peaks were 11–25 April, with times of onset and cessation of host-seeking activities comparable to our results. In Kamloops, British Columbia, Wilkinson (1968) and Gregson (1951) also used transect flagging in several localities to demonstrate unfed, adult *D. andersoni* activity. Population peaks were somewhat earlier than we observed, occurring from the end of March to early April.

The only obvious relationship that we have observed between the initiation and termination of tick activity and a meteorological phenomenon concerns the availability of free ground water. Diapause interruption coincides with the appearance of free water from melting snow in late February and early March, and diapause onset occurs with the completion of the snow melt and rapid evaporation of the sparse rainfall, if any, in June.

The breaking of diapause in late February and early March after a cold conditioning period coincides with increasing ambient temperature, solar radiation reaching 300 langleys daily, and increasing photoperiods. However, cessation of adult activity after only 3–4 months of host seeking, before another winter of hibernation, is more difficult to explain.

In studying the life cycle of *D. andersoni*, one is impressed by how rigidly programmed the species apparently is in regard to the onset and decline of its seasonal activity (Gregson 1951), despite great variation in weather conditions from year to year. Striking adaptations have been made by the species to survive in a hostile environment. *Dermacentor andersoni* is cold-adapted and is apparently not adversely affected by either high or low temperatures. However, by mid-summer the solar radiation is extremely high (Fig. 2), undoubtedly making it difficult for the ticks to maintain water balance.

Both nymphal and adult *D. andersoni* host-seeking periods are very short in relation to the age to which these ticks may live. The lack of a 2nd peak of host-seeking activity following the spring peak in adults, as demonstrated in this study, indicates that newly molted adults become quiescent and hibernate 1 winter before host seeking the following spring. Marking experiments have shown that unfed adults are capable of surviving at least 2 winters of hibernation. This survival is remarkable considering the only energy available is that obtained by nymphal feeding.

Unfed ticks gain water from humid air or water in contact with the cuticle and lose water by evaporation via the cuticle and spiracles. Lees (1946) states that *D. andersoni* was the most resistant to water loss of 8 species of ixodid ticks tested. However, he found the critical equilibrium humidity (CEH) of *D. andersoni* to be fairly high (86–90%). This is the relative humidity at which ticks can absorb sufficient water from the air to maintain an optimum water balance. It becomes increasingly difficult to balance water gain and loss below the CEH.

As can be seen in Fig. 4, weekly mean humidities aboveground in the study area were substantially lower than the *D. andersoni* CEH in 1979. Extreme nocturnal-diurnal humidity fluctuations occurred, with the *D. andersoni* CEH commonly exceeded at night. Relative humidity in the ground litter where ticks occur may be substantially higher than that measured in this study; nevertheless, prolonged exposure to desiccating daytime atmospheric conditions (20–30% relative humidity) plus excessive solar radiation likely exerts cumulative metabolic stress and creates other physiological complications, bringing on inactivity and diapause.

Lees (1946) thought that water gained from humid air is probably the most important source of water for unfed ticks in nature. We consider it unlikely that *D. andersoni* can obtain water in this way for extended periods in the arid Rocky Mountain region, as evidenced by the abbreviated adult host-seeking period.

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