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FACTORS AFFECTING THE DISTRIBUTION AND ABUNDANCE OF THE CATTLE TICK IN AUSTRALIA: OBSERVATIONS AND HYPOTHESES

BY

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I. Introduction.

The distribution of the cattle tick, *Boophilus microplus* (Can.) in Australia, presents an impressive example of the equilibrium reached between an introduced arthropod and the climatic and biotic factors of a continent. The tick was introduced into the Northern Territory from Indonesia in the late 19th Century, either near Darwin (GILRUTH, 1912) or to the Coburg Peninsula (LETTS, 1964). Subsequently the tick has spread through all the climatically suitable areas in western Australia, the Northern Territories and Queensland, where ungulate hosts are available; in New South Wales its spread southwards was probably limited by climatic factors before local eradication measures became effective (MACERRAS et al., 1961). It causes great financial losses to the cattle industry (GEE, 1959). ROBERTS (1965) reviewed the taxonomy of Australian *Boophilus* and found some specimens with features resembling *B. annulatus*, but was able to separate them as *B. microplus* on characters of the female coxae.

In addition to the purely scientific interest, the distribution of this tick has been studied in Australia because, well within the climatically suitable area, certain areas have been reported as having anomalously fewer ticks than the surrounding districts. For convenience, these areas will be referred to as RTS (reputed tick scarcity) areas. The scarcity of ticks comes to the attention of the graziers either by a markedly reduced necessity to dip the cattle compared with adjoining areas, or by unusually numerous cases of babesiosis developing when cattle are moved to or through surrounding tick infested areas, because the cattle have not previously acquired immunity from infected ticks. The existence of some of these areas is well and consistently authenticated, other reports tend to be based on hearsay, or the areas are so close to the boundary of tick distribution as to be explicable on the basis that sparse populations normally tend to become sporadic near the edge of an animal's distribution. Brief details of the areas reported are given in Table 1, with provisional conclusions based on enquiries or observations on (1) micro-climate, (2) predators of ticks, (3) presence of sufficient numbers of susceptible breeds of cattle, (4) dipping and pasture management practices. The full elucidation of the regulation of cattle tick populations in these areas, some of which are inconveniently remote from laboratory facilities, would necessitate much further work.

Cattle owners and rural newspapers frequently drew attention to the possibility that some unidentified factors reduced tick abundance in the RTS areas and expressed the hope that these
TABLE I: Summary of localities within the *B. microplus* infested zone, reported as having anomalously low tick infestation (i.e., R.T.S. — reputed tick scarcity).

<table>
<thead>
<tr>
<th>Code Letter</th>
<th>Locality</th>
<th>Approximate size of RTS area in sq. mi.</th>
<th>Nature of Investigation</th>
<th>Provisional conclusions, if any, on reasons for tick scarcity, and remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Portion of 'Forest Home' property, Georgetown.</td>
<td>500</td>
<td>Visit, study of climatic records (Georgetown, Fig. 2).</td>
<td>Unsuitable microclimate for egg development, except on alluvium of major rivers, and lagoons, e.g., the Gilbert River.</td>
</tr>
<tr>
<td>B</td>
<td>'Robin Hood' property, Forsayth. Contains headwaters of several creeks.</td>
<td>500</td>
<td>Inspection, predator and climatic studies.</td>
<td>Climate intermediate between Georgetown and Hughenden (Fig. 2). Unsuitable microclimate for egg development, except on alluvium of major creeks. Most of property tick-free. Babesiosis outbreaks in wet years.</td>
</tr>
<tr>
<td>C</td>
<td>Dairy Farm, Kairi District, Atherton.</td>
<td>1/3</td>
<td>Inspection, predator and climatic studies.</td>
<td>Predation by <em>Pheidole</em> ants. Formerly rain forest area.</td>
</tr>
<tr>
<td>D</td>
<td>'Desert' country, S.W. of Charters Towers.</td>
<td>1000</td>
<td>Not visited.</td>
<td>Apparently unsuitable for egg development due to dry sandy soils, in a marginal climate.</td>
</tr>
<tr>
<td>E</td>
<td>Portion of 'East-Brook' property Duaringa.</td>
<td>5?</td>
<td>Predator studies.</td>
<td>Predation by <em>Aphaenogaster</em> and other ants on sandy soils. Rest of property tick infested.</td>
</tr>
<tr>
<td>F</td>
<td>Beef/dairy farm Thangool District.</td>
<td>1/2?</td>
<td>Visit.</td>
<td>Tick scarcity not well authenticated. Cleared <em>Acacia</em> (Brigalow) scrub.</td>
</tr>
<tr>
<td>G</td>
<td>Beef property, Gayndah District.</td>
<td>4</td>
<td>Visited, not studied.</td>
<td>Dipping unnecessary, or very infrequent. Causes undetermined.</td>
</tr>
<tr>
<td>H</td>
<td>Dairy farm, Barambah, Murgon.</td>
<td>1/3</td>
<td>Several visits, predator studies.</td>
<td>Tick scarcity not well authenticated. Reputed effect of drinking water.</td>
</tr>
<tr>
<td>I</td>
<td>Beef fattening property, Kalbar.</td>
<td>1/3</td>
<td>Predator studies. Tests of effects of water on cattle infestation.</td>
<td>Heavy populations of <em>Pheidole megacephala</em>, in cleared <em>Acacia</em> scrub. These ants attacked most of the engorged female <em>Boophilus</em> put out experimentally. Tick distribution patchy in whole district, possibly climatically marginal.</td>
</tr>
</tbody>
</table>

Note: Locations are indicated by code letter in Fig. 2. Areas were mainly eucalypt savannah woodland unless otherwise stated. Properties A, B, C, reported babesiosis outbreaks in stock moved from the R.T.S. areas to enzootic areas.
could be used to "solve the tick problem". Preliminary investigations were conducted in some of these areas, and these are recorded in the hope that they may assist further investigations. Some speculative and theoretical discussion of life-tables is included, for the same purpose.

In this paper the autecological approach is used, but as knowledge develops, the distribution should be considered in relation to the whole bioclimatic complex of the "Torresian zone" (Keast et al, 1959).

II. DISTRIBUTION OF Boophilus SPECIES IN OTHER COUNTRIES.

Five species of Boophilus are now recognized (Aeschlimann and Morel, 1965), all with quite similar behaviour and life-histories, but with differences in host preference and climatic tolerances. The factors affecting distribution of B. microplus have not been well defined throughout its range, so that a brief review of the distribution of the other Boophilids is helpful in studying the limiting factors.

Cotton (1915) stated that before eradication schemes in the U.S.A., the northern quarantine line for B. annulatus closely followed the 59°F annual mean isotherm, except that in the more arid southwest, it bent sharply south along the line of 60% annual mean relative humidity. B. annulatus may be better adapted to cooler climates than B. microplus since it spread as far north as Missouri and Virginia, whereas B. microplus appears to have been confined to Florida and the Mexican border. Graham and Price (1966) reported B. annulatus predominant in some arid and semi-arid regions of Mexico, intergrading into a highly variable population with B. microplus characters in a more humid region.

Pomerantz (1950) describes the distribution of B. calcaratus (= annulatus) in the U.S.S.R. as delineated by the middle (sic) annual isotherms of 9-17°C, isopleths of absolute humidity 6.5-10 mm, and relative humidity of 55-75%. The significance of such wide limits is not clear, at least in the translated version.

Morel's (1958) maps show B. annulatus well established in West Africa in areas with rainfall exceeding 1,000 mm (39 ins.) per annum. B. decoloratus (later found to include some B. geigyi) penetrated into the 500-1,000 mm (20-39 in.) zone. Theiler (1964) gives 15 ins. annual rainfall as minimal for decoloratus in South Africa. Yeoman and Walker (1967) report microplus occupying a more humid zone than decoloratus in Tanzania, the first species being absent in areas with rainfall below 20 ins. p.a. and rare on the drier side of the 30 in. isohyet, while the second occurs as far as the 15 in. isohyet and is well established in areas with 20 in. rainfall.

Goth (1967) has demonstrated that B. decoloratus larvae display a greater cold tolerance than B. microplus larvae, under laboratory conditions.

Thus there is some indication that increasing order of cold-resistance would be B. microplus, decoloratus, annulatus, and of resistance to desiccation, B. microplus, annulatus, decoloratus.

III. FACTORS AFFECTING THE DISTRIBUTION OF Boophilus MICROPLUS IN AUSTRALIA.

(a) Climatic factors.

There is an obvious correspondence between Seddon's (1951) small scale map of the Australia-wide distribution of B. microplus, and rainfall isohyets north of the tropic of Capricorn, tick distribution being confined to an area north of a line running between the 15-20 in. isohyets
(Fig. 1), compared with 20-25 in. for the African reports quoted earlier. However distribution of ticks in relation to climate is not easily studied in the Northern Territory or Western Australia because of the sparse distribution of meteorological stations, and because the real distribution of established tick populations is confused by records of ticks on travelling stock, on the large unfenced properties and lengthy stock routes. In the Northern Territory, cursory observation on the Darwin- Alice Springs road suggested that the southern limit of the tick zone occurs where stunting of tree growth is becoming obvious in the transition between savannah woodland and spinifex ‘‘desert’’. In general, it might be said that cattle ticks are found in savannah woodland and more mesic zones in tropical and sub-tropical Australia, but are scarce or absent in open savannah (tropical steppe) and ‘‘desert’’. The alluvia of major water-courses in the interior tend to be moister than the surrounding savannah, as can be seen by the bordering vegetation of trees and shrubs, consequently the presence of rivers and permanent lagoons will affect tick distribution. To illustrate this, Fig. 1 shows that the tick zone corresponds well with the drainage basin of all rivers draining to the sea north of 30° latitude, in areas where rainfall exceeds 15 ins. per annum. This implies that the penetration of ticks into the drier areas is aided by the presence of water-courses and alluvia, but further work would be necessary to show this is not a chance correlation. Western Australia south of 20° latitude has been protected from *microplus* invasion by low rainfall, desert barriers, and quarantine measures applied to cattle from the north (Gee, 1959).

Available maps of tick distribution are probably more reliable in Queensland, than in the Northern Territory and northern West Australia, since periodic reports are made on tick distribution so that regulations governing movements of cattle to and from ‘‘ticky’’ and tick-free

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areas can be drafted, and the cattle "stations" (ranches) tend to be smaller. There is a correspondence between the 20 in. isohyet and tick distribution in Northwest Queensland (Fig. 2). An exact fit between tick distribution and climatic isopleths cannot be expected because the published boundary of tick infestation is drawn in some places to fit convenient administrative boundaries. For instance, from Hughenden to Cloncurry, the Great Northern Railway is taken as the boundary. South of the Tropic of Capricorn, the evaporation becomes less so that one might expect the tick line to move inland of the 20 in. isohyet. In fact (Fig. 2) the tick line below the tropic is to the east of the isohyet. The main cause is undoubtedly because lower winter temperatures have increasing effect as the latitude increases. Hitchcock (1955 b) recorded very

--- Fig. 2 : Map of Queensland depicting several factors affecting tick distribution. Numbers in circles refer to localities in Table 2. Letters A-I refer to RTS areas in Table 1. ---
low percentage hatch in the laboratory at 65° F and if the winter period with mean temperature below 65° F exceeds a certain duration, it seems that insufficient of the last larvae produced in autumn would survive to infest cattle in the following spring, when conditions again become warm enough for engorged females to reproduce adequately (Snowball, 1957). No suitable isopleth has yet been published to illustrate this, but the July (winter) isotherm for 55° F illustrates the extent of winter coolness of this order, and an isotherm for a slightly lower temperature would correspond well with the pattern of B. microplus distribution (Fig. 2). The 55° F isotherm for January in the U.S.A. (Kincer, 1941) corresponds well with probable potential B. microplus distribution in that country.

Further indications of the limiting effects of winter temperatures and aridity are shown in the climographs in Fig. 3, and the explanatory Table 3. From these climographs, it appears that localities with more than five to six months with mean temperature below 65° F are not permanently infested. This is a simplified version of the conclusion of the review of Mackerras et al. (1961), that B. microplus in the southern part of its range would have little chance to survive the winter where more than five months intervened between an "autumn"

mean monthly temperature of 67-69° and a "spring" temperature of 58-60° F. In a more detailed treatment of the New South Wales distribution McCulloch and Lewis (1968) discussed the extent to which the tick would spread in the absence of control and eradication schemes and drew attention to the effects of aspect of sloping ground on soil. There is no doubt that slope and aspect can greatly affect soil temperatures and tick distribution (Wilkinson, 1967). Georgetown and Hughenden are apparently uninfested, except near the alluvial flats of the water-
courses, and this is associated with dryness of the air as shown in the climographs. The saturation deficit of 0.4 ins. shown in Fig. 3 corresponds to a short survival of larvae of about six days or less in Table II of Hitchcock's (1955 b) laboratory tests; both Georgetown and Hughenden have eight months of the year to the right of this line and soils away from water-courses would be correspondingly desiccated (see discussion below on survival of eggs and larvae).

One of Davidson's (1936) Precipitation/Evaporation lines has been included in Fig. 2 since it is customary to consider them in Australian climatology. These lines were intended to illustrate availability of soil moisture in the summer months or "growing season". The closer fit of this P/E line to the tick line south of the Tropic of Capricorn, compared with the 20 in. isohyet, is apparently due to the gradual increasing proportion of rain falling in the winter, causing Davidson's line to lie east of the isohyet, despite the reduced evaporation as one proceeds south. Since there is more evidence for the thesis that low temperatures rather than summer aridity limits the tick distribution in the south, the closer fit of the P/E line relative to the isohyet is probably fortuitous.

The basic difficulty of attempting to relate tick distribution with ordinary climatic indices is that the measurements on which the indices are based are obtained in a Stevenson screen about 3 ft above ground level, or in standard rain gauges. The relation of these measurements to the most probable limiting factors, that is temperature and relative humidity at the oviposition sites of the tick (in the trash layer, soil surface, or cracks in the soil), is not known. Mean daily soil temperatures under long grass cover corresponded closely to mean daily air temperatures at some sites (Wilkinson, 1964), the soil temperature showing less extreme maximum and minimum temperatures than the air temperatures, but the situation would be different with dry bare soil between tussocky grasses.

The evidence to date indicates that the egg is the stage most susceptible to death by desiccation in arid areas. Parasitic stages obtain abundant water in the blood and tissue fluids of the host; larvae are exposed to dew which they can imbibe, and this will extend survival to an extent depending on local conditions (Wilkinson and Wilson, 1959, Harley, 1966). Harley (1966) found that eggs frequently failed to hatch in the dry season at a well drained site in the 24 in. rainfall zone, and as conditions became drier, females failed to oviposit. Death of eggs in dry situations was also seen by Wilkinson and Wilson (1959). Hitchcock's (1955) laboratory data have some gaps at crucial points, and need confirmation, but are sufficient to indicate that fertility of eggs falls steeply between 80 % and 70 % RH, at temperatures between 70° and 85° F. Thus it seems probable that low relative humidity, or high saturation deficit, in the oviposition sites, is the usual limiting factor to the inland spread of cattle ticks in tropical North Australia.

Soil humidities are not recorded by the meteorological services, so some pioneer measurements were made during a tour of Queensland in October, 1961 (Table 2). October was chosen as being at the end of the dry season, and yet warm enough for egg development, and thus likely to illustrate a critical period for tick survival. The technique consisted of inserting the sensing element of an electrical hygrometer, which measured the a.c. resistance of a hygroscopic element, into the upper layers of the soil in apparently typical grazing land, away from water-courses. In position, the flat rectangular element was suspended in a protective perforated cylinder about 1 in. in diameter and about 2 1/2 ins. high (the long axis was vertical to prevent dust falling on the element) and with the solid top flush with the soil surface. The instrument was set up at mid-day each day and left in position near a grass tussock for one hour before reading. The calibration was checked each night and was correct to 4 %, usually 2 %.
Another important factor is the possibility of lethally high soil temperatures, especially in the drier tropics (Gray in Theiler, 1964). However, most ticks drop in the early morning (Hitchcock, 1955a, Wharton et al., 1964) and British breeds of cattle will tend to be in the shade at mid-day (Wilkinson, 1961). In addition, there will be greater vegetative cover near water-courses. To supply information on these soil temperatures, the probes of an electrical resistance thermometer were inserted at the base of two grass tussocks, where ovipositing ticks might shelter, and also in soil exposed to the sun, at the same time as the soil humidity observations. Results are shown in Table 2. It will be seen that at sites 5, 6, 8 and 9, inland of the tick distribution or just bordering on it, soil humidities were indeed low and soil temperatures high, especially on bare soil. The low soil humidity at site 7, within the tick infested zone, is probably due to the reading being taken on a dry ridge away from the local (Flinders) river and its tributaries, and it would be worth investigating whether tick survival is localised around water-courses in this high evaporation area. It is obvious that many more readings would be necessary to accurately test the relationship of soil humidities to tick distribution, but the results are highly suggestive. One informant reported abundant hatching of tick larvae in earth moistened by seepage from an artesian watering place, in a dry area. Another point worthy of investigation is the belief in the drier parts of North Queensland that basaltic soils are more tick infested than the less fertile, and probably less moisture retentive, granitic soils.

(b) Forest Home and Robin Hood Stations.

The situation at these properties (Table 1) illustrated how in the drier parts of the tick distribution, particularly where the cattle population is sparse (eight animals to the square mile at

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Robin Hood), the ticks may persist along the moister alluvial flats but be absent from the more arid hillsides, and from the headwaters of creeks where these have left little alluvial deposits. The annual or more frequent burning of pastures, almost universal in Northern Australia, probably accentuates the effects of aridity near the edge of the tick distribution. The macro-climate in these areas is unfavourable (Fig. 2 and Table 3) but the micro-climate along the rivers may be suitable for hatching of eggs of *microplus*.

### Table 3: Notes on localities shown in climographs of Fig. 3.

<table>
<thead>
<tr>
<th>Place</th>
<th>Whether in tick infested zone</th>
<th>Other localities with similar climographs, and remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brisbane</td>
<td>Yes</td>
<td>Atherton. Further north, but higher altitude makes temperatures comparable. Lower sat. deficits. Ipswich. Warmer summers. Higher saturation deficits. Lismore (N.S.W.) Few ticks on cattle in all these areas, between July and October, can be abundant for rest of year.</td>
</tr>
<tr>
<td>Georgetown</td>
<td>See next column</td>
<td>Upland areas tend to be tick-free, river frontages infested.</td>
</tr>
<tr>
<td>Hughenden</td>
<td>Borderline</td>
<td>Blackall. Outside tick zone. Has colder winters, is drier in spring-time.</td>
</tr>
<tr>
<td>Townsville</td>
<td>Yes</td>
<td>Innisfail. Lower sat. deficits. Rockhampton. Drier summers, colder winters. Ticks on cattle almost throughout the years at all three localities.</td>
</tr>
<tr>
<td>Toowoomba</td>
<td>No</td>
<td>Sydney, N.S.W. Slightly colder winters, drier summers, is also outside ticks zone.</td>
</tr>
</tbody>
</table>

Support for the owner’s account of the tick position at Robin Hood was provided by crush examination of eighteen cows, one steer, and one calf from a tick free area near the “new” homestead. None of these cattle, carried any visible *Boophilus*; two had light infestations of *Amblyomma triguttatum*. Later the owner sent us 12 engorged *Boophilus* and 4 partly engorged *A. triguttatum* taken from cattle on the main alluvial area on the property, the Little Robertson River. At Forest Home, moderately to heavily tick infested cattle from the alluvial flats were seen; lack of tick infestation of the cattle on the hilly RTS area was indicated by the quite regular occurrence of babesiosis when these cattle are taken through tick infested country. It seemed highly probable that in the hills of Robin Hood and Forest Home there was insufficient vegetation and soil moisture to protect ticks and larvae from these dry conditions. In contrast, on the flats of the Gilbert River, shelter and soil moisture were more favourable, as indicated by the lusher grass, and the luxuriant “rubber vine” (*Cryptostegia grandiflora* R. Br.) scrub. Some predation of tethered ticks by ants was seen at both localities but there were no indications that ants were controlling tick populations.

A few enquiries at other smaller properties around Georgetown supported the view that areas with the higher stocking rate, and alluvial soils, were more tick infested than the hill areas. Prescott (1944) has said of the “Tablelands and Ranges” (includes the Georgetown-Forsayth area) “at the end of a long dry spell with intense heat, the vegetative cover is insufficient to prevent erosion during periods of torrential rainfall following the break of the drought” and “the
soil material so eroded is deposited in alluvial plains, and on the marshes of the coast.” The combination of dryness in the spring, well drained soils, sparse vegetation, and low stocking rate could well account for tick scarcity in the RTS areas A and B.

Whereas babesiosis caused considerable losses to the owners of “Forest Home”, the “tick-free” status of most of “Robin Hood” was useful to the owner since he was usually able to sell his cattle to a tick-free area, by travelling them to Hughenden over a route containing only short stretches of tick infested country. The owner treated any babesiosis cases, occurring en route, with appropriate chemo-therapy, which was less expensive than regularly dipping the cattle for tick-worry on the home property.

At both “Forest Home” and “Robin Hood” the owners were actively engaged in installing dams and bores, and effecting other improvements which would alter the distribution of the cattle. These improvements, and annual variations in rainfall, would be expected to affect the distribution of ticks, and outbreaks of babesiosis have since been reported at Robin Hood.

(c) Alleged effects of sulphur intake and other ingredients of drinking water.

The Georgetown-Forsayth area has been extensively mined for gold and other minerals, and cattlemen often suggested that sulphur or sulphur compounds, or some other minerals in the water, were responsible for the tick free areas. Against this view, Francis (1892) was unable to detect any effect from feeding sulphur to a *Boophilus* infested bull for a fortnight, and Mail (1942) found feeding sulphur to lambs was ineffective against *Dermacentor* ticks. At Brisbane, I found that feeding sulphur to a bovine at close to the tolerance level, did not affect tick infestations (Table 4). All these tests were based on few animals, but they reinforce the view that the

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Treatment</th>
<th>No. larvae applied</th>
<th>Yield of engorged female ticks*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Both animals untreated</td>
<td>20,000</td>
<td>313</td>
</tr>
<tr>
<td>2</td>
<td>Animal 1 untreated, Animal 2 received 18 gm Sulphur daily, starting with day of infestation</td>
<td>20,000</td>
<td>221</td>
</tr>
<tr>
<td>3</td>
<td>Animal 1 untreated, Animal 2 received 18 gm Sulphur daily for 3 weeks prior to infestation, then 36 gm daily for two days prior to infestation, and continued for 4 weeks</td>
<td>40,000</td>
<td>356</td>
</tr>
<tr>
<td>4</td>
<td>Animal 1 not infested. Animal 2 infested 59 days after cessation of Test No. 3, to test for delayed effect.</td>
<td>40,000</td>
<td>2106</td>
</tr>
</tbody>
</table>

* Over 5 days of main dropping period, except Test No. 3 in which counts are for 4 days.

Table 4: Numbers of engorged ticks which dropped from infested stalled cattle, with and without addition of powdered sulphur to the ration.

The presence of a systemic acaricide in the drinking water available to cattle in the RTS areas was responsible for the scarcity of ticks. The presence of a systemic acaricide in the drinking water available to cattle in the RTS areas was responsible for the scarcity of ticks. The presence of a systemic acaricide in the drinking water available to cattle in the RTS areas was responsible for the scarcity of ticks. The presence of a systemic acaricide in the drinking water available to cattle in the RTS areas was responsible for the scarcity of ticks. The presence of a systemic acaricide in the drinking water available to cattle in the RTS areas was responsible for the scarcity of ticks. The presence of a systemic acaricide in the drinking water available to cattle in the RTS areas was responsible for the scarcity of ticks.
sent on the cattle, and in one case corixids were swimming unharmed in the suspect water. However, pressure to test this hypothesis was strong, and some compound or element producing an acaricidal or repellent effect indirectly might have been involved. A test was set up at Amberley in which three stalled steers were each supplied exclusively with water from the Kalbar RTS area, three other steers selected at random receiving their usual water supply. One test animal consumed 467 gallons and the other two between them consumed 1215 gallons of the suspect water. After four weeks on the experimental water supply, the six animals were infested with 40,000 larvae each (estimated from the weight of tick eggs before hatching). The number of engorged female ticks resulting from the infestation, noted during five days of maximum fall of ticks, was as follows: — Kalbar water 6,067, 1,611, 3,615, normal water, 2,967, 1,759, 1,581. It was concluded that the Kalbar water provided no protection against maturation of ticks on the cattle.

(d) Host availability.

There were indications from correspondence and reports in laboratory files that sheep running with, and outnumbering cattle, can markedly reduce tick abundance, sheep being more resistant than cattle to infestation with _B. microplus_, despite occasional records of heavy infestation (Legg, 1930). To examine the effect of this factor in limiting tick distribution, the sheep area is shown in Fig. 2. However, if conditions are climatically suitable, sheep would be unlikely to prevent the westward spread of notifiable tick populations, which would be noticeable on station dairy cattle, or other small cattle herds not mingling with sheep. Because in Northern Australia, the tick fails to penetrate appreciably beyond the 15 in. isohyet despite the absence of sheep, it appears it is aridity rather than presence of sheep that is preventing spread of the ticks inland, and the “sheep area” does not correspond closely to absence of ticks.

(e) Predators and parasites of ticks.

(I) Birds. Of birds that have been reported in other countries as tick predators, only the cattle-egret occurs in Australia, being present in large numbers in the coastal plains of the Northern Territory. Rothschild and Clay (1952) quote a report of many ticks found in the crop of the cattle-egret but other authors (quoted by Theiler, 1959) have queried the importance of this bird as a tick predator. Enquiries in the Darwin region in 1961 indicated that although numbers of these birds attended wild and domesticated water buffalo, few were seen around cattle, and heavy infestations of cattle ticks built up despite the presence of the birds. Other native and introduced birds have been mentioned as tick predators (Legg, 1930 and Roberts, 1952) and these, together with the pee-wee (Grallina cyanoleuca G.) and the introduced starlings (_Sturnus vulgaris L._) are quite frequently seen apparently pecking ticks from cattle, and eating ticks which have fallen from cattle, but none of these birds prevent ticks from reaching high populations, when other conditions are favourable.

(II) Parasites. Hymenopterous parasites are confined to three host ticks (Cooley & Kohls, 1934) and no other effective parasites of _Boophilus_ are known, though possibly there are unicellular parasites, or symbionts which may occasionally become harmful.

(III) Ants and Lycosid spiders. The literature on arthropod predators of ticks appears to be very limited (e.g. Barnett, 1961, Hooker, Bishopp and Wood, 1912). Predation on _Boophilus_ by ants, and to a less extent by Lycosid spiders, was first noticed in studies of behaviour of engorged female ticks at Rockhampton. One spider taking ticks was identified as _Lycosa godeffroyi_ Koch. Predation by _Iridomyrmex detectus_ (Fr. Smith) was later found to occur
in many places in the tick infested area, when ticks were put out in the presence of this ant. At Amberley Experiment Station, about 25 miles S.W. of Brisbane, on 10 and 24 November, 1955, and on 29 September, 1956, an attempt was made to estimate the proportion of ticks taken by ants by putting out ticks attached to cotton threads with adhesive, and ticks immobilized in pairs by sticking the ventral surfaces together, at randomly selected sites. On the first occasion, 7 out of 20 and on the second occasion, 13 out of 20 ticks were certainly or probably damaged by ants or lycosid spiders. On the third occasion, there were three ticks per site, possibly overloading the potential predators at each site, since the number of ticks attacked dropped to six out of sixty exposed. These are the figures obtained on an examination the day after exposure, and mortalities increased with longer exposure. Sufficiently large numbers of untethered mobile ticks could not be followed for long periods with these techniques, but naturally dropped ticks would no doubt be mainly concealed after about 48 hours and less subject to attack. Possibly

### Table 5: Observations on predation of ants on B. microplus.

<table>
<thead>
<tr>
<th>Ant Species</th>
<th>Localities</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Iridomyrmex detectus</em> Sm. (Meat Ant).</td>
<td>Rockhampton, Amberley (S.W. of Brisbane).</td>
<td>This ant seen carrying a naturally dropped tick at Rockhampton.</td>
</tr>
<tr>
<td><em>Pheidole megacephala</em> (Fabr.).</td>
<td>I, C. Also suspected predation on a property on red volcanic soil near Brisbane.</td>
<td>See text.</td>
</tr>
<tr>
<td><em>Pheidole weissi</em> Ford.</td>
<td>Amberley.</td>
<td></td>
</tr>
<tr>
<td><em>Aphaenogaster longiceps</em> Sm.</td>
<td>E.</td>
<td></td>
</tr>
<tr>
<td><em>Chalcoponera metallica</em> Sm.</td>
<td>Rockhampton, Amberley, E.H.</td>
<td>Frequently investigates or attacks ticks, but behaviour unpredictable.</td>
</tr>
<tr>
<td><em>Iridomyrmex mjobergi</em> Ford.</td>
<td>Rockhampton, A. E.</td>
<td></td>
</tr>
<tr>
<td><em>Iridomyrmex anceps</em> Roegr. var. <em>papua</em> Emery.</td>
<td>B.</td>
<td></td>
</tr>
<tr>
<td><em>Polyrhachis aurea</em> Mayr.</td>
<td>Rockhampton.</td>
<td></td>
</tr>
<tr>
<td><em>Notoncus foreli</em> Andre.</td>
<td>E.</td>
<td></td>
</tr>
<tr>
<td><em>Monomorium gracillum</em> Sm.</td>
<td>‘Cardington’ station (S.W. of Townsville.)</td>
<td></td>
</tr>
<tr>
<td><em>Rhytidoponera cristata</em> Mayr.</td>
<td>H.</td>
<td></td>
</tr>
<tr>
<td><em>Rhytidoponera nudata</em> Mayr.</td>
<td>E.</td>
<td></td>
</tr>
<tr>
<td><em>Meranoplus hirsutus</em> Mayr.</td>
<td>H.</td>
<td></td>
</tr>
<tr>
<td><em>Acrocoelia australis</em> Mayr.</td>
<td>B.</td>
<td></td>
</tr>
</tbody>
</table>

**Spiders.**

| Lycosa spp. | Rockhampton, H. | One specimen identified as *L. godfroyi* Koch. |

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1. These identifications were from specimens forwarded to and retained by the Division of Entomology, C.S.I.R.O., Canberra. Identities of the common *I. detectus*, *P. megacephala* and *C. metallica* were not always checked.

2. These species were offered tick eggs and larvae, which they sometimes investigated but did not damage. On one occasion *P. megacephala* was seen extracting tick larvae from a gauze covered tube, used in other experiments, and carrying them away.

3. Localities in Queensland at which the species was observed attacking experimentally exposed engorged female *B. microplus*. Code letters A to I refer to table I.
arthropod predation on ticks at Amberley in the spring would reduce the numbers of eggs produced by engorged females to about half of what it would be without predators, but probably at other times of the year the proportion would differ, depending on the availability of other foods and the activity of the predators. Locality records for other tick predators, and remarks, are given in Table 5.

In three RTS areas (C, E, I, Table I), two species of ants were seen to reach such high populations that it was reasonable to expect that survival of adult ticks, up to completed oviposition, might fall below the level needed to maintain the species, taking into account other causes of mortality. In two of these areas, and in one RTS area near Brisbane which was only superficially investigated, the ant was *Pheidole megacephala* (F.), an introduced species which, according to some farmers, may still be spreading in areas where soil and other conditions are suitable for its nesting requirements. This ant is well known in Queensland for its thorough searching of houses for foodstuffs and dead insects. It appears to be common in the friable volcanic soils originally carrying rain forest or Acacia scrub, but rare in undisturbed *Eucalyptus*-savannah woodland, on more compact soils. In areas where this ant was abundant, e.g. at Kalbar and in the Atherton districts (Table 1), no native ants were seen, paralleling experience in other tropical and sub-tropical areas where this ant displaced native ants (ILLINGWORTH, 1917, HASKINS and HASKINS, 1965). Although engorged female ticks were frequently attacked in the field, the ants first removing the ticks' legs, engorged ticks placed in a laboratory colony of this ant were rarely attacked. In the field, the intensity of attack is unpredictable, and probably varies with some unknown physiological requirements of the ants. Possibly there are closely similar species of ants which can be confused.

The other ant observed to reach high densities in favourable localities was the "funnel ant", *Aphaenogaster longiceps* (SMITH). On the RTS area of Eastbrook Station (E, Table 1), the large "funnels" (SAUNDERS, 1967) leading to entry holes about 1 in. diameter, were present at about 1 ft intervals in some areas, and the nocturnal foragings of this ant must have encountered a very high proportion of ticks dropped. Tethered ticks were attacked overnight by this ant.

**Ant predation in relation to life-tables.**

Although some tick predation by ants occurs in heavily tick infested areas, this does not preclude more intensive ant predation acting as a decisive factor in the RTS areas. No concurrent figures of increase per generation of ticks and percentage of ant predation are available, but WILKINSON (1964) reported increase of between 1.15 to 4.8 times per generation for the age-class of female ticks over 0.5 cm long, in the more favourable months of the year, at Amberley near the southwestern edge of tick distribution. Climatic conditions and the class of stock used in these observations might be said to be of intermediate favourableness to ticks, compared with the highly favourable situation for Shorthorn cattle kept in northern coastal Queensland (HARLEY and WILKINSON, 1964), or the unfavourable situation of resistant cattle at Amberley (WILKINSON, 1962). Postulating a rate of increase of twice per generation in the face of destruction of half the engorged ticks in a "ticky" area, it would then only require ants to prevent egg laying by a little over half as many adults again to reduce the rate of increase to zero. An increase in predation at periods of the year when the population is stable or declining would tend to reduce the residual population below the recovery level when the conditions became favourable. Table 6, compiled after the method of MORRIS and MILLER (1954) illustrates in approximate fashion how ant predation may act in conjunction with other known mortality factors.

In compiling Table 6, data were sought on the proportion of host-seeking larvae in a field which succeeded in attaching to cattle grazing the field. In Table 7, this proportion is calculated, using data (admittedly slender) on larvae picked up by cloth-covered sampling devices.

<table>
<thead>
<tr>
<th>x</th>
<th>lx</th>
<th>dxf</th>
<th>dx</th>
<th>Source of information on dx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eggs from five females</td>
<td>10,000</td>
<td>Infertility.</td>
<td>2,000</td>
<td>Snowball (1957)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Desiccation.</td>
<td></td>
<td>Wilkinson and Wilson (1959)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Desiccation or drowning before grass ascent and clustering completed.</td>
<td>7,000*</td>
<td>Wilkinson and Wilson (1959)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Larvae die before cattle approach, or otherwise fail to reach cattle.</td>
<td>800**</td>
<td>Table III</td>
</tr>
<tr>
<td>Unfed larvae on grass</td>
<td>8,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larvae on cattle</td>
<td>200</td>
<td>Removal by licking, rubbing, or death due to immune reactions of cattle</td>
<td>180</td>
<td>Based on 10% survival (Authors in Wilkinson, 1962)</td>
</tr>
<tr>
<td>Engorged adults</td>
<td>20</td>
<td>50:50 sex ratio.</td>
<td>10</td>
<td>Hitchcock (1955)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Predators and death by isolation (after falling to ground).</td>
<td>5</td>
<td>See text</td>
</tr>
<tr>
<td>Engorged females ovipositing</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected eggs</td>
<td>10,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* This mortality figure is likely to be too high for localities where repeated dipping is necessary, and the reference quoted may have failed to account for larvae difficult to locate.
** This figure supplied to balance table to steady-state value. It would be affected by the number of cattle per unit area.

TABLE 7: Estimates of larvae on grass traversed by cattle, compared with larvae picked up by cattle, based on Table 3 (Wilkinson, 1961) and cattle mileages in the same paper. Figures rounded to nearest whole number, or two decimal points for ratios.

<table>
<thead>
<tr>
<th>Date</th>
<th>Col. 1</th>
<th>Col. 2</th>
<th>Col. 2/Col. 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Larvae encountered by cattle, calculated from number of larvae per 500 yards of sampler travel (mean of two sampling devices) × 6 *</td>
<td>Number of larvae actually crawling onto cattle **</td>
<td></td>
</tr>
<tr>
<td>24.XI.58</td>
<td>1,578</td>
<td>528</td>
<td>0.38</td>
</tr>
<tr>
<td>7.XI.58</td>
<td>1,401</td>
<td>576</td>
<td>0.41</td>
</tr>
<tr>
<td>5.XI.58</td>
<td>138</td>
<td>360</td>
<td>2.60</td>
</tr>
<tr>
<td>9.I.59</td>
<td>243</td>
<td>524</td>
<td>2.15</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>1.51</td>
<td></td>
</tr>
</tbody>
</table>

* Assuming the cattle averaged 3000 yd travel per day and swept the same frontage as the sampling devices. This concept does not allow for pick up of larvae on bedding grounds, and at other times when not travelling.
** Column E of Table 3 (Wilkinson, 1961), × 10 for larvae dying before growing to specified adult stage, × 2 because only females counted. The size class 0.5 cm and over, counted at mid-day, would represent the product of about one day's pick up of larvae (Roberts, 1968) 21 days previously, assuming no rapid fluctuations in pick up on consecutive days.
propelled through the grass, compared with counts of adult female ticks on the cattle about 20 days later. These results would, of course, be highly sensitive to variations in cattle habits, size of cattle in relation to cloth sampler, and many other factors. There is an interesting suggestion that when larvae were more numerous on the pasture, a smaller proportion matured on cattle than when they were fewer, i.e. a density dependent effect tending to control tick numbers.

IV. Summary.

*Boophilus microplus* (Can.) has established itself in Australia in an arc across the northern part of the continent, where annual rainfall exceeds 15-20 ins. It extends southwards down the east coast within this zone, but is progressively limited to the coastal region by low inland winter temperatures. Within the favourable zone are areas of reputed tick scarcity (RTS). In some of these areas, predation of engorged ticks by ants was sufficiently intense to provide a probable explanation of scarcity of ticks.

In other RTS areas the tick scarcity was apparently due to the aridity of the soil surface of hilly areas, in contrast to adjacent tick infested alluvial plains.

Some evidence is presented against the widely held view that the drinking water consumed by the cattle in the areas is responsible for the reputed tick scarcity.

Hypothetical life-tables are presented, to place the potential losses due to ant predation in perspective. Even in tick infested areas, about half the engorged females may be killed by ants and Lycosid spiders.

Acknowledgements.

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