and the nymphs then take another four to seven days to become replete with blood, after which they drop off. Thus in the case of a *Hyalomma* remaining on the host the attachment period would be about 17-20 days (K.R.P. Singh, personal communication). On a migrating bird, this would allow for transportation, of the attached tick, a considerable distance.

It therefore appears probable that the nymph of *Hyalomma m. issaci* on the wagtail was picked up in a dry area somewhere along the migratory route of the host and brought into the study area. The phenomenon of transportation of ticks by migratory birds from one place to another, has important disease spreading potentialities if the ticks thus transported by migratory birds are carrying pathogens and are capable of establishing themselves in the area into which they are introduced.

* * *

6. DISCUSSION

6.1. General Remarks:

The present study has involved examination, for tick ectoparasites, of 8,474 birds belonging to 184 species, in Shimoga District, Mysore State, India. Of this sample, 1,082 birds of 81 species were found infested with various species of ticks. The total number of ticks collected from these birds was 9,821, of which 9,774 (99.5%) were of the genus *Haemaphysalis*. The rest of the sample belongs to the genera, *Dermacentor*, *Amblyomma*, *Boophilus*, *Rhipicephalus*, *Eisenia*, etc.
Khipicephalus and Hyalomma. Not a single *Ixodes* was found on any of the birds, though two species, *I. petauristae* and *I. ceylonensis* commonly occur in ground drags in some seasons and as ectoparasites of small mammals in the study area.

6.2. Generalized outline of the life history of *Haemaphysalis*:

Before any discussion on tick-bird inter-relationships is undertaken, it is necessary to understand the general outline of tick life history. The genus *Haemaphysalis* is taken as an example, since 99.5% of the tick sample taken on birds were of this genus. The data given below are based on laboratory rearing at ambient temperatures.

An engorged female after detaching from the host remains quiescent for five to ten days and then start laying eggs. The process of egg laying continues for several days and results in the deposition of 1,000 or more eggs. These hatch into larvae after 20-30 days. The freshly hatched larvae remain quiescent for about a week and thereafter start questing. It has been observed in the field that questing larvae were often found on blades of grass in the forest. When a host is encountered, the larvae attach to the host and start feeding for two to four days. The engorged larvae drop off the host, move about for two to three days after which they become dormant for about two weeks before they moult into nymphs. The nymphs start questing about a week after they moult. When a suitable host is found they attach and feed for two to five days, after which they drop off. The engorged nymphs moult into adults two to three weeks after they have dropped. Freshly moulted adults
start questing after 20-30 days. After adults crawl on a suitable host to feed, they mate while the female is still attached to the host. The female engorges for about eight days and drops to the ground. The engorged female lays eggs shortly afterwards and thus the life history is continued. This broadly represents the life cycle of a *Haemaphysalis* tick, though the time required for feeding and moulting varies with different species.

As can be seen above, there are differences in the duration of attachment on the host for each of the three developmental stages, larva, nymph and adult. Unfortunately, no precise data were obtained on the differences in the duration of feeding affecting the infestation pattern. However, it should be borne in mind that the differences in the duration of attachment on the hosts exhibited by the larvae, nymphs and adults, may affect the infestation pattern shown by the three different stages in this study. The larva stays on the host for the shortest duration and the adults the longest.

Not all the eggs that are laid hatch into larvae, and not all the larvae and nymphs find suitable hosts or successfully moult into next stages. Adult ticks might not find suitable hosts or have an opportunity to mate and lay fertile eggs. Hence from the progeny of one female tick, only a few may ultimately develop into the adult stage. Consequently, the relative proportion of larvae in nature is much higher than that of the nymphs, and that of nymphs is much higher than of adults.

The time taken to complete the life cycle in nature may be much prolonged and depends on climatic conditions and the time
interval necessary for the different stages to find suitable hosts.

6.3. Factors governing the infestation of birds by ticks:

6.3.1. Seasonal abundance of various tick stages:

During the present study, birds were found infested during different months with the immature stages as well as by adults of certain species. For most Haemaphysalis ticks, there appears to be a distinct pattern in the number of each stage taken on birds in different months. Therefore, the seasonal abundance of each stage of Haemaphysalis in different seasons is given below:

In the study area, the postmonsoon period, from the middle of September to about the middle of March or April, can be considered the larval Haemaphysalis season with peak drag collections. By about the middle of October, nymphs start appearing in the ground drags and persist in fairly large numbers till the onset of monsoon in June. The largest number of nymphs in ground drags is encountered in February. During the monsoon, from June to middle of September, the terrain is wet from heavy rains. A few nymphs were occasionally taken in ground drags during the season, when there was a brief spell of sunshine and the ground surface became somewhat dry. Adults were most frequently taken from forest vegetation during the monsoon. Immediately after rains, larvae started to appear in the ground drags. Thus we have distinct larval, nymphaal and adult seasons though there was always an overlap in the populations of adults and larvae, larvae and nymphs and nymphs and adults.

The infestation of birds by ticks during the present study closely follows the pattern of general abundance of the various
stages of ticks, in the study area (Table-7). The infestation rate of birds can be divided into categories, corresponding to the seasonal abundance of the various stages. The highest infestation on birds occurs in the months when the larvae of *Haemaphysalis* are abundant. The medium infestation on birds occurs during the nymphal season. The lowest infestation on birds occurs in the period May to September. In the months of May the lowest infestation appears to be due to the fact that larvae and nymphs are not able to withstand the high temperatures. In the monsoon months of June to September, the lowest infestation on birds may be attributed to two causes. Firstly, the immature stages are not found in the study area in the same numbers as in the months October to April. Secondly, the monsoon period corresponds with the general abundance of adult ticks in the study area and adults, barring a few species, do not readily attach on birds.

6.3.2. Relative abundance of various tick species:

In the study area, *H. spinigera*, all stages, was the dominant tick species, followed by *H. turturis* and *H. papuana kinneari*, as evidenced by drag collections and handpicking collections on forest vegetation. But other tick species taken on birds in fairly large numbers were not encountered in drags in the same proportion. These factors are discussed in detail under the accounts of the individual tick species.

The abundance of any particular tick species in the area depends mainly on the availability of adult hosts. Cattle are the chief adult host of *H. spinigera* and *H. bispinosa* and to a lesser
degree also for *H. turturis*. Cattle graze not only in the open pastures but also in the forest. Adults of these three tick species drop in areas where cattle graze. While the immature stages of *spinigera* and *turturis* were found in the forest in large numbers, *bispinosa* larvae and nymphs were found only in small numbers. It appears that while *spinigera* and *turturis* survive and proliferate in the humid environment in the forest, *bispinosa* larvae and nymphs are not able to withstand the high humid environment in the forest and seem to prefer a much drier climate and open environment afforded by the open grasslands and maidans. This affords a reasonable explanation for the fact that many birds which are associated with cattle in peridomestic situations, but are not commonly found inside the forest, are infested with *H. bispinosa*.

*H. wellingtoni*, which is a bird tick and which forms the second most abundant species in this study, appears to have a localized distribution and hence is not met with in large numbers in drags. I have found the greatest numbers of *H. wellingtoni* larvae and nymphs under lantana bushes where the adult host take cover and live, and where the adults might drop after engorgement.

Nymphs of *H. kyasanurensis* were found in unusually large numbers in certain areas where the adult hosts, porcupines, appear to be locally concentrated. Species of ticks found in lesser numbers on birds are dealt with in the descriptions for individual tick species.

6.3.3. Behaviour and habitats of the avian host species:

With few exceptions, host species infested with ticks are either entirely terrestrial or frequent the ground surface in the course of their nesting, roosting, or feeding activities.
Birds of the family Phasianidae live, nest and move on the ground resorting to very short flights to escape from enemies. The junglefowl, spurfowl and the peafowl have the greatest opportunity to come into contact with the questing ticks of all stages. Other birds such as the crow-pheasant, babbler, myna, thrush and magpie robin live and nest in trees, but hunt for food on the ground, and thus become tick-infested.

Birds such as paddy birds and the cattle egrets, move on land, but were not found infested with ticks, because they move in terrain like mud flats and tank bunds, which are devoid of ticks. However, I have on one occasion observed a large group of cattle egrets in the middle of an evergreen forest, near a herd of grazing cattle. I have also found tick fragments in the stomachs of cattle egrets.

Many lapwings, mynas and larks in the study area were often associated with cattle. In the study area, it is a common sight to see many of these birds amongst a herd of cattle grazing in open grassy lands. Immature stages of *H. bispinosa*, a cattle tick, were found on these bird species.

Though house sparrows, spend considerable time hunting for food on the ground, their activities are centred around peridomestic situations which are usually devoid of forest ticks. One house sparrow was infested with a larva of *H. bispinosa*, the adults of which are chiefly parasitic on domestic cattle and whose larvae have been found on the domestic fowl.

Immature stages of several species of *Haemaphysalis* have
been taken from tree trunks, at considerable heights. Some arboreal birds, like the grey hornbill and green pigeon, might pick up ticks in this way, and this may account for infestation of arboreal birds.

Young birds of several arboreal species which leave the nest early when they are not yet able to fly well, may be on the ground for considerable periods and thus contact ticks with greater frequency than adults of the same species. This is also true of birds that are injured and unable to fly. These factors may contribute to the finding of ticks on several arboreal birds, whose habits are not favourable for tick infestation, generally.

The emerald dove, yellowthroated sparrow and babblers are 'roadside' birds. While driving on forest paths, it is a common sight to see these birds moving on roadsides, hopping from place to place or from trees to the ground and vice versa. As explained under the accounts of the individual tick species, the immature stages of H. intermedia develop in areas frequented by imported sheep and goats (See under 5.2.2.5.). It is thus of interest that H. intermedia larvae were found on the emerald dove and the yellowthroated sparrow.

As discussed under H. megalaimae (See 5.2.2.9), the habits and habitats of the small green barbet are ideally suited for the continuation of the life cycle of this tick which has been found only on the small green barbet, an exclusively arboreal bird. The fact that the barbet lives and nests in the holes, and re-uses the old nest holes is a significant factor in the life cycle of this tick.

6.3.4. Bird activity affecting infestation rates:

During the monsoon, bird activities are reduced due to the limited availability of food and the fact that their movements are
considerably handicapped by heavy rains. Barring trees like *Albizia prosera*, *Dillenia pentagyna*, *Cassia occidentalis* and a few other species, very few trees are either flowering or fruiting. The forest floor is saturated and the insect population also dwindles considerably. The decreased sources of food coupled with limitations of freedom of movement of birds result in a considerable decrease in the active bird population.

The bird population appears to be higher and more active in the post-monsoon season. The increase in the forest insect fauna after the rains and the flowering of many trees attract large numbers of birds. The increased activity of the birds, coupled with the fact that in the post monsoon period the immature stages of ticks of many *Haemaphysalis* species are abundant and readily attack avian hosts, resulting in a higher infestation rate.

**6.3.5. Acceptance of avian hosts by different tick species:**

During this study, birds have been found infested with immature stages of almost all *Haemaphysalis* species recorded in this area. The exceptions are *H. centropi*, *H. corrigera shimoga* and *H. leachii*.

*H. centropi* was found parasitizing crow-pheasants in some areas which are much drier and several hundred miles north of the study area, and also has been reported parasitizing the crow-pheasants in other countries. During the present study only one male was found on a common myna while none was found on any of the 151 crow-pheasants examined. The rarity of this species may be a result of the study area being near the geographical limits of the distribution of *H. centropi*. 
H. cornigera shimoga is relatively a not uncommon species in the study area. Adults were taken on forest vegetation and though it ranks fourth in abundance after spinigera, turturis and papuana kinneari in some areas, it has been taken on a few occasions only on the bison, Bos gaurus. The hosts of immature stages of this tick are still not known and none was taken on birds.

H. leachii, though not common in drags, has been taken on deer and mongoose in the study area. The fact that none among the large sample of birds examined during this study had any H. leachii suggests that this species is exclusively a mammal ectoparasite.

Birds are the important sources of blood meals for the immature stages of H. spinigera, H. turturis, H. bispinosa and H. papuana kinneari as the immature stages of these species have not been taken on any non-avian hosts in such large numbers.

The immature stages of H. aculeata, H. cuspidata and H. kyasanurensis were found in small numbers on birds, but are mainly parasitic on mammals.

H. wellingtoni, a bird tick has not been taken in the adult stage on mammals. Immature stages are occasionally found on small mammals and wild monkeys, but these stages also are chiefly parasitic on birds. Their distribution in the study area is also centered around the habitations of their important host, the junglefowl.

H. minuta is also chiefly a bird tick. In this study all the adults were taken only on the junglefowl. The immature stages have been taken on man, monkeys and small mammals and one adult on a mongoose.
H. intermedia adults are common ectoparasites of cattle, sheep and goats in the drier areas, east of the study area. This tick is introduced into the study area (See under 5.2.2.5.) by immigrant sheep and goats which must drop engorged females. The progeny of these females attack birds. More than a third of all H. intermedia taken on birds, and 15 of the 16 adults taken, were from the crow- pheasant, suggesting some host preference for this bird.

H. megalaimae exhibits the highest degree of host specificity, as this tick has been found only on the small green barbet (Megalaima viridis).

Thus we find a wide spectrum of host range among the different species of Haemaphysalis in the study area, as detailed below:

<table>
<thead>
<tr>
<th>Species</th>
<th>Hosts Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>H. megalaimae</td>
<td>All stages exclusively parasitic on one host species, Megalaima viridis.</td>
</tr>
<tr>
<td>H. centropi</td>
<td>All stages exclusively parasitic on birds, chiefly Centropus sp.</td>
</tr>
<tr>
<td>H. wellingtoni</td>
<td>All stages parasitic on many bird species; immature stages occasionally also attack monkeys and small mammals.</td>
</tr>
<tr>
<td>H. minuta</td>
<td>All stages parasitic chiefly on birds; all stages also attack mammals.</td>
</tr>
<tr>
<td>H. intermedia</td>
<td>Adults principally parasitic on domestic animals, but also parasitise birds. Immature stages frequently attack birds.</td>
</tr>
<tr>
<td>H. bispinosa</td>
<td>All stages chiefly parasitic on mammals; immature stages also attack birds.</td>
</tr>
<tr>
<td>H. aculeata</td>
<td></td>
</tr>
<tr>
<td>H. cuspidata</td>
<td></td>
</tr>
<tr>
<td>H. kyasanurensis</td>
<td></td>
</tr>
<tr>
<td>H. spinigera</td>
<td>Adults parasitize large mammals. Immature stages have a wide host range and attack birds and mammals. Birds appear to be the chief source of bloodmeal for immature stages.</td>
</tr>
<tr>
<td>H. turturis</td>
<td></td>
</tr>
<tr>
<td>H. papuana kinneari</td>
<td></td>
</tr>
</tbody>
</table>
The numbers of ticks belonging to the genera other than *Haemaphysalis* are so few in the sample, no definite conclusions could be drawn. It appears that birds are only adventitious hosts for the immature stages of *Boophilus*, *Rhipicephalus*, *Dermacentor* and *Amblyomma*, the adults of which are parasites of mammals.

6.3.6. Areas from where birds were collected:

The species of tick taken on a bird depends on the area from where the bird was taken. Ticks usually found on birds in drier areas, are species which have lower moisture requirements like *H. bispinosa* and *H. intermedia*. Immediately after the study period, nearly one hundred junglefowl examined were found to be infested with all stages of *H. bispinosa*. All these junglefowl were obtained from an area which is much drier than the study area.

6.4. The spotted dove question:

During this study 261 spotted doves were examined. None was infested by ticks. Although they live and nest in the forest, and often feed on the ground, it is puzzling that not a single dove was found infested with ticks. Possibly doves hunt for food in microhabitats devoid of ticks, like open roadsides and maidan. It has been opined that these birds prune their feathers. The stomach contents of many of the doves examined failed to reveal the presence of tick parts - the soft skin of the doves also might not be suitable for tick infestation.

It still remains unexplained why not a single dove was found infested with ticks.

6.5. Site of attachment of ticks on the body of the host:

Bishopp and Trembley (1945) have recorded the sites on the body of the host from which ticks were taken. They found
Haemaphysalis leporia-palustris on the top of the head and around the eyes and ears of the host. Rosicky and Balat (1954) give the following locations on the body of the birds from which they have taken Ixodes ricinus: head; close to the beak; under the beak and in its corners; eyes and eyelids; neck and close to the neck.

In this study, birds were wrapped in the field immediately after they were taken and examined for ticks later in the laboratory. Ticks from most of the birds had dropped into the wrapper when the examination was made. For the purpose of determining the preferred location of ticks on the body of the host, only such birds have been considered which had all the ticks attached on them at the time of examination. The results obtained from an analysis of ticks collected from 182 birds belonging to 30 species are presented in Table-35.

Our findings are consistent with those cited above, the majority of the ticks being found on the head, neck and throat, vicinity of the beak, eyebrows and ear. A few ticks were also collected from the wings (8.7%) and one nymph from the anus. These ticks were of various species and no evidence was obtained of variations in site preference on the host for the different tick species.

6.6. Comparison of the frequency of separate and mixed infestations on individual hosts by H. spinigera, H. wellingtoni and H. turturis:

The frequency of separate and mixed infestations of larvae, nymphs and adults of Haemaphysalis ticks of all species, by months is summarised in Table-16, while the figures for H. spinigera, H. wellingtoni and H. turturis are presented in Tables 17, 18 and 19 respectively. (Figs. 5 to 8).
If we consider all species of *Haeamaphysalis*, we find birds having (1) only larvae on them, (2) with both larvae and nymphs and (3) with only nymphs on them, in all months of the year. Birds with only larvae, are found in much larger numbers during October and November, and birds with only nymphs, in February. These periods correspond respectively to peak larval and nymphal months in the forest, as evidenced by dragging operations.

For *spinigera* (Table-17), and *turturis* (Table-19), the pattern of the frequency of separate and mixed infestations on individual avian hosts by larvae and nymphs, conforms to the general distribution and seasonal abundance of these two species in the study area. For *spinigera*, the largest number of birds with only larvae occur in October, which is the larval peak period for this species in the forest. The peak nymphal month of February, has the largest number of birds with only nymphs on them. The lowest infestation for larvae and nymphs occurs during the monsoon season, when these two stages are scarce in nature. The pattern for the infestation of larvae and nymphs of *turturis*, also follows the pattern of seasonal abundance of this species in nature, the infestation pattern also showing clearly the delayed larval peak (November) and the persistance of the nymphal season of *turturis* in nature.

For *H. wellingtoni* (Table-18) all stages of the tick prefer avian hosts, with the adults exclusively parasitic on birds. The adults are dropped in niches where birds live, nest or roost, and hence the infestation of birds by the different stages of *wellingtoni*, might be expected to occur in all months of the year,
subject to the availability of the hosts frequenting those niches, and the general abundance of these stages governed by climatic factors. *H. wellingtoni* presents a pattern of a tick, which is parasitic in all its stages on avian hosts, unlike *spinigera* and *turturis*.

The mixed infestation of an individual host by two or three stages of any tick species appears to have some epidemiological significance. If a larva and a nymph attached to the host at the same moment, with the nymph contributing the infective agent, the larva would have dropped off the host before infective quantities of the pathogen would be likely to be circulating. This is because of the shorter duration of feeding of the larva in comparison with the nymph. But there must be a great deal of staggered feeding on the host by larvae and nymphs. If a larva attaches to a host towards the last days of feeding of a nymph, by the time the larva engorges, the host bird might be circulating sufficient quantity of the infective agent to infect the larva and it is in this context that the mixed infestation by both larva and nymph on the same host assumes epidemiological importance.

6.7. Introduction of ticks into the study area

*Hyalomma marginatum isaei* is a common ectoparasite of livestock and cattle in the drier parts of India. The immature stages of this tick have also been taken on several bird species in Bharatpur (Rajasthan) and Kutch in northwestern India. The finding of a nymph of *Hyalomma m. isaei* on a migrant wagtail can be considered with some degree of assurance, a case of introduction
of a tick not indigenous to the area by a migrating bird (See under 5.2.5.17).

6.8. Remarks on the absence of ticks of the genus Ixodes:

_IXODES_ petauristae and _I. ceylonensis_ are two common ticks occurring in ground drags in the study area, and as common ecto-parasites, in its immature stages, of small mammals in the area. The immature stages have been found very abundant during the monsoon in ground drags. _I. ceylonensis_ larvae and nymphs have a seasonal prevalence immediately after the monsoon. The absence of even a single _Ixodes_ tick on any of the large number of birds examined clearly indicates that _Ixodes_ species of the area do not parasitize birds.

* * *

7. SUMMARY

A two year study on the Ixodid ticks (Acarina: Ixodidae) of wild birds of Shimoga district, Mysore State, was undertaken by the writer as part of the overall program of work of the Virus Research Centre, Poona, on the epidemiology of Kyasanur Forest Disease in Shimoga District, Mysore State, India.

A total of 8,474 birds belonging to 184 species, was collected and examined for ticks during the two year period. Birds of widely differing habits and habitat were taken in every month of the year, to study the seasonal pattern of infestation and also to correlate the tick infestation with the habits and