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Ticks and Tick-borne Diseases

Proceedings of an international workshop on the ecology of ticks and epidemiology of tick-borne diseases, held at Nyanga, Zimbabwe, 17–21 February 1986

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Foreword

Ticks and tick-borne diseases are major constraints to the improvement of livestock productivity in Africa. They reduce growth and milk yields, and cause high calf and adult cattle mortalities in many situations. Repeated attempts to improve animal productivity through breeding have been thwarted by the very high level of susceptibility of exotic breeds to African ticks and tick-borne diseases.

Africa's tick and disease problems are extraordinarily complex, with a multitude of host types, tick species and tick-borne diseases. Historically, control of the ticks and diseases has relied on weekly chemical “dipping” of cattle in expensive chemical solutions, which are a continual drain on foreign currency. Australia suffered a similar but less severe problem until the 1970s, when tick-resistant beef breeds were exploited, using ecological, epidemiological and genetic research as a basis for the program. The Australian experience and expertise was a logical partner to African research efforts aimed at vaccination and at understanding the complexity of the field problems.

In 1983 a collaborative ACIAR research project, titled, “Tick Ecology and Epidemiology” was established between the CSIRO and several African countries and international agencies, notably FAO. The aim of the project was to develop economically optimal tick control strategies that exploited the concepts of host resistance to ticks and the endemic stability of tick-borne diseases, and relied on sound estimates of losses in productivity caused by these parasites. This workshop was, therefore, a natural extension of the project, and enabled the widely represented gathering of researchers and administrators to discuss tick-related problems and methods for their alleviation.

ACIAR wishes to thank the word processing staff at the CSIRO Long Pocket Laboratories and the staff of the regional office of the FAO in Harare for their valuable assistance.

Thanks are also due to Mr David Herwood, Mrs Kath Lenaghan and to Carol Murray for their diligent help in the preparation of the proceedings manuscript.

During the meeting all participants gave willingly of their time and energies when asked to chair sessions, lead discussion groups and prepare summaries and recommendations. ACIAR acknowledges these efforts with gratitude.

Finally, ACIAR would like to thank Mr Mahachi, Minister for Lands, Agriculture and Rural Settlement for acting as host for the workshop.

J.R. McWilliam

Director

ACIAR
Summary and Recommendations

These proceedings are an account of a workshop which brought together relevant researchers and administrators from countries in east, central and southern Africa, as well as from Australia, USA, Europe and several international agencies. Their task was to define the current status of research into the ecology of ticks, the epidemiology of tick-borne diseases, the losses in productivity caused by the parasites and the impact of traditional livestock management practices on these problems and on attempts to alleviate them. In addition, Directors of Veterinary Services of each country were invited to participate and share their experiences and problems with the researchers.

Informal exchanges of information were of prime importance, so formal presentations were kept to a minimum number of reviews of different aspects of the modelling activities. Participants were invited to present brief “position papers” covering aspects of their research which were pertinent to the topics under discussion. Abstracts of these presentations are included in this publication to inform other research groups of these activities, which were not yet at the stage where formal publication of results was possible.

Participants divided into four groups after each field had been covered. They evaluated the data available and made recommendations on future research priorities, with emphasis on the following areas:

1. specific field problems to be studied;
2. modelling needs (needs of users and of modellers);
3. data requirements for process-based models;
4. data requirements for defining the field situation.

Recommendations

The workshop recognised the progress already made in the control of economically important ticks and tick-borne diseases in the parts of Africa represented at the workshop. The following eight recommendations for further activity were made:

- There be continued resource allocation for the development of models involving ecological, epidemiological and economic management aspects of tick-borne diseases and their vectors.
- Data be collected on the Amblyomma/Cowdria complex and the improvement of diagnostic methods for cowdriasis be accelerated.
- Research on host resistance to ticks and tick-borne diseases to receive a high priority and take into account increased livestock productivity.
- That each African country in the region be encouraged to appoint an epidemiologist to interact with colleagues in neighbouring countries and with tick modelling groups, such as that in Australia. In addition, research on host resistance to ticks and tick-borne diseases to receive a high priority and take into account increased productivity; with consideration given to training postgraduate and other selected staff in epidemiology.
• Countries to undertake thorough economic assessments of theileriosis and/or cowdriasis, of vaccination trials and of the implication of modifications to current tick control policies.
• Research and trials on vaccine against ticks and tick-borne diseases to continue.
• Governments be encouraged to carry out surveys of the perceptions of farmers, their practices and livestock management, taking into account the wide diversity of management practices in the region.
• A specialist workshop be organised to explore the use of expert systems, initially to clarify research objectives and later to provide expert advice on ticks and tick-borne diseases.
I. Introductory Papers
Australian-African Collaboration on Tick Ecology and Epidemiology of Tick-borne Diseases

R.W. Sutherst*

The ACIAR tick project has its roots in Uganda in 1978 when Dr M.N. Kaiser of FAO made detailed observations on tick populations of Zebu cattle in Uganda, as part of a team led by Dr R.J. Tatchell. The team recognised Australia's strengths in quantitative ecology, host resistance and mathematical statistics and sought assistance from the CSIRO to analyse the large amount of ecological data that had been collected. At the time, DANIDA/FAO proposed a regional program on ticks in Africa with a major component being the measurement of economic losses due to ticks in east and central Africa.

The role of host resistance against 3-host ticks had not been recognised, largely because the data of Roberts (1968) on the rejection of different stages of *Boophilus microplus* by the host had been widely misinterpreted. In fact, that data demonstrated that almost equal proportions of larvae, nymphs and adults were being rejected by host resistance, giving good support to the belief that resistance would be effective against 3-host ticks also. The wide Australian experience with host resistance to control *B. microplus* (Sutherst and Utech 1981) therefore complemented Africa's needs very well. Since a visit by the author to Uganda, mutually beneficial cooperation has taken place between CSIRO and national governments, supported by FAO in Burundi and Zimbabwe. Cooperation at a less intensive level has occurred with ICIPE and KARI in Kenya and FAO in Zambia.

By 1982-83, the amount of informal contact between the author in Australia, FAO and national researchers had grown beyond a level that could be sustained without formal support. Coincidentally the Australian Centre for International Agricultural Research (ACIAR) came into being and was approached for funds to support the cooperative activities. As a result, previously informal collaboration has become more formal and the roles of both African and Australian researchers need to be spelled out, so that each may appreciate better his place in this regional effort.

Recognition in Australia of the need for ecological research on ticks arose from very severe problems with the high cost of acaricides and the repeated development of acaricide resistance. In 1970, an attempt was made to build a computer model of the population dynamics and control of the cattle tick. It was based on the assumption that there was enough ecological data available to enable a model to be built. However, it immediately became clear that 30 years of ecological research produced very little of the specialised data needed to build models. That lesson should provide a warning to other teams planning to build population models.

The model of *B. microplus* was designed initially to answer a specific question: what is the role of host resistance in the control of cattle tick in different geographical regions of Australia? Host resistance had been studied intensively by Dr R.H. Wharton and others and it was seen as a means of alleviating the tick problem (Wharton et al. 1973). Any combination of control methods inevitably leads to the need for an understanding of the host-parasite system and from there to an integrated pest management approach (Sutherst 1981).

Initially, a climate driven model (TICK1) was produced to simulate the population dynamics and control of the cattle tick. In order to make the model much more relevant to management, economic relationships were incorporated into a simplified version (MATIX) in association with Dr G.A. Norton and colleagues at Imperial College, London (Sutherst et al. 1979; Norton et al. 1983). Meanwhile, a generalised approach to the study of tick ecology was being formulated (Sutherst et al. 1978) and a comparative study was being carried out on the 1-host tick, *B. microplus*, and the 3-host tick, *Haemaphysalis longicornis*, with the aim of eventually producing a model applicable to 3-host ticks also (Maywald et al. 1980). Unfortunately, most of the data on the free-living stages of both

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species has yet to be published. Gradually other features were built into the models to simulate acaricide resistance and, more recently, transmission of tick-borne diseases. The original Boophilus model (TICK1) was set aside and further development has been concentrated on a new generation model (TICK2) and on an extension of TICK1 to 3-host ticks (T3HOST). In addition, a climate-matching model (CLIMEX) has been developed (Sutherst and Maywald 1985) to answer some of the ecological questions before extensive data are collected. This avoids some of the long delays that are unavoidable when population models are being developed for a new species. The incomplete nature of all models means that their potential users may make major misinterpretations unless they work closely with the authors of the models. Because such problems also threaten the credibility of the models, we believe that it is very important that users run the models in collaboration with us. Far from being a valuable commodity open to exploitation, the models should be seen as fragile structures full of traps for the unwary.

The tick problems in Africa are far more complex than those in Australia where there is only one host species of significance, cattle, one tick species of major economic importance, B. microplus, and only two important tick-borne diseases, anaplasmosis and babesiosis. In Africa, complexities are greater in every aspect: there are multiple species of hosts, multiple species of ticks and several different tick-borne diseases. This complexity provides compelling reasons for a holistic and detailed ecological study. In order to meet that need, the aim of the ecological and economic study, initiated by FAO and national governments, was to design control programs which were economically optimal but, at the same time, did not disturb the endemic stability of tick-borne diseases.

Objectives, Scope and Structure

The general objective of the ACIAR project was to devise an integrated pest management approach to the control of ticks and tick-borne diseases that could be applied by users to local conditions in Africa.

The specific objectives were: to determine the economic losses caused by ticks and tick-borne diseases; to define the role of host resistance of different breeds of cattle in tick control; to describe the population dynamics of Rhipicephalus appendiculatus, Amblyomma spp. and Boophilus spp.; to describe the epidemiology of theileriosis and babesiosis; and to design integrated control programs for adapted cattle in different climatic zones.

The main point to emphasise concerning the project is that the Australian contribution is to provide a source of specific, specialist expertise in the following areas: the identification of research problems with highest priority in relation to understanding tick populations and designing tick control strategies; the design and analysis of the experiments necessary to collect the specific data required; modelling the population biology of 3-host ticks; and modelling the epidemiology of tick-borne diseases.

Tick research in Africa must of necessity be the primary responsibility of scientists based in Africa. The data collected in collaboration with Australian scientists are recognised as being the property of those African scientists who collect the data. The Australian contribution is to play a support role to enable African scientists to achieve their objectives. We see ourselves, in all cooperative activities, as partners who do not want to threaten national aspirations, to undermine government policy or to duplicate or disrupt existing multilateral projects. However, the nature of the Australian contribution is such that it must provide a degree of leadership in identifying the ecological problems and pointing towards solutions. Indeed, the terms of reference of ACIAR state not that it is a donor agency or an extension body, but that it will support collaborative research with bilateral benefits to Africa and Australia. We look, therefore, for partnership with national government researchers.

The project is aimed at east and central Africa, with emphasis on Commonwealth countries, and has close links with the existing FAO regional program. The FAO program was established on a regional basis because no single country in Africa had the resources to develop such a program on its own. Even in wealthy, developed countries such a project is a massive undertaking. The regional nature of the research effort enables the necessary data to be collected where and when it is possible. Each country has different resources that can complement each other to produce the data needed to acquire an overall understanding of the problem for the benefit of all. Limiting resources initially were: the lack of research stations suitable for large-scale field experimentation; insufficient numbers of experimental animals; a lack of expertise in the areas of quantitative ecology, computing, statistics and economics. In addition, enormous funding was
needed, and this has since been provided largely by DANIDA.

The richness of the African tick and disease fauna means that initially efforts have to be concentrated on the most important species of ticks and of tick-borne diseases. The first targets therefore have been *R. appendiculatus* and theileriosis, and, secondly, *A. variegatum/hebraeum*, the vectors of cowdriosis (heartwater). A survey of the literature suggests that much of the information on *B. microplus* can be translated to *B. decoloratus*, with specific measurements to identify differences between the two species and interactions between them. The research findings are aimed to apply equally to traditional and to commercial farming systems.

Because it has developed out of such informal history the current project has a minimum of structure. There are three main thrusts:

(i) the identification of necessary research data, with follow-up design and analysis of experiments for data collection;

(ii) extension of the previously existing 3-host tick model (T3HOST) to describe the population dynamics of *R. appendiculatus* and later of *A. variegatum/hebraeum*;

(iii) continuation of the development of the much more ambitious and realistic "new-generation" model (TICK2) to describe the population dynamics of 1- or 3-host tick species, transmission of tick-borne diseases and tick control methods.

**Future Prospects**

The eventual outcome from the current thrust on ecological research in Africa is expected to be a great moderation of the use of acaricides in tick control. This should come about firstly by exploiting host resistance and secondly by using the knowledge of geographical, annual and seasonal variation in the numbers of ticks to reduce the frequency of dipping. This knowledge will help to design economically optimal tick control strategies which would provide tangible benefits to stockowners and governments.

The possible future extension of the project is the subject of review at the present time. Several areas for development are readily discernible: the extension of present ecological and epidemiological studies to cover the other important tick species, mainly the *Amblyomma-Cowdria* complex for which data collection is just beginning in earnest; more work on the animal production side of the problem to relate productivity of cattle and other domestic animals to their resistance to ticks; an increased emphasis on economic analysis to define the benefits of tick and tick-borne disease control programs; further training of African national scientists in a pest management approach to tick control; and a wider communication of the knowledge generated during the project to traditional and commercial farmers by government technical personnel and policy makers.

Successful achievement of these objectives within a reasonable time scale will require greatly increased support for national researchers and an acceleration of the computer modelling. It is therefore vital that all governments and international agencies involved work closely together to achieve our common goals for Africa. Hopefully, this workshop will contribute to that cooperation and understanding. We must remember that it is the collaborative efforts of individual scientists rather than organisations that really make research successful.

**Acknowledgments**

ACIAR provided financial support for the development and use of tick models in Africa. Dr J. Copland and Ms S. Hibberd provided great encouragement and assistance with both the tick project and this workshop. Ms B. Watts carried most of the load of word processing for the many papers required to meet the close deadline for the workshop. Their help was invaluable and is greatly appreciated.

**References**


Control of Ticks and Tick-borne Diseases in Burundi

A. Niyonzema* and H.H. Kiltz**

BURUNDI covers an area of 21,834 km², has 4.5 million inhabitants and approximately 600,000 head of cattle. The problems of ticks and tick-borne diseases represent major handicaps in the development of a profitable livestock industry. The high priority accorded these problems by the Government is reflected in its five-year economic and social plan for 1983–87.

The country has two veterinary laboratories, situated in Bujumbura and Gitega, carrying out diagnostic work and vaccine production. The veterinary service is organised according to provinces (15) and districts (114). One veterinarian is assigned to each province, while districts are equipped with one veterinary centre each and at least one veterinary technician. Burundi has a total of 30 veterinarians.

The distribution of cattle is shown in Fig. 1. Apart from a few Government farms where Friesian, Jersey, Sahiwal or crossbred cattle are kept, the majority of bovines are of the Bos indicus type, a half-Zebu breed of low production, called Ankole. The cattle production system is mainly traditional, governed by security aspects and social status. However, it is beginning to diminish in importance and the Government is attempting to upgrade local breeds by introducing Bos taurus cattle to meet the increasing demand for milk and milk products.

The classical type of theileriosis, East Coast Fever (ECF), is endemic in Burundi. However, the incidence of the disease varies with the distribution of the vector tick Rhipicephalus appendiculatus. Intensive serological studies by the GTZ Project have shown that 63% of the sera collected had positive titres to Theileria parva antigen. The incidence ranged from 7.3% (Kisozi region) to 96.5% (Karuzi region). Apart from T. parva parva, the Theileria spp., T. mutans, T. velifera and T. orientalis, were proved to exist in the country. Other tick-borne diseases endemic in Burundi are Anaplasma marginale, Babesia bigemina and Cowdria ruminantium.

Fig. 1. The distribution of cattle in Burundi. 1, heavy; 2, moderately heavy; 3, moderate; 4, sparse. ———, national border; ——, regional border; ———, lake.

Tick ecology studies have been carried out by the FAO project with intensive censuses of populations of all tick species on livestock in 5 major ecoclimatic zones in Burundi. Similar research on the development and survival of free-living stages of R. appendiculatus was done at selected sites in these zones. A national tick survey covered the entire country. Thirteen tick species were found but R. appendiculatus, Amblyomma variegatum and Boophilus decoloratus made up most of the

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**GTZ Veterinary Project, B.P. 1118, Bujumbura, Burundi.
collections (FAO unpublished reports). The FAO project is recommending the introduction of strategic tick control for economic reasons, taking care to maintain enzootic stability and to minimise acaricide pressure which could result in the development of tick resistance. The national policy is to improve control measures for ticks and tick-borne diseases by supporting external research projects in these fields (FAO, GTZ) and to follow their recommendations.

Ticks and tick-borne diseases in Burundi are controlled in three ways: chemical control of ticks, immunisation by chemoprophylaxis and chemotherapy. The country is served by a total of 159 dipping tanks of which about 80% are operational. Individual smallholders have begun to practise hand-spraying. Cattle are usually dipped at irregular intervals, but acaricide resistance has not been observed yet in Burundi and does not constitute a tick control problem. The costs for acaricides amount to about US$150 000 per year.

Studies of economic losses from ticks have not been carried out. As far as tick-borne diseases (mainly ECF) are concerned, losses are difficult to assess, but mortality in calves in indigenous breeds in endemic regions does not exceed 5%. However, it must be stressed that other health factors can influence the mortality rate to a great extent. The upgrading of Ankole cattle by crossbreeding with exotic cattle greatly increases the risk of major economic losses caused by tick-borne diseases.

Livestock production constitutes an important factor in the country’s economy, in spite of the inevitable shift from traditional to more intensive cattle production, because of the decrease in pasture land. Meat and milk products are exclusively for local consumption, although beef has been exported in the past.
Tick Ecology and Epidemiology in Tanzania.

I. Mainland

R.A. Chiomba*

TANZANIA has an area of about 940 000 km², of which about 56 900 km² are under water. The country lies between lat. 1° and 12°S and between long. 30°E. and the Indian Ocean. It is bordered by Lakes Victoria, Tanganyika and Nyasa (Malawi).

The relief, climate and vegetation of Tanzania may be described broadly under the following 4 regions (Hance 1964; Jarrett 1970):

(i) the coastal plains: these are made up of a low, narrow belt extending about 20 km inland from the Indian Ocean, with an elevation from 0 to about 300 m above sea level. Average rainfall varies between 800 mm at the base of the highlands to over 2000 mm on higher ground. In the north, rains fall during Oct.—Nov. and again during Mar.—May/Jun., while the south has generally one rainy season lasting from Nov. to May. Temperatures vary between 26°C and 4°C. Vegetation consists of Brachystegia—Julbernardia woodland and Hyperrhenia grasslands;

(ii) low eastern plateau (Nyika): this region lies to the west of the coastal plains and has an elevation of between 300 and 600 m above sea level. Temperatures are fairly uniform throughout the year giving a hot and humid atmosphere. They vary between 30°C in Dec./Jan. and 20°C during Jun./ Jul. Vegetation consists of Acacia—Commiphora bushland with Pennisetum—Themeda grasslands;

(iii) eastern highlands: the Nyika plateau rises sharply to about 2100 m above sea level to form the eastern highlands, which extend from the Pare highlands and Usambara mountains in the north, through the Nguru, Uluruguru, and Iringa to the Livingstone mountains in the south. Average annual rainfall varies between 800 mm at the base of the highlands to over 2000 mm on higher ground. In the north, rains fall during Oct.—Nov. and again during Mar.—May/Jun., while the south has generally one rainy season lasting from Nov. to May. Temperatures vary between 26°C and 4°C. Vegetation consists of Brachystegia—Julbernardia woodland and Hyperrhenia grasslands; and

(iv) central plateau: this is the main feature of the country. It extends from the eastern highlands to the western highlands which form the eastern border of the western Rift Valley. The central plateau has an altitude of between 1100 and 1800 m above sea level. The eastern highlands tend to form a rain barrier to the neighbouring plateau, so that rainfall tends to increase westwards. While the average rainfall for most of the central plateau is about 850 mm, around the lakes and on the slopes of the western highlands it is heavy (1000—1200 mm). Most of the rain falls between Oct. and May. Temperatures vary between 29°C in Dec. and 16°C in Jun./Jul. Vegetation consists of Hyperrhenia, Panicum and Themeda grasslands with shrubs of Acacia spp., Combretum spp. and Brachystegia—Isoberlina spp.

For administration, mainland Tanzania is subdivided into 20 regions (Table 1).

Human and Livestock Population

Human population was estimated at 17.5 million during the 1978 census (Table 1). It was further estimated that population was increasing at 3.3% since 1967 and would therefore be about 23.0 million by 1990.

Population of livestock (cattle) during the 1978 census was estimated to be 12.0 million. With an estimated annual growthrate of 2.3% since 1964 the population was estimated to be 13.8 million in 1984 and 15.8 by 1990. However, the census taken in 1984 revealed a decline in the growth rate. Ninety-nine per cent of the livestock population consists of the Tanzania short horn Zebu which is therefore the main source of beef and milk. This animal weighs on average only 250 kg and produces about 250

*Ministry of Agriculture and Livestock Development, P.O. Box 9152, Dar es Salaam, Tanzania.
### Table 1. The human and cattle populations of the regions of mainland Tanzania.

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<td>41.4</td>
<td>345.9</td>
<td>63.1</td>
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<td>18.8</td>
<td>1864.4</td>
<td>26.7</td>
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<td>1026.9</td>
<td>1.2</td>
<td>998.0</td>
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<tr>
<td>Iringa</td>
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<td>479.9</td>
<td>6.7</td>
<td>472.1</td>
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<td>Mbeya</td>
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<tr>
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<td>564</td>
<td>36.1</td>
<td>1.4</td>
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<td>Mara</td>
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<td>2.4</td>
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<td>Mwanza</td>
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<td>1.7</td>
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<td>5.5</td>
<td>368.7</td>
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<td>1652.1</td>
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<td>1810.6</td>
<td>2.2</td>
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<td>Tabora</td>
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<td>994.1</td>
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<td>925.0</td>
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<tr>
<td>Singida</td>
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<td>777.5</td>
<td>0.1</td>
<td>939.2</td>
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<td>Kigoma</td>
<td>649</td>
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<td>0.3</td>
<td>61.8</td>
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<tr>
<td>Rukwa</td>
<td>452</td>
<td>183.6</td>
<td>0.1</td>
<td>381.3</td>
<td>1.2</td>
</tr>
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</table>

### Table 2. Incidence of tick-borne diseases in cattle.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Dippings (millions)</th>
<th>East Coast Fever</th>
<th>Anaplasmosis</th>
<th>Babesiosis</th>
<th>Heartwater</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Incidence ('000)</td>
<td>Deaths ('000)</td>
<td>Incidence ('000)</td>
<td>Deaths ('000)</td>
<td>Incidence ('000)</td>
</tr>
<tr>
<td>1980</td>
<td>47.5</td>
<td>9.1</td>
<td>16.9</td>
<td>20.7</td>
<td>4.5</td>
</tr>
<tr>
<td>1981</td>
<td>52.3</td>
<td>44.5</td>
<td>11.9</td>
<td>23.7</td>
<td>4.9</td>
</tr>
<tr>
<td>1982</td>
<td>39.1</td>
<td>43.0</td>
<td>18.0</td>
<td>21.0</td>
<td>8.7</td>
</tr>
<tr>
<td>1983</td>
<td>20.1</td>
<td>23.3</td>
<td>12.0</td>
<td>7.6</td>
<td>2.5</td>
</tr>
<tr>
<td>1984</td>
<td>26.3</td>
<td>40.7</td>
<td>20.0</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

It is estimated that per capita consumption of beef in Tanzania is only 7.5 kg and that of milk is 22.4 litres. It is intended to increase these levels to 8.5 kg beef and 28.0 litres of milk by 1990 and to raise offtake to 12%. Beef has not been exported during the past five years.

As shown in Table 2 quite a substantial number of cattle die from tick-borne diseases. Apart from tick-borne diseases, a lot of damage is inflicted on hides by the ticks. For the above intended levels to be achieved, one of the measures that must be taken is to control ticks.

### Tick Distribution and Ecological Zones

Based on the country's physical features, which, as already mentioned, have a great influence on Tanzania's rainfall pattern, vegetation and temperatures, six tick ecological zones have been identified for a tick control program (Fig. 1).

#### 1. North-eastern zone

This zone lies within the coastal plains and the low eastern plateau. Administratively it includes Tanga, Dar es Salaam and Pwani regions.

The zone has major commercial towns and is essentially a consumer area. Livestock from up-country move into this zone. Another important factor is that the zone provides the outlet for livestock exports. According to the FAO Technical Report (FAO 1977) the following tick situation was identified within the zone. *Rhipicephalus appendiculatus* was collected some 25 km southwest of Dar es Salaam, but the team was of the opinion that this species was not a normal inhabitant of the zone, the collections being a result of cattle movement from up-country. *Boophilus decoloratus* and *Amblyomma* spp. could not survive in the too
Fig. 1. Tick ecological zones of Tanzania. 1, North-eastern; 2, South-eastern; 3, Northern; 4, Southern. ---, national border; ---, regional border; ----, lake border.

In all zones, dairy animals are managed within the location of an owner. Depending on the size of the land, the animals are either zero grazed or taken for grazing within a few metres of the house. The animals are housed in a shed with adequate water supplies and feed supplementation is practised. Milking is done twice a day, with records of milk yields. On the whole, good animal husbandry is practised in culling, castration, vaccination, etc. Large-scale farmers have their own dipping vats while smaller farmers use hand-spray pumps.

2. South-eastern zone

This zone is similar to 1. above. It includes the Lindi, Mtwaru and Ruvuma regions.

The significance of the zone is that it did not originally have large numbers of livestock, primarily because of heavy tsetse fly infestation. There is now a deliberate move by the government to introduce cattle into the area. With this introduction, ticks and tick-borne diseases are bound to assume some importance. No tick surveys have been carried out and our knowledge on tick ecology in the area is virtually nil.

There are 56,184 local Zebu and 2,284 dairy cattle in the zone. Very few families own more than 15 head. The common practice is to tether the animals, while those with a relatively large herd take their animals for grazing not very far from their homes. The animals are kraaled at night. Milking is done twice a day, but neither culling nor castration is practised.

3. Northern highlands

This zone lies within the eastern highlands. It includes Arusha, Kilimanjaro, Tanga (Usambara) and Morogoro regions. The zone is important because it has the most developed dairy industry in the country. Furthermore, it is surrounded by several national parks and so livestock are prone to exposure to a variety of tick species, whose significance to livestock has not been fully studied. Despite the importance of the zone, little work seems to have been done on tick ecology in the area and, because of its similarity to the southern highlands, *R. appendiculatus* may be numerous during the rainy season.

The livestock population consists of 667,390 local Zebu and 102,729 dairy cattle. The Arusha region has nomadic pastoralists and husbandry is the same as that in the north-eastern zone. Kilimanjaro and Tanga (Usambara) are densely populated and so there is little room for grazing except at lower altitudes. Animals are housed day and night and grass is carried to them. At lower altitudes the cattle are grazed during the day. The Morogoro region has nomadic people on its northern part and non-nomadics to the south. The behaviour of these groups is similar to that described earlier.
4. Southern highlands

This zone is similar to Zone 3. It includes Iringa, Moeya and Rukwa regions. The zone is important because it supports a dairy industry and because it is on the border with Zambia and Malawi.

Extensive tick studies have been carried out in this zone. *Rhipicephalus appendiculatus* is found in significant numbers during the rainy season and in negligible numbers during the dry season. *Rhipicephalus evertsi* is found throughout the zone all the year round, greater numbers occurring in the lower, drier areas. *Amblyomma variegatum* is uncommon in the zone, as is *B. decoloratus*. The latter occurs in very small numbers early in the rains and tends to disappear in the middle of the rainy season. *Boophilus microplus*, however, occurs in the zone without being influenced by variation in season. *Hyalomma albiparamatum* is present at higher altitudes and tends to increase in numbers during the mid and late wet season. *Hyalomma ruifipes* occurs at lower altitudes with a hot climate.

There are 1 751 005 local Zebu and 13 948 dairy cattle. The human population is not nomadic and husbandry practices are very similar to those described already.

5. Lake zone

Although this zone is within the main plateau, its climate, vegetation and rainfall are greatly influenced by Lake Victoria. The zone includes Mara, Mwanza and Kagera regions.

Like the Southern highlands, fairly extensive studies have been carried out on tick ecology in this zone. *Rhipicephalus appendiculatus* is present in significant numbers throughout the zone, and although numbers decline as one moves away from the lake, there seems to be no seasonal variation. *Amblyomma variegatum* is present in lower numbers than *R. appendiculatus*; it also declines away from the lake, with little seasonal variation. *Rhipicephalus evertsi* is present throughout the year. *Boophilus decoloratus* is found in small numbers near the lake but tends to increase further away. *Hyalomma albiparamatum* and *H. ruifipes* are present in the zone throughout the year.

This zone includes an endemic ECF area, with adjacent areas being prone to epidemics.

There are 2 591 459 local Zebu and 11 778 dairy cattle. The human population is not nomadic, individuals owning large herds (up to 1000 head). During the dry season, grazing is done several miles away from homestead, but the animals are always returned home at night.

6. Central zone

This zone consists of the main plateau and includes Shinyanga, Tabora, Kigoma, Singida and Dodoma regions.

*Rhipicephalus appendiculatus* is present in the wetter areas closer to the lakes but Dodoma and Singida regions do not sustain the species. Those specimens that are found in the area have been introduced by transit animals. *Amblyomma variegatum* is present in the zone and has significant seasonal variation, with numbers increasing during the rainy season and declining significantly during the dry season. *Boophilus decoloratus* appears in small numbers and does not show seasonal variation. *Rhipicephalus evertsi* is present throughout the year, while *R. kochi* and *R. lunulatus* seem to increase during the wet season.

Central zone is an epidemic ECF area.

There are 5 164 108 local Zebu and 4133 dairy cattle. The human population is not nomadic and, as in the lake zone, individuals own large herds and behave in a similar manner.

**Tick Control Policy in Tanzania**

Tick control in Tanzania aims: (a) to protect livestock from the scourge of ticks and tick-borne diseases; (b) to control the introduction or spread of ticks from enzootic areas to non-enzootic areas; (c) to control the movement of ticks and tick-borne diseases into or from neighbouring countries; and (d) to improve the performances of livestock in such parameters as weight gains and increased milk production through tick eradication.

In order to achieve these aims, the country's policy is:

(i) to dip/spray all livestock on traditional and private farms. There are at the moment some 1800 dips and the aim is to increase this to 2000 by 1990. Unfortunately, nearly 700 of these dips are not working owing to lack of water, especially during the dry season, or, in some cases, to vandalism, where roofing materials have been removed. Dipping is not compulsory, though any one introducing *Bos taurus* cattle on to a farm is required to have dipping/spraying facilities. In the traditional sector, a small fee is charged to the farmer. The acaricides used are chlorinated hydrocarbon and organophosphorus compounds, but because their cost is high, availability is not guaranteed throughout the year;

(ii) to construct stock routes and holding grounds. Currently, there are some 2234 km of stock routes and 23 holding grounds. All livestock movements are required to take place along the official routes so that livestock may be dipped/sprayed to minimise the spread of ticks. However, the use of stock routes is not compulsory, nor are dipping facilities in good working condition, so that the combination of the two has nullified the exercise; and

(iii) to carry out research on ticks and tick-borne diseases with emphasis on tick ecology and
immunisation. Some work on tick ecology has been done but very little on immunisation. It is intended to intensify work in these fields so that dipping does not remain the only method for tick control in Tanzania, especially in those areas which can support the dairy industry.

Disease and Control Facilities

Tanzania has one main central veterinary laboratory located at Temeka in Dar es Salaam. Its main role is to conduct research, investigations and diagnosis/confirmation of diseases. Another role is to produce vaccines. At the moment the laboratory is producing bacterial vaccines only i.e. anthrax, blackquarter and haemorrhagic septicaemia.

The laboratory is supported by six Veterinary Investigation Centres located at Arusha, Mtwara, Mwanza, Tabora, Mpwapwa (Dodoma) and Iringa. These centres investigate disease outbreaks and provide diagnostic facilities to the regions.

Weekly dipping is the main method of tick control. There are 1800 dip tanks. The aim is to have dip tanks 15 km apart in areas with high livestock populations (Arusha, Mara, Mwanza, Shinyanga, Iringa) and in ECF endemic regions e.g. Kagera (Bukoba).

The acaricide in use at the moment is Toxaphene. Arsenicals and BHC are no longer used because ticks have developed resistance to them. In the Kagera region, resistance to Toxaphene has been confirmed and so organophosphorus compounds (Delnav and Bacdip) are now in use. Sporadic cases of resistance against the organochlorines in other regions have been reported but these tend to disappear after the use of organophosphates for three months.

References

Zanzibar (see Fig. 1 in previous paper) consists of two islands, Unguja and Pemba, and covers an area of 2600 km². The human population is about 500,000. The climate is hot and humid with a temperature of 27-30°C for most of the year. Yearly rainfall is about 1450 mm. There are two main rainy seasons (March-May and October-November) but there is rainfall throughout the year.

The cattle population in the 1978 census was: Unguja, 28,000; Pemba, 33,000; 97% being East African Zebu. Only 1.5% are purebred Bos taurus, mostly Friesian and Jersey, and are found on government farms. Another 1.5% are crossbreeds, mostly Jersey × Zebu, which are owned by smallholders. There are three Government farms on Zanzibar, each with 100-375 head of cattle. Smallholders rarely own more than four head with most animals tethered and not fed supplements. Beef cattle are brought from the mainland for slaughter, 5075 being shipped in 1983. No quarantine is enforced.

Three tick species are present: Rhipicephalus appendiculatus, Amblyomma variegatum and Boophilus microplus. Theileria parva parva is present and theileriosis is endemic, with a challenge from East Coast Fever throughout the year.

The main tick control problems are malnutrition, uncertain availability of acaricide (Toxaphene), and the lack of quarantine for beef cattle shipped from the mainland.

Research is in progress on the isolation and characterisation of the strains of *T. parva* present on Zanzibar, and their possible use for immunisation.
Zambia has a cattle population of about 2.8 million. In addition to cattle, other livestock include sheep and goats, which are estimated at about 1 million, and pigs about 1.5 million. The main cattle rearing areas are: Southern Province, 1,068,331; Western Province, 600,000; Eastern Province, 286,757; and Northern Province, 89,612. Cattle distribution is heavily influenced by the presence of tsetse flies, the vectors of trypanosomiasis which infest about one-third of the country. About two-thirds of the national herd belong to the traditional sector. Most of the dairy herd belong to the commercial sector which is concentrated along the railway stretching from the south of the country through to the Copper Belt in the north.

Apart from trypanosomiasis, tick-borne diseases are the main diseases affecting the livestock industries, particularly cattle. These include anaplasmosis, babesiosis, heartwater and theileriosis. Soft ticks are believed to play a role in the transmission of African Swine Fever. This disease is confined to the eastern part of the country along the Malawian border where it is endemic.

Of the above tick-borne diseases, theileriosis, caused by *Theileria parva parva* and *T. parva lawrencei*, is economically the most important. Classical East Coast Fever is endemic in the northeastern corner of the country along the Zambia/Tanzania border and along the eastern border with Malawi. Theileriosis caused by *T. lawrencei* is endemic in some parts of the Southern Province, and has recently been introduced into the Kabwe district of Central Province (1985), and into the Lusaka district in 1986. The disease reaches epidemic proportions in new foci, particularly in the Central and Southern Provinces, but is present only in traditional local cattle of the Sanga breed. In the Eastern and Northern Provinces, the breed of animals resembles the East African Zebu. In 1984, 1,076 cattle died of confirmed malignant theileriosis in the Southern Province and 476 in the Eastern Province. It is estimated, however, that as many as 5,000 cattle died of theileriosis in Southern Province in 1984.

Anaplasmosis and heartwater are important tick-borne diseases both in indigenous and exotic breeds of cattle. These diseases are most prevalent in the rainy season (April–November). During this period of the year, strict tick control through regular dipping of cattle is not observed, particularly in the traditional sector, because of the inadequacy of acaricide supply and lack of understanding by the cattle owners of the need for regular dipping.

Babesiosis has been widely reported in Zambia. *Babesia bigemina* is the most widely distributed, but *B. bovis* is more important. It is encountered in exotic, crossbred and indigenous cattle, mainly in the cerebral form.

Heartwater (*Cowdria ruminantium*) is most prevalent during the rainy season, with high mortality.

Ticks are abundant in Zambia. Detailed surveys have been carried out mainly in Central, Eastern, Western and Southern Provinces. High infestations have been recorded in Central Province of *Amblyomma variegatum* and *Hyalomma truncatum*. *Rhipicephalus appendiculatus* and *Boophilus decoloratus* are abundant. Tick populations on the Kafue River Flats in the Southern Province and in the Zambezi river plains of the Western Province are lower because of seasonal flooding. In the Eastern Province, low infestations of ticks occur, including *R. appendiculatus*. In the Western Province, *B. decoloratus* is most prevalent, *A. variegatum* is less abundant than in other provinces and *R. appendiculatus* is rare.

**Control of Ticks and Tick-borne Diseases**

Acaricide application is the main method of tick control. The Government advocates construction of dip tanks in strategic positions throughout Zambia for control of ticks and tick-borne diseases. Specific legislation exists for theileriosis in certain areas. In these areas, twice-weekly dipping and/or spraying is recommended between November and March.
Dipping is very expensive and purchase of acaricides 
requires foreign exchange because all dip chemicals 
are imported. Acaricides cost US$3 per animal per 
year. Trials to treat overt theileriosis using Clexon 
have been carried out in Zambia and gave a 91% 
recovery rate. This method of control is too 
expensive for most peasant farmers. In 1986, the 
price per treatment was estimated at US$10 per 
animal. Livestock movement is difficult to control 
because of communal grazing and poor availability 
of pasture during the dry season leading to extensive 
migration (e.g. in Southern Province, to the Kafue 
Flats).

Acaricide resistance has been identified in ticks 
collected from traditional cattle and is most 
pronounced in areas with a long history of dipping. 
In Southern Province, *R. appendiculatus* resistance 
to dimethoate, dieldrin and dioxathion has been 
recorded. Resistance to chlorofenvinphos and 
coumaphos has also been demonstrated although 
these acaricides have not been widely used in 
Zambia. *Boophilus microplus* and *A. variegatum* 
have shown resistance to various acaricides and, on 
commercial farms around Lusaka, there has been 
resistance shown by *B. decoloratus* to 
organophosphorus acaricides.

**Milk and Meat Production**

Zambia’s potential for meat and milk production 
lies in the traditional sector which accounts for 80% 
of the cattle. Cattle form an integrated part of a 
multipurpose agricultural system (meat, milk, 
traction for cultivation and haulage, dowry and 
other social obligations). Milk is widely used for 
food and cash income. In both the commercial and 
traditional sectors most products are for local 
consumption, but increased attention is being given 
to beef and other animal products for export. 
Introduction of more productive cattle breeds and 
provision of incentives by the Small Industries 
Organization to beef and milk producers is expected 
to increase production for both local and export 
markets.

**Research into Ticks and Tick-borne Diseases**

At the present time, research into ticks and tick- 
borne diseases is given top priority by the 
Government. At the control level, they are 
considered equal to tsetse and trypanosomiasis, 
which form the major constraints to animal health 
and production in Zambia.
Tick Ecology and Epidemiology of Tick-borne Diseases in Malawi

R. Mkandiwire*

Malawi is a landlocked country located along the sector of the Rift Valley between lat. 10°S and 17°S. The country is bordered by Zambia to the west, Mozambique to the east and south and Tanzania to the north. Administratively, the country is divided into Northern, Central and Southern regions. The population of Malawi is about 6.5 million, occupying about 94,000 km² of land. Population density varies, being highest in the Southern region and lowest in the Northern region (Anon. 1978). The population growth rate is 2.9%

Malawi's economy is based on agriculture, which employs about 85% of the people and accounts for over 85% of the total export earnings. Tobacco, tea and sugar are the major exports (Anon. 1978).

Agnew and Stubbs (1972) divided the country into three topographical zones:

(i) Rift Valley floor: this extends from the lower Shire valley, where the altitude is as low as 35 m above sea level at the southern end of the country, northwards to Lake Malawi and then along the lowlands of the western lakeshore to an altitude of 760 m above sea level. Annual rainfall varies from 635 mm in the lower Shire valley to over 2500 mm in lakeshore areas facing the rain-bearing winds;

(ii) Middle plateau: this includes the area lying 760-1370 m above sea level and separated from the Rift Valley floor by dissected escarpments; and

(iii) Hill zones: these comprise all areas 1370-1540 m above sea level.

Malawi experiences two main seasons. A rainy season occurs from November to April, during which it is usually warm to hot, with the highest rainfall in January and February. The dry season is subdivided into a cool period (May-July) with some precipitation over the highlands and a dry, hot period (August-October).

Livestock Sector

The estimated livestock population is currently about 1 million cattle, 900,000 goats, 200,000 pigs, 150,000 sheep and 10 million poultry. Cattle are considered the most important component of the livestock population. Most of the cattle are kept under the traditional management system in which grazing and the use of various crop residues is communal.

The dominant breed is the small-humped indigenous East African Zebu (Malawi Zebu). However, exotic breeds like Friesians and Holsteins are to a smaller extent kept at government livestock centres and on some private estates. Malawi Zebu and Friesian crosses are common on smallholder farms.

Government policy is to diversify agriculture. Besides crops, there is great need to increase livestock productivity in order to meet the rising consumer requirements arising from the country’s general development. The national strategy for implementing the policy is the adoption of integrated livestock planning in which disease control, improved breeding and husbandry methods are promoted for the total production system within the framework of a national marketing and pricing policy.

Beef production

Malawi has been able to produce almost all the meat it requires for the domestic market, the obvious advantage being the saving on foreign exchange. The bulk of meat comes from the traditional herd and only about 15% of the total meat is derived from the commercial farms, which produce most of the top grade beef. In order to boost the production of better quality meat, a smallholder stall-feeding scheme is being promoted. Under this scheme, farmers are encouraged to castrate their surplus young bulls and to cull non-productive stock, which are then fattened in stalls that hold 2-4 animals.

Dairy production

The dairy industry in Malawi is based on the smallholder dairy farming system, which has developed around the cities of Blantyre, Lilongwe and Mzuzu. There are about 10,000 dairy cattle
(mostly Zebu/Friesian crosses) which account for over 50% of total fresh milk supplied to the urban centres. Although the country still imports some dairy products, a great deal of potential exists to produce enough for the local market and a surplus for export.

**Ticks and Tick-borne Diseases**

One of the major constraints to the expansion of beef and dairy farming is the incidence of tick-borne diseases, the most serious of which is East Coast Fever (ECF). Nzima (1985) reported that, in the milk shed area of Lilongwe (smallholder dairy farms around Lilongwe), 79.4% of all deaths were caused by tick-borne diseases and that ECF alone was responsible for about 59% of the total deaths. In the Blantyre milk shed area, anaplasmosis and babesiosis caused about 70% of the total deaths during the study period (Nzima 1985). While anaplasmosis and babesiosis are endemic throughout the country, clinical manifestation of ECF appears to be confined to the Central and Northern regions.

**Tick species that affect cattle**

Over 30 tick species have been identified from various animal species but those that are found on cattle, their importance and distribution are shown in Table 1.

The major tick species that are found throughout the country are: *Rhipicephalus appendiculatus* (main vector of ECF), *Boophilus microplus*, *B. decoloratus* and *Amblyomma variegatum*. In the lowlands and along the lakeshore are found *Hyalomma truncatum* and *H. marginatum rufipes*. Other tick species belonging to the genus *Rhipicephalus* have been identified, but these are rare and exact information is not available. Little work has been done to correlate species distribution with vegetation physiography or climate. However, it has been observed that the period of highest tick challenge is the rainy season (November–March).

**Tick-borne diseases**

Tick-borne diseases that occur in the country are shown in Table 2. Theileriosis is the most important of the tick-borne diseases. East Coast Fever (*Theileria parva* infection) is a major cause of cattle mortality in the country but is confined to the Northern and Central regions. In the Southern region, the vector, *R. appendiculatus*, is present but *T. parva* is absent. However, serological investigations done at the Central Veterinary Laboratory have indicated the presence of an unidentified, non-pathogenic *Theileria*. While serum from cattle infected with this parasite cross-reacts serologically with *T. parva* in schizont antigen, these seropositives are generally completely susceptible to challenge from *T. parva*. It has been speculated that the unidentified *Theileria* could be related to *T. taurotragi* (FAO 1982) which is considered to be non-pathogenic. *T. velifera* and *T. mutans* are not pathogenic but have been identified.

The other tick-borne diseases of economic importance are babesiosis and anaplasmosis, which occur throughout the country. Cowdriosis and sweating sickness are rarely diagnosed.

**Control of Ticks and Tick-borne Diseases**

Control of ECF and other tick-borne diseases is based on intensive tick control by weekly dipping. All cattle within a five-mile radius of a dip tank are

<table>
<thead>
<tr>
<th>Tick species</th>
<th>Order of importance</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Rhipicephalus appendiculatus</em></td>
<td>1</td>
<td>Throughout the country but mostly in Central and Northern regions</td>
</tr>
<tr>
<td><em>Boophilus microplus</em></td>
<td>2</td>
<td>Throughout the country</td>
</tr>
<tr>
<td><em>B. decoloratus</em></td>
<td>3</td>
<td>Throughout the country</td>
</tr>
<tr>
<td><em>Amblyomma variegatum</em></td>
<td>4</td>
<td>Throughout the country</td>
</tr>
<tr>
<td><em>Hyalomma marginatum rufipes</em></td>
<td>5</td>
<td>Lowlands and along the lakeshore</td>
</tr>
<tr>
<td><em>H. truncatum</em></td>
<td>5</td>
<td>Lowlands and along the lakeshore</td>
</tr>
<tr>
<td><em>R. evertsi</em></td>
<td>6</td>
<td>Widespread</td>
</tr>
</tbody>
</table>

| *R. pravus group*                      |                      | Reported to occur, but exact information not available |
| *R. simus group*                       |                      |                                                   |
| *R. sanguineus group*                  |                      |                                                   |
| *R. tricuspis*                         |                      |                                                   |
| *R. compositus*                        |                      |                                                   |

*From FAO Report 1982.*
**Table 2. Major tick-borne diseases in Malawi cattle***

<table>
<thead>
<tr>
<th>Disease</th>
<th>Species</th>
<th>Animals at risk**</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theileriosis</td>
<td><em>T. parva</em></td>
<td>66% (1)</td>
<td>Central and Northern region (2/3 of country)</td>
</tr>
<tr>
<td></td>
<td><em>T. velifera</em></td>
<td>-</td>
<td>(T. lawrencei not recorded)</td>
</tr>
<tr>
<td></td>
<td><em>T. mutans</em></td>
<td>100% (2)</td>
<td>Not important</td>
</tr>
<tr>
<td>Babesiosis</td>
<td><em>B. bigemina</em></td>
<td>100% (2)</td>
<td>Throughout country; not pathogenic</td>
</tr>
<tr>
<td></td>
<td><em>B. bovis</em></td>
<td>100% (2)</td>
<td>Throughout country</td>
</tr>
<tr>
<td></td>
<td><em>B. microplus</em></td>
<td>100% (2)</td>
<td>Much less common, but more pathogenic</td>
</tr>
<tr>
<td></td>
<td><em>B. americanum</em></td>
<td>100% (2)</td>
<td>Throughout the country but rare</td>
</tr>
<tr>
<td>Anaplasmosis</td>
<td><em>A. marginale</em></td>
<td>100% (3)</td>
<td>Difficult to apportion importance between species</td>
</tr>
<tr>
<td></td>
<td><em>A. centrale</em></td>
<td>-</td>
<td>Present but rarely diagnosed</td>
</tr>
<tr>
<td>Cowdriosis</td>
<td><em>C. ruminantium</em></td>
<td>- (4)</td>
<td>Present but not common</td>
</tr>
<tr>
<td>Sweating sickness</td>
<td><em>H. truncatum</em> (toxin)</td>
<td>- (4)</td>
<td>Present but not common</td>
</tr>
</tbody>
</table>

**Order of importance in parentheses.

required by law to be dipped, but this regulation is not enforced. The Government operates over 350 communal dipping tanks (including a few sprayers) which are distributed throughout the country. These tanks are staffed by government veterinary assistants and dip from 1000 to 3000 cattle per week. Acaricides such as arsenic, Toxaphene and Supona are used. Their proportions depend upon availability, differences in price and simplicity in monitoring acaricide strength in dip liquids.

In order to keep ECF confined to the Northern and Central regions, no animals are allowed to move from these two regions to the south without vigorous serological tests, unless they are for immediate slaughter.

Although outbreaks of ECF and other tick-borne diseases have been reduced by dipping, numerous cases still occur. This is partly caused by irregular dipping attendance among traditional cattle holders, and, in some cases, inadequate supply of acaricides and dip tank mismanagement, which have led to cattle being dipped in weak solutions. Acaricide resistance has been shown to exist in some *Rhipicephalus* and *Boophilus* species. However, not much work has been done in this field and more research is required in order to ascertain the extent of the problem.

Dip tank operational costs, especially in terms of acaricides, are very high and will be prohibitive in the future. Use of an effective ECF immunisation technique plus strategic dipping may be the answer to the problem and is currently being investigated. The Central Veterinary Laboratory in Lilongwe has for the past five years, under the FAO/DANIDA Project, been doing research on immunisation of cattle against ECF through the "treatment-infection" method originally developed at Muguga, Kenya. This method has shown some promising results and is now undergoing field trials.

Recognising the seriousness of the economic losses that occur in the livestock industry from ticks and tick-borne diseases, the Government of Malawi is very committed to find solutions to these problems through research.

**References**


Ticks and Tick-borne Diseases in Zimbabwe

R.A.I. Norval*

Zimbabwe is self-sufficient in milk and meat, and exports beef to the European Economic Community and several other countries. Almost all the milk and a large proportion of the beef marketed are from the commercial sector, although commercial livestock production in the traditional areas is increasing.

For tick control, Zimbabwe can be divided into two major zones: the high rainfall highveld and the low rainfall lowveld. The most important tick species in the highveld is *Rhipicephalus appendiculatus* and, in the lowveld, *Amblyomma hebraeum*. Theileriosis caused by *Theileria parva* bovis occurs commonly in the highveld, and heartwater caused by *Cowdria ruminantium* occurs commonly in the lowveld. Babesiosis caused by *Babesia bigemina* and anaplasmosis caused by *Anaplasma marginale* can occur throughout the country, but these are seldom the causes of large disease outbreaks.

The country's tick control policy is intensive dipping. This was introduced in the early part of the century to control East Coast Fever, which had been introduced from East Africa. As dipping is becoming increasingly costly this policy is now being reassessed and a relaxation of the strict dipping regulations is being considered.

Resistance to arsenical, organochlorine and organophosphate acaricides is known to occur in ticks in Zimbabwe, but the problem of acaricide resistance has not been studied in depth.

The Government of Zimbabwe gives high priority to research on ticks and tick-borne diseases because it is felt that there is an urgent need to develop more economic control programs.

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Ecological and Epidemiological Studies on Ticks and Tick-borne Diseases in the Sudan

A.A. Latif*

Hoogstraal (1956) reviewed the climatic and biotic features of the Sudan. According to the distribution of the annual rainfall, five major ecological zones could be identified (Fig. 1). In the Sudan, the livestock sector contributes about 19.6% of the gross domestic product (12 million cattle, 8 million sheep, 7 million goats and 2.8 million camels). The majority (80%) of the animal population belongs to the traditional sector, mostly nomads. There is a unique and regular seasonal livestock migration from the north to the south in the dry season, and vice versa during the rainy season (Fig. 2).

Osman (1976, 1980) reviewed the situation regarding ticks and tick-borne diseases in this country and their current methods of control. Hoogstraal (1956) identified 62 tick species infesting animals. Apart from that there has been little systematic tick research, an exception being the work of Karrer et al. (1963) who provided basic epidemiological clues to the relationships between *Amblyomma lepidum* infestation and heartwater in Kassala Province. The major contribution in tick research has occurred since the recent establishment of the tick project in 1978 by the Government of the Sudan with the assistance of FAO, acting as executing agency for DANIDA.

**Objectives of the Tick Control Project**

The long-term objective of the project was to obtain sound basic and practical information on which to formulate a national program for the control of ticks and tick-borne diseases that will contribute to the improvement and more efficient development of animal resources in the Sudan. These objectives could not be implemented for the whole country in the 3-year period and, therefore, the surveys were restricted to the triangle between the White and Blue Nile comprising parts of Blue Nile, Gezira and Khartoum Provinces. This is not the area of heavy livestock population or tick challenge but it was studied because it is the only region where exotic breeds of cattle have been introduced.

The project activities started with the following short-term objectives:

(a) to determine the distribution, incidence, population dynamics and biology of ticks of veterinary importance;

(b) to assess the resistance of breeds and strains of cattle to tick infestation;

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Present address: ICIPE, P.O. Box 30772, Nairobi, Kenya.
(c) to determine the incidence, distribution and epizootiology of tick-borne diseases of livestock, with particular attention to theileriosis, babesiosis, anaplasmosis and heartwater; and (d) on the basis of the ecological and epidemiological information collected, to formulate detailed plans for the control of ticks and tick-borne diseases which will form the basis of future operational phases of the program.

In this report, a summary of the project activities and future plans is given.

Methods

A laboratory for the study of ticks and tick-borne diseases has been established and provides facilities for diagnosis, tissue culture isolation, serological surveys, tick breeding and large and small animal accommodation units.

Results

Tick ecology

The most important tick species infesting livestock in the study area were: *Hyalomma anatolicum* anatolicum, *Amblyomma lepidum*, *Boophilus annulatus*, *B. decoloratus*, *H. marginatum rufipes*, *H. dromedarii*, *H. impeltatum*, *Rhipicephalus evertsi* and *R. sanguineus* group. The most studied tick was *H. a. anatolicum* (Latif 1982, 1985). The studies on host resistance showed that indigenous breeds (Kenana and Butana) carried fewer ticks on average than exotic crossbred cattle, although some of the latter were highly resistant (Latif, 1984a, 1984b).

Epidemiological studies

In the study area, *Theileria annulata*, *T. mutans* (Morzaria et al. 1981), *T. velifera*, *Babesia bovis*, *B. bigemina* (Abdalla 1984), *Anaplasma marginale*, *A. centrale*, *Cowdria ruminantium* (Jongejan et al. 1984) were all isolated and identified, and are now held by the project (Table 1). *H. a. anatolicum* was found to be the chief vector of *T. annulata*. *H. dromedarii*, *H. m. rufipes* and *H. impeltatum* were experimentally shown to transmit the parasite (Mustafa et al. 1983; Jongejan et al. 1983). Under experimental conditions *T. annulata* was found to be highly pathogenic to Friesian calves, causing over 80% mortality (Mustafa 1983). The field studies on infection rates of ticks with *Theileria* parasites showed that 38–86% of ticks collected were infective (Walker et al. 1983). *Trypanosoma theileri* was also isolated from ticks collected in the field and these, when applied to susceptible calves, transmitted the parasites (Morzaria et al. 1986).

![Fig. 2. Some aspects at the Tick Control Project in the Sudan. Dot, cattle distribution; double arrow, seasonal cattle migration; solid dot, Provincial Veterinary Headquarters with established diagnostic laboratories; open circle, PVH without established diagnostic laboratories; hatch, ticks and tick-borne disease survey sites.](image)

Table 1. Haemoparasites, sera and stabilates cryopreserved and held by the Tick Project

<table>
<thead>
<tr>
<th>Organism</th>
<th>Nature and origin</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>T. annulata</em></td>
<td>Tc* (from 6 locations), blood, tick-derived</td>
</tr>
<tr>
<td><em>T. mutans</em></td>
<td>blood</td>
</tr>
<tr>
<td><em>B. bigemina</em></td>
<td>blood</td>
</tr>
<tr>
<td><em>A. marginale</em></td>
<td>blood (sheep, goats, cattle)</td>
</tr>
<tr>
<td><em>C. ruminantium</em></td>
<td>blood, tick-derived</td>
</tr>
<tr>
<td><em>Trypanosoma theileri</em></td>
<td>tick-derived</td>
</tr>
<tr>
<td><em>T. ovis</em></td>
<td>Tc*, blood</td>
</tr>
</tbody>
</table>

*Tissue culture schizonts.*
Conclusions and Recommendations

Tatchell (1983) and Morzaria (1983) have made the following conclusions and recommendations:
(a) in view of the importance of host resistance in the natural, biological control of ticks, it is strongly recommended that studies on the nature of resistance and/or means to detect and assess resistance should have the highest priority; and
(b) in the study area, where major tick-borne diseases are present, the indigenous cattle are not seriously affected (although occasional Babesia infection outbreaks were reported) but calf mortality in crossbred cattle is evident (Table 2).

Table 2. Calf mortality* in crossbred cattle on Nisheishiba Dairy Farm

<table>
<thead>
<tr>
<th>Year</th>
<th>No. born</th>
<th>No. deaths</th>
<th>Mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>166</td>
<td>29</td>
<td>17.5</td>
</tr>
<tr>
<td>1980</td>
<td>95</td>
<td>16</td>
<td>16.8</td>
</tr>
<tr>
<td>1981</td>
<td>115</td>
<td>33</td>
<td>28.7</td>
</tr>
<tr>
<td>Total</td>
<td>376</td>
<td>78</td>
<td>20.7**</td>
</tr>
</tbody>
</table>

*100% of the necropsied cases died of acute Theileria annulata infection.
**Average.

Therefore, if importation or distribution of exotic stock is considered, it is essential that means of immunisation against theileriosis (Latif et al. 1985) and babesiosis are available.

Future Plans

Control measures such as regular dipping, spraying or immunisation have never been practised in the Sudan against ticks and tick-borne diseases. Hand dressing using BHC (Gamatox) is practised in individual cases and acaricide resistance has not been shown.

Since the results of the studies on the host-parasite relationship have confirmed that cattle are able to acquire a significant level of resistance to ticks, therefore, the future for tick control is promising if balanced and ecologically sound methods of control are used. The integrated pest management approach requires a thorough knowledge of the host-parasite relationship, but such information is lacking for nomadic cattle.

The seasonal cattle migration covers more than 500 km from south to north i.e. cattle cross three different ecological zones. Therefore, it would be interesting to see whether calves born in the north, where they are exposed to infestation by some species of ticks, would respond to an infestation with different species when they moved south.

Future studies of importance include the development of resistance by these nomadic cattle to ticks and diseases, calf mortality, assessment of tick damage and tick population dynamics.

The Sudan Government recognised the problems caused by ticks and tick-borne diseases, particularly after the introduction of exotic stock, and has responded to it. It has encouraged and promoted research in this direction by constructing separate laboratories of high calibre with residential accommodation. The laboratories have been well equipped with the assistance of DANIDA and the project is staffed by national veterinarians (four with Master's degrees) who need to pursue further training in the fields of ecology and epidemiology. And lastly, the unavailability of consumable chemicals poses yet another problem.

Acknowledgments

The effort put by the Government of the Sudan, DANIDA and the FAO into the implementation of the tick control project is highly appreciated and acknowledged. We remain grateful to the FAO staff, Dr R.J. Tatchell, the project manager, Dr S.P. Morzaria, Dr V. Pedersen, Dr G. Paine and to the National Co-manager, Dr A.M. Osman, for their keen interest, advice and guidance, which led to the initiation and completion of the different project activities.

References


II. Ecology
Modelling Tick Populations. 1. Introduction

R.W. Sutherst*, R.B. Floyd*, G.F. Maywald* and M.J. Dallwitz**

A question in the minds of many of the audience will be: "Why develop models of tick populations?" The simple answer is that computer models are the only known tool available to help us understand the complexity of agricultural systems. The effects of ecological, economic and management variables have to be integrated before we can understand their effects on the enterprise in question. Computer models are well suited to this task and have the added advantage that they assist in handling changes in the climatic and economic environments. When the price of commodities or cost of control alters, a model can simply be rerun to recalculate the costs and benefits from different management options.

In this series of five papers we describe the types of data that are needed to build models of tick populations. In later papers we describe some of the models that have been developed in Australia. We then show how they can be used to understand ecological, epidemiological and management problems. Finally, an example is given of the use of economic data to design a chemical control program for a 3-host tick.

The objectives of past modelling efforts aimed at the cattle tick, *Boophilus microplus*, in Australia are shown in Table 1. They give some idea of the value of models both as academic tools and in particular as aids to the solution of the practical problems associated with reducing the adverse effects of ticks and tick-borne diseases on animal productivity.

Data Collection for Computer Models

The development of computer models requires quite different types of data from those which would normally be collected by a traditional biologist. There are three different types of activity involved.

---

Table 1. Long-term objectives of modelling in tick ecology

| 1. | To provide a research framework to guide data collection |
| 2. | To define the biological relationships in tick life-cycles |
| 3. | To assess the climatic favourability of different geographical areas for tick propagation |
| 4. | To understand and delay the development of acaricide resistance |
| 5. | To understand the epidemiology of tick-transmitted diseases |
| 6. | To design and test integrated tick control strategies that preserve the endemic stability of tick-borne diseases |
| 7. | To summarise current ecological knowledge on cattle ticks |
| 8. | To develop a systems approach to the analysis and management of populations of other metazoan parasites of domestic stock |
| 9. | To teach students and advisory personnel |

1. Estimation by experimentation of the values of parameters describing the processes in the life cycle

The key to efficient data collection is to identify those population parameters which are relevant and to avoid collecting data on those which are not useful (Sutherst et al. 1978). It helps to divide the life cycle into its three phases and to consider each separately before integration into a life cycle. The three phases are:

(i) development of free-living stages — oviposition, the development of eggs and of engorged larvae and nymphs of 3-host ticks (Maywald 1987);

(ii) host-finding — the survival and behaviour of unfed ticks and their success in being picked up by a host (Floyd 1987); and

(iii) parasitic feeding and mating (Sutherst 1987a).

The main processes within each of these three phases will be discussed in detail in subsequent papers. The format for these papers was designed

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to present an assessment of the available data for each of the processes for the most important tick species, as a basis for discussion at the meeting. The criteria considered were:

(a) the sensitivity of the process in the context of a population model, or, alternatively, the usefulness of the process in management, taken as a measure of importance;

(b) the feasibility of collection of the necessary data as indicated from past experience only;

(c) the availability of published and unpublished data for incorporation into models; and

(d) the priority placed on the collection of further data as given from the viewpoint of a population modeller interested in tick management.

For each of these processes, those criteria are given a weighting from 0 to 5 stars as a basis for discussion by the audience. The audience is invited to criticise and modify these assessments as points to the direction of future research. Later papers in this section illustrate the type of data needed to meet the requirements for modelling of each of the three ecological phases.

2. Measurement of the geographical distribution and seasonal variation in size of tick populations in a range of climatic zones

These observations help to identify sources of variation and to provide data against which to test the predictions of the models based on life cycle processes. Working versions of climatic zones suitable for the division of eastern and southern Africa into relatively homogeneous units are presented in the fifth paper in this series, together with an assessment of the adequacy of census data in each zone (Sutherst and Floyd 1987). As with the data on ecological processes, we have rated the adequacy of the data and our ideas on the priority to be given to collection of further data, using a weighting of 0 to 5 stars. These interpretations are intended as a basis for discussion by the audience.

3. Integration of life cycle processes into a population model

When mathematical descriptions of the processes referred to above have been derived, they can be coupled together to form life cycles for a given species of 1- or 3-host tick. These computer simulation models, as they are called, link each phase of the life cycle to the next to produce the cycle. The model can be developed so that many of the temperature- or moisture-dependent processes are dependent upon the value obtained from the meteorological data for a given location. In this way, the model can be used in different climatic environments where experimental data are lacking. The model then becomes our analytical tool, but before it can be used we still need to define some further relationships — those which relate tick feeding to various damaging effects on the host (Sutherst and Kerr 1987), the transmission of diseases (Dallwitz 1987) and the management options available (Sutherst 1987b). The range of models currently available and their status in relation to their potential use as management tools are given in Table 2.

<table>
<thead>
<tr>
<th>Model</th>
<th>Target tick species to 1985</th>
<th>Stage of development</th>
<th>Future plans for development</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLIMEX</td>
<td>B. microplus</td>
<td>****</td>
<td>*1</td>
<td>Sutherst and Maywald (1985)</td>
</tr>
<tr>
<td></td>
<td>B. decoloratus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A. variegatum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R. appendiculatus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H. longicornis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TICK1</td>
<td>B. microplus</td>
<td>****</td>
<td>*2</td>
<td>Floyd et al. (1987)</td>
</tr>
<tr>
<td>T3HOST</td>
<td>R. appendiculatus</td>
<td>***</td>
<td>*3</td>
<td>Maywald et al. (1980)</td>
</tr>
<tr>
<td>TICK2</td>
<td>B. microplus</td>
<td>**</td>
<td>***4</td>
<td>Dallwitz et al. (1986)</td>
</tr>
<tr>
<td></td>
<td>R. appendiculatus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H. longicornis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MATIX</td>
<td>Tick-borne diseases</td>
<td>****</td>
<td>—</td>
<td>Sutherst et al. (1979)</td>
</tr>
<tr>
<td></td>
<td>B. microplus</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1Planned inclusion of "climate surfaces" in place of meteorological data from recording stations; overlaying of vegetation, soils, host availability, etc.

2Development suspended in favour of TICK2. Main deficiencies are in overwintering of eggs, effects of daylength and host nutrition on resistance, effect of host-evasive behaviour on host-finding.

3Further development awaits experimental data on host resistance and host-seeking behaviour of ticks.

4Generalisation to apply to most economically important ticks and tick-borne diseases.
Once a functional tick population model is available it is possible to incorporate descriptions of the transmission of tick-borne diseases and of the available methods of tick control. In addition, the effects of ticks on animal production can be described mathematically for incorporation into the model. Given these relationships, which are discussed in separate papers, a functional management model can be produced for application to tick problems in Africa.

Acknowledgments

ACIAR provided financial support for the development and use of tick models in Africa. Many people helped in various ways including Dr M.N. Kaiser, Mrs A. Bourne, Ms T. Fiocco, Ms J. Leung and Mr M. Soilleaux. Mr S. Fiske produced most of the illustrations for the series of papers by the authors for this workshop, for which we are grateful.

References

Dallwitz, M.J. 1987. Ecological models. 3. TICK2 -- a general program for modelling ticks and tick-borne diseases. These proceedings.


Modelling Tick Populations. 2. Developmental Phase

G.F. Maywald*

This paper covers the processes in the tick's life cycle from the drop of the engorged female into the pasture to the point when the larvae are ready to attach to a host. Also considered here, for 3-host ticks, are the development of the engorged larvae and nymphs in the pasture, their moult and the subsequent hardening of the nymph and adult. Predation of the unfed stages is also discussed.

Each process is treated by considering the type of data needed and the techniques used to collect the data, followed by a discussion of the types of function used for modelling. Finally, for each process, the adequacy of available data is assessed with reference to *Rhipicephalus appendiculatus*, and priorities for further research are assigned (Table 1).

Experimental Methods

The development and survival of the free-living stages can be readily studied in the laboratory, under controlled conditions of temperature and humidity. However, the relationships obtained are not easily applicable to field conditions. The most useful data, for modelling purposes, are obtained in the field. Such a method, used to study the development stages in *Boophilus microplus* under field conditions, is referred to as the Tickplot technique. It involves placing ticks or batches of eggs in mesh containers, and putting these into the pasture in positions resembling natural tick oviposition sites as closely as possible. Probes may be placed next to these containers or in similar positions to monitor temperature and humidity. It must, however, be remembered that the mesh containers may somewhat modify the microclimate for the tick. Temperatures should be logged at least two-hourly to obtain an adequate record of daily fluctuations. The effect of temperature and moisture can be separated by having both irrigated and dry plots. Predation may also be included in the study by exposing some ticks without containers. The method is described in detail in Sutherst et al. (1978).

Egg Production

Egg production is considered to consist of two components. The first is fecundity, the total number of eggs laid per female. This is a function of temperature and the weight of the tick (Bennett 1974). The second component, the egg production rate, is a function of temperature, and determines the distribution of eggs over time. At high temperatures, egg production rate peaks early, while at low temperatures, oviposition is spread over a considerable period of time, with a much less pronounced peak somewhat later.

Data on the egg production rate are most readily obtained in the laboratory by collecting and counting the eggs produced daily from ticks of known weight placed at selected constant temperatures. This will also yield data on fecundity. Data at high temperatures, which on their own would be lethal, can be obtained by placing the ticks at those temperatures for only a part of each day and keeping them at a lower temperature for the remainder of the day. The results from the laboratory can be checked with data obtained under fluctuating temperatures in the field using the Tickplot technique.

At most temperatures, almost all the eggs produced are laid within a few days of the start of oviposition, a period that is short compared with the development time of the eggs. When temperatures are low and egg production extends over a longer period, survival of the eggs is low. It is therefore usual, especially in models with a weekly timestep, to simplify the treatment of egg production by ignoring the spread of oviposition over time.

The type of function used in the models to predict oviposition rate at given temperatures is shown in Fig. 1a for two temperatures. At any temperature, the fecundity is given by the sum of the daily egg output. A plot of fecundity as a function of

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### Table 1. Adequacy of data and research priorities for modelling development of several important species of ticks

<table>
<thead>
<tr>
<th>Process</th>
<th>Sensitivity/usefulness</th>
<th>Feasibility of collection</th>
<th>Availability of data for models</th>
<th>Priority for future research</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rhipicephalus appendiculatus</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finding oviposition site</td>
<td>***</td>
<td>**</td>
<td>—</td>
<td>****</td>
</tr>
<tr>
<td>Predation</td>
<td>***</td>
<td>**</td>
<td>*</td>
<td>**</td>
</tr>
<tr>
<td>Oviposition rate</td>
<td>*</td>
<td>****</td>
<td>***</td>
<td>*</td>
</tr>
<tr>
<td>Fecundity</td>
<td>**</td>
<td>****</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Egg development rate</td>
<td>*****</td>
<td>****</td>
<td>*****</td>
<td>**</td>
</tr>
<tr>
<td>Egg survival rate</td>
<td>*****</td>
<td>****</td>
<td>*****</td>
<td></td>
</tr>
<tr>
<td>Larval viability at hatch</td>
<td>**</td>
<td>***</td>
<td>—</td>
<td>**</td>
</tr>
<tr>
<td>Larval success at ascending pasture</td>
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</tr>
<tr>
<td>Larva-nymph devpt. and survival</td>
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<tr>
<td>Nymph-adult devpt. and survival</td>
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<tr>
<td><strong>Amblyomma variegatum</strong></td>
<td></td>
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<tr>
<td>Finding oviposition site</td>
<td>***</td>
<td>**</td>
<td>—</td>
<td>****</td>
</tr>
<tr>
<td>Predation</td>
<td>***</td>
<td>**</td>
<td>*</td>
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</tr>
<tr>
<td>Oviposition rate</td>
<td>*</td>
<td>****</td>
<td>***</td>
<td>*</td>
</tr>
<tr>
<td>Fecundity</td>
<td>**</td>
<td>****</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Egg development rate</td>
<td>*****</td>
<td>****</td>
<td>*****</td>
<td>**</td>
</tr>
<tr>
<td>Egg survival rate</td>
<td>*****</td>
<td>****</td>
<td>*****</td>
<td></td>
</tr>
<tr>
<td>Larval viability at hatch</td>
<td>**</td>
<td>***</td>
<td>—</td>
<td>**</td>
</tr>
<tr>
<td>Larval success at ascending pasture</td>
<td>**</td>
<td>***</td>
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<tr>
<td>Larva-nymph devpt. and survival</td>
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<tr>
<td>Nymph-adult devpt. and survival</td>
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<tr>
<td><strong>Boophilus microplus</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Finding oviposition site</td>
<td>***</td>
<td>**</td>
<td>*</td>
<td>****</td>
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<tr>
<td>Predation</td>
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<td>Oviposition rate</td>
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<tr>
<td>Fecundity</td>
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<td>***</td>
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<tr>
<td>Egg development rate</td>
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<td>**</td>
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<td>Egg survival rate</td>
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<tr>
<td>Larval viability at hatch</td>
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<td>**</td>
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<tr>
<td>Larval success at ascending pasture</td>
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<td>—</td>
<td></td>
</tr>
<tr>
<td><strong>Boophilus decoloratus</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Finding oviposition site</td>
<td>***</td>
<td>**</td>
<td>—</td>
<td>****</td>
</tr>
<tr>
<td>Predation</td>
<td>***</td>
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<td>**</td>
</tr>
<tr>
<td>Oviposition rate</td>
<td>*</td>
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<td>***</td>
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<tr>
<td>Fecundity</td>
<td>**</td>
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<tr>
<td>Egg development rate</td>
<td>*****</td>
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<td>**</td>
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<tr>
<td>Larval viability at hatch</td>
<td>**</td>
<td>***</td>
<td>—</td>
<td>**</td>
</tr>
<tr>
<td>Larval success at ascending pasture</td>
<td>**</td>
<td>***</td>
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</tr>
</tbody>
</table>

Temperature is shown in Fig. 1b. In the less complex models, this function is approximated by the straight-line segments shown dashed.

Some data on egg production rate of *R. appendiculatus* have been published by Branagan (1973). Fecundity data are available (N. Short, unpublished), although in a restricted range of temperatures. The models are considerably more sensitive to the fecundity, and henceforth more data on this process would be valuable (Table 1).

**Egg Development**

Egg development is generally modelled as a function of temperature only. Moisture deficit may be a factor in lengthening the development period, but its effect is small and can usually be neglected.

For convenience in modelling, especially for the simpler weekly timestep models, the period of egg development can be considered as the time from the drop of the engorged tick into the pasture to the
point when half the larval progeny is ready to seek a host. It then includes the pre-oviposition period, the egg development time, and the larval hardening period. There is a considerable spread in the oviposition time, and again in the hatching time. This spread in development times can be conveniently lumped together in a single distribution of hatching times.

The Tickplot technique is the most useful method for obtaining data on this process. Engorged female ticks or batches of freshly laid eggs are exposed in gauze containers at regular intervals to cover a range of climatic conditions. Exposures can also be made in short and long pasture simultaneously to gauge the effect of pasture height. If engorged ticks are exposed, some of them could be sampled to determine the time of egg laying. Then, over the time that hatching occurs, containers are destructively sampled to obtain the data on hatching time and distribution. Alternatively, the gauze containers can be opened just before hatch occurs, and the larvae sampled from the pasture at frequent intervals (at least twice-weekly) using flannelette bats. The latter method will include, within the development time, the time for larvae to become active.

One method that is often used to analyse development data, both for ticks and other poikilothermic animals, is the day-degree method. It is assumed that there is a temperature, the development threshold, below which no development takes place, while above this threshold, the development rate is a linear function of temperature (Fig. 2). Then development is completed when a certain total value of degree-days have been accumulated. This total, as well as the threshold temperature, is constant for any species. Values of degree-days can be obtained for any threshold temperature, either from tables for constant temperature experiments, or using computer programs for fluctuating temperatures (Baskerville and Emin 1969).

A more general approach is to assume that, for each model timestep, the increment in development is given by

\[ \text{development rate} \times \text{timestep/unit time}. \]

These increments are accumulated, and development is complete when their sum equals 1. Development rate is not required to be a linear function of temperature, any function can be used as needed. Such alternative functions may be necessary to predict more accurately development at low temperatures near the threshold, or to deal with high temperatures when development rates are often reduced. Computer programs such as DEVAR (Dallwitz and Higgins 1978) are available to fit the selected development rate function to fluctuating temperature field data. If any diapause is present during egg development, it must be taken into
account before fitting development rate parameters. Development rates were measured for *R. appendiculatus* by Branagan (1973) and Tukahirwa (1976), using laboratory techniques, while an extensive set of field data is available (Short, unpublished). These data are adequate for deriving development rate parameters at all except high temperatures.

**Egg Survival**

Egg survival, as treated here, is considered to be dependent on the temperature and moisture deficit experienced by the eggs in the pasture. Another factor that affects survival is predation (treated later), while trampling of the engorged females and eggs, though important in some situations, is not considered in this paper.

The effect of non-ideal conditions of temperature and moisture on the eggs can be manifested in two ways. There is a reduced percentage of eggs that hatch successfully (i.e. egg survival is reduced). Secondly, there may be a reduced viability of the larvae hatched from these eggs. Data on both these effects can be obtained using the Tickplot technique. The contributions of temperature and moisture should be separated out by the use of both irrigated and non-irrigated plots. Batches of eggs are randomly sampled at regular intervals during development and placed in an incubator at ideal temperature and humidity at the laboratory. The number of eggs hatching successfully can be recorded, and resulting larvae kept in the incubator to record their longevity. During the course of the experiment, temperature and humidity readings should be taken from positions similar to those where tick eggs are placed. Soil moisture at several depths ranging between 0 and 100 cm should be measured regularly.

The survival of eggs is modelled by assuming that wherever the eggs are at non-ideal conditions of temperature or moisture, they experience stresses which are additive. These stresses are scaled such that there is no survival if the total of either the temperature or moisture stress accumulated equals or exceeds 1. A fraction of the stress is carried over to the larvae, thus reducing their longevity.

In general, there will be stress accumulation both at low and high extremes of temperature (Fig. 3). Since tick eggs are laid on the ground, beneath the pasture, their rate of moisture loss will be a function of both soil moisture status and atmospheric dryness. To cope with this situation, an index (Soil Dryness Index, SDI) that is a product of soil moisture deficit and atmospheric evaporation has been developed (Sutherst and Dallwitz 1979). Soil moisture deficit is derived from a simple soil water balance model (Fitzpatrick and Nix 1969) and evaporation can be estimated using standard methods. The index is scaled between 0 (ideal wet conditions) and 1 (extreme dry). Then, moisture stress is handled similarly to temperature stress, with a function that increases stress rate as the SDI increases from 0 to 1 (Fig. 4).

One other factor that needs to be considered in the interpretation of the survival data is that the age of eggs is important when determining their sensitivity to extremes of temperature and moisture. Freshly laid eggs are considerably more sensitive to
high levels of moisture deficit than older eggs (Sonenshine and Tigner 1969), and a similar relationship holds for temperature sensitivity. Functions to adjust the stress rates for very young eggs take the form shown in Fig. 5.

![Diagram showing function modifying the effect of moisture stress with age of eggs.](image)

**Fig. 5.** Function modifying the effect of moisture stress with age of eggs.

Branagan (1973) has published survival data on *R. appendiculatus* at two locations in Kenya, while some data are available at four locations in Burundi (Gorissen, unpublished). Additional survival data are available for one location in Zimbabwe (Short, unpublished). Parts of these data are difficult to interpret as such factors as high temperatures and dryness occur at the same time. Since this process is critical in the tick's life system, more data that allowed separating the components of survival due to moisture and temperature would be highly desirable. This could be achieved by the use of irrigated and non-irrigated plots as described earlier. There is no evidence of any developmental diapause for this tick (Branagan 1973).

### Pre-moult/Hardening of Nymphs and Adults

In general, the pre-moult periods and hardening periods of nymphs and adults can be treated similarly to egg development. It will usually be necessary to include any periods of inactivity (behavioural diapause) at the end of the development period. Survival of these stages is high, though Koch (1983) found considerably reduced survival of engorged larvae of *Amblyomma* at average temperatures below 20° and above 30°C.

Good data on development of engorged larvae and nymphs of *R. appendiculatus* are available for most temperatures likely to be important (Short, unpublished). No data are available on the hardening periods, while very little has been published on survival of these stages.

### Predation

Predators may take a considerable fraction of engorged females and eggs. The level of predation will in general be highly site-specific, with factors such as pasture cover and proximity to natural bushland being important. Predators that have been found to be important in Australia include rodents and ants, though more specific predators and parasites may be important in Africa. Data on predation can be obtained by exposing both protected and unprotected ticks in the pasture, although this will not identify the particular predator responsible.

Short (unpublished) has observed predation of *R. appendiculatus* possibly by rodents. Very little is known about parasites of this tick.

### Acknowledgments

ACIAR provided financial support for the development and use of tick models in Africa. Messrs N. Short and A. Gorissen gave us generous access to their unpublished data. Dr M.N. Kaiser assisted in retrieving data in Burundi and Dr R.B. Floyd provided helpful discussions.

### References


Current Observations on Development and Survival of *Rhipicephalus appendiculatus* in Kenya

R.M. Newson*

A thorough study of development and survival in *Rhipicephalus appendiculatus* was made on captive ticks over 20 months, with monthly observations, at Muguga (altitude 2100 m) and at a nearby site in the Rift Valley (altitude 1900 m) by Branagan (1973a). This was complemented by laboratory studies under controlled conditions (Branagan 1973b). Branagan concluded that temperature is the determining factor in development in this species and the combined interaction of temperature and saturation deficit governs survival. The observations on development were repeated at Muguga by Punyua (1984) who compared an open and a shaded site. Newson et al. (1984) gave survival curves for *R. appendiculatus*, also at Muguga, by sampling unfed larvae, nymphs and adults from the vegetation.

This tick, however, occurs from sea level to approximately 2500 m in Kenya, whenever rainfall is adequate (Walker 1974). A collaborative study is therefore being carried out by the staff of four laboratories (ILRAD, ICIPE, MALD and KARI) at eight sites in Kenya, using standardised methods, with simultaneous observations.

**Material and Methods**

The eight sites of exposure are shown in Fig. 1 and described in Table 1. The ticks are raised in bulk from a single strain (Muguga) on cattle and rabbits at ILRAD and are all ready at the same time. The ticks are then counted and sealed in nylon gauze bags, according to the protocol given in Table 2, by ICIPE staff, and the bags of ticks required for each monthly sample at each site are then placed in small galvanised wire cages approximately 3 × 3 × 5 cm and labelled. The ticks are distributed in the cages and placed in series on the ground, well covered with vegetation and litter and, in some cases, with a wire marker passing right through the cage (which is to protect against rodent damage). Maximum and minimum temperature, wet and dry bulb temperatures and rainfall are recorded daily by staff on site.

Sets of ticks were put out in May, August and November 1985 and the next exposure will be in March 1986. Once per month the next cage in series for each set at each site is removed for examination of the ticks in the laboratory. The results obtained will provide information on the proportion of engorged female ticks that lay eggs and the subsequent hatching success of their eggs, plus data on survival of unfed larvae, nymphs and adults over long periods.

*ICIPE, P.O. Box 30 772, Nairobi, Kenya.
Table 1. Sites being used in the current joint study of *R. appendiculatus* in Kenya

<table>
<thead>
<tr>
<th>Site</th>
<th>Eco-climatic zone*</th>
<th>Elevation (m)</th>
<th>Temperature (Max./Min. °C)</th>
<th>Rainfall (mm)</th>
<th>Rainy season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kabete</td>
<td>III</td>
<td>1860</td>
<td>25/13</td>
<td>900</td>
<td>double</td>
</tr>
<tr>
<td>Kiboko(1)</td>
<td>V</td>
<td>1000</td>
<td>30/19</td>
<td>600</td>
<td>double</td>
</tr>
<tr>
<td>Kiboko(2)</td>
<td>V</td>
<td>1000</td>
<td>30/19</td>
<td>600</td>
<td>double</td>
</tr>
<tr>
<td>Malindi</td>
<td>III</td>
<td>50</td>
<td>30/23</td>
<td>700</td>
<td>one peak</td>
</tr>
<tr>
<td>Ukunda</td>
<td>III</td>
<td>10</td>
<td>30/22</td>
<td>1200</td>
<td>one peak</td>
</tr>
<tr>
<td>Intona</td>
<td>II/III</td>
<td>1600</td>
<td>26/14</td>
<td>1500</td>
<td>all year</td>
</tr>
<tr>
<td>Ukunda</td>
<td>III</td>
<td>2100</td>
<td>21/10</td>
<td>1000</td>
<td>double</td>
</tr>
<tr>
<td>Muguga</td>
<td>II</td>
<td>1160</td>
<td>29/17</td>
<td>800</td>
<td>double</td>
</tr>
</tbody>
</table>

*Eco-climatic zones of Pratt et al. 1966
**Locally modified by the presence of trees and water.

Table 2. Ticks required per site per exposure; destructive sampling at monthly intervals

<table>
<thead>
<tr>
<th>Stage</th>
<th>Ticks No./bag</th>
<th>Months sampled</th>
<th>Bags required</th>
<th>Total ticks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engorged</td>
<td>1</td>
<td>6</td>
<td>10 x 6</td>
<td>60</td>
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<tr>
<td>Unfed larvae</td>
<td>150 mg eggs</td>
<td>10</td>
<td>4 x 10</td>
<td>6.0 g eggs</td>
</tr>
<tr>
<td>Unfed nymphs</td>
<td>30 moult. larvae</td>
<td>17</td>
<td>4 x 17</td>
<td>3400 larvae</td>
</tr>
<tr>
<td>Unfed d.d. + ??</td>
<td>30 moult. nymphs</td>
<td>19</td>
<td>4 x 19</td>
<td>2280 nymphs</td>
</tr>
</tbody>
</table>

Results

These are now being obtained but it is too early to begin interpretation and analysis. The results will be analysed by the laboratory servicing each site and it is hoped that they will be brought together later for possible use in modelling.

Discussion

Some difficulty is being experienced in servicing the more distant sites regularly, and plans to make complementary collections of ticks from cattle and vegetation are also proving difficult to carry out. Nevertheless, the program is working and the objective of obtaining standard data from a series of sites is being met.

Acknowledgment

The study described here is a cooperative effort involving many members of staff in the collaborating laboratories. The author is the coordinator responsible for the execution of the project and acknowledges his debt to all of them.

References


Development of the Free-living Stages of Three Species of Ticks in Zimbabwe

N.J. Short*

The development of *Rhipicephalus appendiculatus*, *Boophilus decoloratus* and *B. microplus* was recorded over a period of two years in highveld grassland pastures at the Veterinary Research Laboratory, Harare (17°S; 31°E), Zimbabwe. Engorged ticks were exposed in small observation and control cages placed 1.5 cm beneath the ground in long grass (80-140 cm) and short grass (5 cm) habitats in three seasons of the year: warm wet, cool dry and hot dry. All the engorged females from four exposures were weighed to determine the reproductive potential. Observation cages were examined daily to determine pre-oviposition, pre-eclosion and pre-moulting times. Soil temperatures were measured on one day of each week and estimated, by multiple linear regression, for the remaining six days. Developmental times for each stage in each exposure were expressed as medians and developmental rates in per cent/day. The relationship between developmental rate and temperature was determined using a computer package named DEVAR (Dallwitz and Higgins 1978).

In both habitats, the development times for all species and stages were shortest in the hot season, intermediate in the wet season and longest in the cool season when temperatures dropped below the respective development thresholds. The development threshold temperatures for pre-oviposition of *R. appendiculatus* and *B. decoloratus*, derived from the fluctuating field temperatures, are virtually identical to the zero development temperatures observed for these species by Branagan (1973) and Londt (1974). The threshold temperature for *B. microplus*, however, was closer to the minimal development temperature observed by Hitchcock (1955). Under fluctuating conditions, the temperature thresholds for eggs of the three species were somewhat lower than those observed under laboratory conditions by the same authors. The development of all species and stages was most rapid in the short grass habitats where the highest temperatures were recorded.

The duration of the pre-oviposition period was shortest in *B. microplus* and longest in *R. appendiculatus*. The development rates of the three species were similar during the pre-eclosion periods, although development was slightly more rapid in *B. microplus* than the other species at all temperatures and slightly more rapid in *R. appendiculatus* than *B. decoloratus* at higher temperatures.

References


*Veterinary Research Laboratory, P.O. Box 8101, Causeway, Harare, Zimbabwe.
A Low-cost Field Data Logger

G.F. Maywald*

A MICROPROCESSOR-BASED data logger has been developed by the Division of Entomology to satisfy the need for a low-cost field logger for the collection of microclimatic data at remote sites. The unit is powered by rechargeable lead-acid or nickel-cadmium batteries, with the former allowing up to 4 months of data collection between recharges. Up to 16 sensors may be connected to the logger at one time, with temperature, humidity and radiation sensors being available. As well as these, an extra logger input can be connected directly to a tipping-bucket rain-gauge or anemometer.

The logger is able to transfer its data directly to a microcomputer connected to it, thus removing the need for transcribing of data from paper charts to coding forms and their typing into a computer. By storing all data in internal memory chips, the system is not dependent on unreliable magnetic tape storage, though it becomes essential that the power supply is uninterrupted during the whole data collection process.

In addition to receiving data from the logger, a microcomputer is also used to change logger-operating characteristics such as the number of probes in use and the time interval between reading the probes. Time and date are also entered into the logger in this way.

The logger is capable of storing 3000 items of data. The length of time that it can remain in the field before its memory capacity is exceeded will obviously be dependent on such factors as the number of probes being used and the sampling interval. A typical application might use six probes with data being recorded 2-hourly, in which case memory capacity would be adequate for almost 42 days of data collection. However, if this capacity is not sufficient, it is possible to expand the memory of the logger to a total of 12,000 items of data.

At current (1986) prices, the total cost of the fully assembled and tested basic logger is about $A600. Details of the logger have been published, but it is recommended that assembly of the logger is undertaken only by someone with extensive experience in the construction of microelectronic circuits. The total cost of the components is approximately $A250. Suitable probes for the logger are available at the following approximate prices:

- Temperature probe $A40
- Humidity probe $A30
- Radiation probe $A120
- Tipping-bucket rain-gauge $A200
- Anemometer $A150

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Modelling Tick Populations. 3. Host-finding Phase

R.B. Floyd*

The host-finding phase commences after moulting, when the exoskeleton of each instar is sufficiently hard to allow locomotion, and finishes when ticks attach to a host. The ecological processes of survival and being picked up by a host are involved in this phase. The factors affecting survival are mainly climatological while those affecting the rate of transfer to a host are tick activity, stocking rate, pickup efficiency and evasive behaviour of hosts at high tick densities.

The following discussion will cover the types of data required to model these processes, methods of interpretation and a review of the available data. Finally, an attempt to assign priorities for further research on this phase of the life cycle for *Rhipicephalus appendiculatus*, *Amblyomma variegatum/hebraeum*, *Boophilus decoloratus* and *B. microplus* is presented in Table 1.

Survival

The survival rate of host-seeking ticks is reduced by dry conditions and extremes of temperature. From a modelling point of view, the most useful survival data can be collected when a known number of ticks are released into a field enclosure and survival recorded after various periods of time. Data need to be collected on the number of ticks surviving, their location within the sward and the conditions of temperature and humidity experienced by the ticks. Tick survival needs to be monitored at intervals such that at least four measurements occur in the range of 10–90% survival. Standard atmospheric climatic parameters (Maywald 1987) should be recorded during these experiments.

One further consideration in designing these experiments is to produce conditions where two potentially lethal factors are acting simultaneously (e.g. hot and dry conditions). This can be done by watering or shading some enclosures.

Two different approaches have been used to model the survival of unfed stages. The first was described by Utech et al. (1983) and uses the accumulation of stress, which is assumed to be proportional to mortality. Stress can be caused by high and low temperatures and dryness. In the case of *B. microplus* it was found that the two temperature stresses were sufficient to account for most survival patterns. The shape of the functions relating temperature (Fig. 1) and dryness to stress factors can be chosen by the researcher, and a non-linear least squares optimisation technique then used to fit them. A complete description of this approach is given in Utech et al. (1983).

A second approach has been used by Steele and Randolph (1985) where a metabolic model was adopted. Survival is considered to be determined by the metabolic use of fat reserves, assumed to be proportional to time. This approach excludes the lethal effect of dryness and extremes of temperature. It may be appropriate under some conditions such as mesic temperate climates but is unlikely to be appropriate in much of Africa.

Quite a number of studies have measured survival of different instars of *R. appendiculatus* under various laboratory and field conditions. However, most of these studies do not present adequate climatic data or information on the movement of the ticks to interpret their survival. The most

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intensive study has been done by Short (1987) which has led to a reasonable understanding of the survival of this tick. Unfortunately, in Harare, hot and dry conditions occur simultaneously, as do cold, dry conditions, and further experiments need to be done to separate the effects of these factors.

Transfer of Ticks on to Hosts (Pickup)

Tick activity, stocking rate, efficiency of transfer of ticks on to the host and evasion of high densities of ticks by hosts all have an important effect on the rate at which ticks are picked up. This section concentrates on the methods of collecting

Table 1. Adequacy of data for modelling and priorities for future research on the factors that modify the rates of survival and pickup of *Rhipicephalus appendiculatus*, *Amblyomma variegatum/hebraeum*, *Boophilus decoloratus* and *Boophilus microplus*

<table>
<thead>
<tr>
<th>Modifying factors</th>
<th>Sensitivity/usefulness</th>
<th>Feasibility of collection</th>
<th>Availability of data for models</th>
<th>Priority for future research</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

### *Rhipicephalus appendiculatus*

**Survival**

- Microclimate: ***
- Level of tick activity: ****
- Stocking rate: ****
- Pickup efficiency: ****
- Evasion of high densities of ticks: ****

**Pickup**

- Microclimate: ****
- Level of tick activity: ****
- Stocking rate: ****
- Pickup efficiency: ****
- Evasion of high densities of ticks: ****

### *Amblyomma variegatum/hebraeum*

**Survival**

- Microclimate: ***
- Level of tick activity: ****
- Stocking rate: ****
- Pickup efficiency: ****
- Evasion of high densities of ticks: ****

**Pickup**

- Microclimate: ****
- Level of tick activity: ****
- Stocking rate: ****
- Pickup efficiency: ****
- Evasion of high densities of ticks: ****

### *Boophilus decoloratus*

**Survival**

- Microclimate: ****
- Level of tick activity: ****
- Stocking rate: ****
- Pickup efficiency: ****
- Evasion of high densities of ticks: ****

**Pickup**

- Microclimate: ****
- Level of tick activity: ****
- Stocking rate: ****
- Pickup efficiency: ****
- Evasion of high densities of ticks: ****

### *Boophilus microplus*

**Survival**

- Microclimate: ****
- Level of tick activity: ****
- Stocking rate: ****
- Pickup efficiency: ****
- Evasion of high densities of ticks: ****

**Pickup**

- Microclimate: ****
- Level of tick activity: ****
- Stocking rate: ****
- Pickup efficiency: ****
- Evasion of high densities of ticks: ****

†Data on *B. microplus* are considered to be an adequate substitute.
appropriate data for estimating the rate of pickup of *R. appendiculatus*, and a summary of the available data for *A. variegatum/hebraeum*, *B. decoloratus* and *B. microplus* is presented in Table 1.

**Tick activity**

Unfed ticks on pasture often have periods of inactivity during which they cannot be stimulated to attach to a host. Climatic parameters (temperature, moisture and possibly daylength) appear to determine these periods of inactivity. Data on the effects of climate on tick activity can be readily obtained by exposing ticks in field enclosures at different times of the year. The sampling strategy would need to be structured to investigate both diurnal and seasonal patterns of activity. When counting the number of active ticks, the criteria for activity should reflect the ability of ticks to attach to hosts. Secondly, a distinction needs to be made between ticks that are inactive at the base of the sward and those that are dead. Ideally, these experiments need to be supported by grazing trials in paddocks in which ticks have been released, to verify the criteria for activity in the enclosures. Microclimatic records of temperature and humidity in the pasture and rainfall would be required.

The proportion of active ticks can be related to extremes of temperature, dryness and daylength. Simple functions with increasing inactivity under more extreme conditions are usually sufficient to explain the daily activity level. The seasonal activity pattern is rarely a direct response to environment but has the added complications of sensitive and responsive stages, thermodistinct photoperiodic thresholds and different factors inducing, maintaining and terminating periods of inactivity. Data on the effects of climate on tick activity can be obtained using an approach similar to that used for *B. microplus* (Sutherst et al. 1978). Therefore, an estimate of the density of cattle in a particular area can be obtained from local farmers or veterinary authorities but the density of game animals is not well documented. Visual surveys at various times of year are required to assess the seasonal abundance of game species. Surveys of this type have been done in the lowveld of Zimbabwe (Colborne and Floyd 1987).

**Efficiency with which ticks transfer to passing hosts**

The efficiency of transfer from pasture to host can be affected by many factors including the diurnal activity pattern of the host and its degrees of coincidence with the activity of the ticks. Data on the efficiency with which ticks transfer to different breeds of cattle and wild hosts could be obtained using an approach similar to that used for *B. microplus* (Sutherst et al. 1978). Therefore, an estimate of the relative favourability of different hosts can be obtained by counting the number of ticks on hosts sampled at the same time from the same grazing area. This survey would have to be repeated at different times of the year to collect data on each instar. This indication of host favourability would be a combination of the pickup efficiency of the host and its resistance to ticks.

When modelling the effect of game on tick populations using the T3HOST model, which has only one class of host, all game are converted to undipped cattle equivalents according to the number of ticks they carry. Each species of game is assigned a value which relates its tick burden to that of cattle. The seasonal fluctuation of game numbers is modelled by varying the stocking rate of undipped cattle.

The overall assessment of the rate of pickup has been attempted by Sutherst et al. (1978) and
Randolph and Steele (1985). Randolph and Steele's approach would be difficult to apply since it was developed for a system with few ticks carried by wild hosts. The approach used by Sutherst et al. could be used, although the experimentation required is rather intensive.

Evasion of high densities of ticks

The grazing behaviour of hosts can be a major determinant of the rate at which ticks transfer to hosts, since hosts can actively avoid or return to areas of high tick numbers. Observations of the diurnal and seasonal movement patterns of both wild and domesticated hosts are needed to assess the likelihood of ticks being picked up. These observations would describe host behaviour temporally and spatially as well as estimate the area of pasture swept by the grazing host (Sutherst et al. 1978).

A second set of behavioural observations is required to determine whether cattle avoid areas of pasture with high densities of ticks, as has been shown for B. microplus (Sutherst et al. 1986). If host-evasive behaviour can be demonstrated, it would be of interest to know what sensory cues were being used to detect ticks. This density-dependent process needs to be investigated for each instar of a range of species of ticks with clumped distributions on pasture.

Conclusions

The sensitivity of the model to the factors determining the rate of survival of unfed ticks is higher for short-lived than long-lived species. This is particularly important in areas where discontinuous stocking is practised. For long-lived species of ticks, it is more important to quantify the factors that affect the rate at which unfed ticks transfer to hosts.

A summary of the adequacy of the data for modelling the processes of survival and transfer of ticks to hosts in the host-finding phases of the life cycle of R. appendiculatus and A. variegatum/hebraeum is given in Table 1. For the more long-lived species (R. appendiculatus and A. variegatum/hebraeum), the model was less sensitive to the effect of climate on survival than to any of the other factors since, under most circumstances, stocking rates are sufficiently high to ensure that most of the ticks are picked up before they die on the pasture, provided they are active for long periods. The effect of stocking rate on the rate of transfer of ticks on to hosts needs to be defined for all species in the African context. The other high priority for future research is understanding the factors that determine the level of activity of R. appendiculatus and A. variegatum/hebraeum.

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References

Colborne, J.C., and Floyd, R.B. 1987. The effect of game animals on tick control. These proceedings.


Behaviour and Survival of Unfed Ticks in Zimbabwe

N.J. Short*

The behaviour and survival of *Rhipicephalus appendiculatus*, *Boophilus decoloratus* and *Boophilus microplus* were studied over a 2-year period in highveld grassland pastures at the Veterinary Research Laboratory, Harare (17°S; 31°E), Zimbabwe. Ticks were exposed in columns, 63 mm diam., in long grass (140 cm) habitats and short grass (5 cm) habitats. Above ground level, long grass columns were demarcated into seven 20 cm zones. An additional zone, the soil surface, was included for *R. appendiculatus* adults only, to detect any diurnal or seasonally-related behaviour patterns. The ticks in each zone were counted (adults and nymphs) or estimated (larvae) on one day of each week at 2-hourly intervals between 0600 and 1800 h. during their entire host-seeking phase.

At one site in the study area, wet and dry temperature sensors were arranged in horizontal pairs at heights corresponding to the mid-point heights of each zone in the long grass and at 5 cm in the short grass. Temperatures were recorded at the same time as the ticks were counted to give temperature and saturation deficit profiles for each observation time throughout the host-seeking periods.

For each exposure, the heights preferred by the majority of each stage in the long grass habitats remained unchanged throughout the day. However, significant diurnal changes in numbers were detected for *R. appendiculatus* larvae and nymphs in both habitats, when consistently fewer ticks were observed at midday compared with the early morning or late evening. These changes were associated with season and increasing temperature and saturation deficit. The numbers of *R. appendiculatus* adults did not change significantly during the day. The limited data for *B. microplus* larvae suggest diurnal changes in number similar to those observed with *R. appendiculatus* larvae. The data available for *B. decoloratus* were vary variable and no diurnal changes could be detected.

Under experimental conditions it was found that larvae of the three species and *R. appendiculatus* nymphs could be active at any time of the year, whereas the activity of *R. appendiculatus* adults was confined to the period between the late hot season and post-rainy season.

The movement of adults from the soil to the soil/air interface appeared to be stimulated by either rainfall or high soil temperatures. Upward movement occurred only when rainfall became regular and the maximum temperatures and saturation deficits in the microclimate had decreased. No seasonal effect on larvae or nymphs was found.

The survival times of larvae of the three species and nymphs of *R. appendiculatus* were influenced by the low temperature stress in June/July and the high temperature stress in September/October. The 50 per cent survival times of *R. appendiculatus* adults in long grass were similar to those recorded in Kenya (Branagan 1973; Newson et al. 1984). The ability of *R. appendiculatus* adults to survive in Zimbabwe, a sub-tropical climate, for similar periods to those in Kenya, a tropical climate, has been attributed to the seasonal behaviour patterns observed in this study.

References


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The Ecology of Free-living Instars of Rhipicephalus appendiculatus in Burundi

L.P. Gorissen*, M.N. Kaiser* and R.W. Sutherst**

Observations were made on the development and survival of all three stages of Rhipicephalus appendiculatus, placed under quasi-natural conditions in four ecologically different regions of Burundi, over a period of two years. They demonstrated that the desiccation of eggs was a limiting factor for population growth and that the percentage of eggs hatching was determined by dryness and the type of grass cover.

The "Reproduction-Index", determined as the number of living larvae divided by the weight of female in grams, was high during the rainy season and low during the dry season; but, during the dry season, a higher percentage of nymphs moulted successfully than during the wet season. Correlations between the moulting of larvae and the meteorological data could not be established, probably because of the inadequacy of the technique. In pasture, 50% of unfed adults survived for 16 to 17 months after moulting. Larvae and nymphs all died within 2 to 9 months.

The results were correlated with the data from the monthly tick collections on hosts, and an explanation for the seasonal activities of larvae, nymphs and adults was given.

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Modelling Tick Populations. 4. Parasitic Phase

R.W. Sutherst*

It is during the parasitic phase on livestock that ticks cause the losses to animal production which lead man to define them as pests. The time spent on the host, the amount of blood ingested, the amount and type of foreign material introduced into the host and the response of the host to those events determine the success rate of the ticks as well as the loss of production of the host. Whilst the duration of feeding times of most instars and species of ticks is adequately known for practical purposes, there is a great shortage of data on the role of host resistance in limiting the size of populations of economically important species of ticks in Africa. There is an even more severe lack of understanding of how tick resistance of African livestock is affected by environmental factors.

Ecological Data

Two types of ecological data on parasitic stages are needed.

(a) Population dynamics

The availability of data for population modelling of the four main species of importance in Africa are shown in Table 1. The parameters for which data are needed are:

(i) Host specificity — the host range of a particular species of tick must be defined in order to understand the involvement of each host type in the ecology of the tick and the epidemiology of any disease it transmits. The range of most species has been determined by surveys (Walker 1974; Yeoman and Walker 1967) or by ecological studies (Norval 1979). When a tick has important alternate host species, quantitative comparisons are needed to define the role of each (Sutherst et al. 1978; Colborne and Floyd 1987);

(ii) Predilection sites — ticks share the available hosts very well by feeding on different parts of the body (Kaiser et al. 1982). This segregation must also reduce attempts at interspecific matings. Thorough examination of hosts for each instar of 3-host ticks is needed to define the predilection sites for each new geographical location because there is evidence of variation within species such as Rhipicephalus appendiculatus;

(iii) Engorgement patterns — all species of ixodid ticks go through a rapid, final phase of engorgement. This observation has been used to develop the "standard tick" concept for sampling (Wharton and Utech 1970) and it is also important in understanding the role of daily animal movements in the ecology of ticks, particularly in Africa where livestock is usually kept indoors overnight;

(iv) Duration of feeding — the duration of feeding of each instar on the host determines the rate of turnover of ticks on the host, the proportion of the population on the host on a particular day, the proportion killed by acaricides and the time available for transmission of diseases. For modelling purposes, this readily observable parameter has been adequately defined for all important species (Norval and Capitini 1974; Branagan 1974), but care is needed to use data relevant to the host of interest in the environment of interest; and

(v) Survival rates and engorgement weights — the largest effect of host resistance is on survival but the size and, hence, fecundity of ticks is determined by the resistance of the host, as shown so elegantly by Chiera et al. (1985). The main deficiencies in data relate to those many factors that affect the expression of host resistance in the field. Their measurement requires facilities for field experiments, statistically adequate numbers of hosts and good support facilities for culturing ticks, etc. The large literature on host resistance has been reviewed by Sutherst and Utech (1981) and FAO (1984), with more recent observations having been made by Kaiser et al. (1982) and Sutherst et al. (1983).

The factors affecting the expression of host resistance against feeding ticks are:

(i) the degree of previous exposure by the host to that species of tick. Whilst adult animals are fully susceptible if they receive their first exposure late in life, calves born to resistant dams are highly resistant

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