Risk Assessment on Cattle Ticks and Tick Fever March 2006

Report for the New South Wales Department of Primary Industries

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TECHNICAL REVIEW OF USE OF CATTLE TICK FEVER VACCINE and RISK ASSESSMENT OF SPREAD OF CATTLE TICK FOLLOWING MOVEMENT OF LIVESTOCK

TERMS OF REFERENCE

1. A risk assessment be undertaken to assess the risk of cattle ticks being spread if livestock were permitted to travel from the Queensland Cattle Tick Infected and Protected Areas direct to slaughter in NSW.

2. A technical review of use of Cattle Tick Fever Vaccine:

   - Assessment of the risk associated with the use of tick fever vaccine in New South Wales;
   - Assessment of the risk of reversion to virulence of vaccine strains in the NSW situation; and
   - Recommendations on the value of vaccination in risk areas of NSW as a risk management option.

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Executive summary

Part 1- Technical Review of Cattle Tick Fever Vaccine

Observations

Australian cattle producers outside of NSW have free access to both fresh and frozen live tick fever vaccines manufactured under audited GMP conditions at the Tick Fever Centre in Wacol, Brisbane.

- Historically there have been problems associated with vaccine reactions and contamination of the live vaccine, and theoretically the vaccine could be associated with “lighting up” ticks or reversion to virulence.

- Research conducted over the past thirty years to improve the efficacy and safety of the vaccine strains, as well as the strict adherence to the GMP manufacturing code mean that the problems mentioned above are rarely observed, and APVMA records show an extremely low rate of adverse experiences with the vaccine. With approximately 800,000 doses of vaccine used per year there are less than three cases per year of reported vaccine problems.

- Tick outbreaks in NSW are relatively common (40-80 per year over the last decade) but the incidence of tick fever is very low. In the last decade there has been an average of less than one outbreak per year involving at most several dozen cattle each time. NSW DPI policy of tick eradication is generally successful in quarantining infected properties and treating cattle until ticks can no longer be detected.

- Trends towards lower government funding of tick control, and the increase in resistance of ticks to common acaricides such as amitraz leads many to think that tick control will become more difficult in NSW.

- The NSW herd probably contains cattle that carry tick fever organisms, either because they were vaccinated or had natural infection before being transported from Queensland.

- Other measures available for decreasing the risk of tick fever outbreaks include quarantine, acaricides and antiprotozoal treatments. Tick and tick fever-resistant breeds of cattle are available and are used by many cattle producers, especially for crossbreeding with British and European breeds. However none of these would give the level of protection to cattle that arises from proper use of the tick fever vaccine.

- Public opinion in NSW over the introduction of tick fever vaccine is divided, largely over two issues. The first is the sincerely-held belief that using live tick fever vaccine poses a risk to the spread of tick fever in NSW. The second is that some farmers believe that allowing the use of tick fever vaccine in NSW would provide grounds for state policy of tick eradication to change. They fear that responsibility for tick control would be handed over to individual cattle producers, as it is in the tick-infected zone of Queensland.

- The role of small landholders in the control of ticks and tick fever has been commented upon, but in the absence of any reliable data on their level of awareness of ticks, or commitment to quarantine, any conclusions on the role of this group would be speculative.

Conclusions

- The risk of vaccine use causing animal morbidity due to reversion to virulence, or causing outbreaks by "lighting up" ticks is remote, even if the vaccine were used widely in NSW. Opposition to the use the use of tick fever vaccine due to these reasons cannot be supported scientifically.

- If tick outbreaks increase in frequency it is inevitable that tick fever outbreaks would also become more common, especially because the NSW cattle herd is largely composed of *Bos taurus* cattle that are highly susceptible to both ticks and tick fever. One option for increasing the immune protection of these cattle is to use the tick fever vaccine in outbreaks.

- Use of tick fever vaccine surrounding an outbreak is not standard practice for producers in the tick free areas of Queensland, and could not be justified as standard practice in NSW following tick fever outbreaks, given the current incidence of tick fever. However providing the option of tick fever vaccine use would allow NSW cattle producers to protect their own herds against the threat of tick fever outbreaks.

- It is not considered that cattle carrying tick fever organisms constitute any risk to NSW cattle producers. Rather the level of immunity of the "at risk" population of cattle is being improved by their presence.

- It has been shown that the most effective measure of preventing tick fever infections in high risk areas of Australia such as coastal Queensland is the use of the tick fever vaccine. Due to the low number of outbreaks of tick fever in NSW at present the need for this vaccine is not pressing. However the likely presence of tick fever organism-carrying cattle already in NSW means that the policy of restricting vaccine availability is largely redundant. There appears to be no cogent scientific argument why producers wishing to have access to the vaccine for their farm biosecurity programs should not have it made available. Increasing the availability of tick fever vaccine would have little effect on herds in Northern NSW.

- A survey of attitudes to tick control among small landholders would be useful to establish whether extra measures are needed to educate this group. Extension of information to both small landholders and commercial cattle producers would help decrease the risk of tick fever outbreaks.

Part 2- Risk assessment of importing cattle

This report provides a risk assessment on the importation of cattle from the cattle tick-infested 'Protected' and 'Infected' zones of Queensland direct to slaughter in NSW. A poor outcome was defined as; a tick from imported tick-positive cattle from QLD entering and being released into the NSW environment. This outcome would increase the risk of tick infestation and tick-borne diseases of cattle in NSW. The findings of this risk assessment can serve a broader purpose as a decision-making tool for considering further market access for QLD cattle.

Definitions and background

In order to define the risk of importation of cattle ticks into NSW, the objective of this survey was to explore the question:

> **If a consignment of cattle were imported into NSW direct to slaughter at concessional abattoirs, what would be the risk of transferring ticks to cattle in NSW?**

We expressed this risk on ‘per 100,000 consignments’ and on ‘annualised risk’ bases.

- The ‘entry’ steps for cattle ticks describe the probability that a consignment of cattle entering NSW from Queensland contains at least one tick-positive beast.
- The ‘release’ steps for cattle ticks describe the probability that ticks from a tick-positive consignment are released into the NSW environment.
- Cattle from different zones of QLD (protected and infected zones) are processed and treated differently before entering NSW. The risks based on these different steps were assessed separately.
- The computed probabilities and estimates presented in this report are based on historical data and current regulations. When specific data were not available estimates and expert judgments were sought from people involved in tick control and the cattle industry.

Risk identification

- The vast majority of properties in NSW are tick free, and the endemic form of tick fever does not present in NSW, contrary to the situation on properties in the Protected and Infected zones of QLD. There is the potential to transfer ticks to NSW if access is granted to cattle from the protected and infected zones.
- Surveys indicate that outbreaks of tick fever in NSW were common up until 1968, with an average of 10 outbreaks per year. Since the 1970’s outbreaks have only occurred every few years.
- Currently cattle imported from Protected and Infected zones of QLD are transported directly into concessional abattoirs in NSW following treatment and inspection at the border. The total number of cattle transported into NSW for slaughter between 2002 and 2003 from different zones of QLD was approximately 150,000/year.
- Factors most likely to affect manifestation of tick-borne disease are the number of ticks introduced, and survivability of these in the NSW climate. Impacts resulting from the introduction and establishment of cattle ticks are likely to be severe.

Risk assessment conclusions

- No tick fever outbreak in NSW has been reliably attributed to importation of cattle tick from QLD. In many recent tick outbreaks the source and route of introduction of ticks into an area previously believed free of *B microplus* were not identified.
- We made a conservative assumption that the introduction of ticks into NSW from QLD is possible, even though an outbreak has not yet been demonstrated to have occurred as a result of introduction of ticks from QLD on cattle going direct to slaughter. The following quantitative risk assessments used historical data on the infestation rate of cattle properties in QLD and number of cattle transported from QLD to NSW to provide estimates of median and 95% confidence limits for the likelihood of tick entry and release per 100,000 consignments.

- The probability of ticks introduced, en route to slaughter and in the abattoir environment,:

  - For cattle commercially transported into NSW by trucks from the **protected zone** of QLD is 0.0002 (95% CI: 0.00008 – 0.027) per 100,000 consignments. This indicates that the possibility of **release of ticks into the environment from a consignment would be highly unlikely, that is approximately one event in the next 10,000 years**.

  - For cattle commercially transported into NSW by trucks from the **infected zone of QLD under current surveillance regulations** (treatment and Tick Line inspection) is 0.02 (95% CI: 0.001 – 0.10) per 100,000 consignments. This indicates that it is very unlikely that **release of ticks into the environment from a consignment would occur, that is approximately one event in the next couple of thousand years.**

  - For cattle commercially transported into NSW by trucks from the **infected zone of QLD, if the current surveillance regulations are lifted** (no treatment and no Tick Line inspection) is 93.8 (95% CI: 13.60 – 287.30) per 100,000 consignments. This indicates that it would be **likely that release of ticks into the environment from a consignment would occur approximately every 4 years**.

- Climex (CSIRO, Australia) software was used to estimate the survivability of ticks in different regions of NSW with different temperature and humidity (rainfall). The north east coastal region of NSW was considered as a favourable environment for tick survival if a tick infestation occurs. Other sites were generally not favourable to tick survival.

- This risk assessment and qualitative assessment of literature and previous reports indicates that it is unlikely that the outbreaks of tick infestation and tick fever in NSW that were reported in recent years were related to importation of cattle from QLD direct to slaughter.

- The quantitative risk assessment also indicates that under the current circumstances of importation of cattle from QLD, the risk of entry and release of cattle ticks into the NSW environment is negligible.

- Proposed changes to regulations allowing importation of untreated and un-inspected cattle from the infected and protected zones of Queensland into NSW would result in a measurably increased risk compared to the current situation.

- The increased risk would be exacerbated should the number of cattle imported increase, and if QLD producers presented more untreated cattle for sale, resulting in a higher number of ticks per head.

- The computed probabilities and estimates presented in this report were based on the historical data, current estimates on infestation rate in different zones, expert judgments and current regulations (treatment and Tick Line inspection). It was also assumed that the effectiveness of treatments (chemicals) and treatment procedures (e.g. dip, pour on, etc.) remained constant over the years. It is intended that the issue of tick resistance to chemicals is not accounted for in this assessment. However, since the efficacy of acaricide products in the market is unlikely to remain constant, it is suggested that findings of this study should be interpreted in the light of possible changes in the infestation rate and resistance to chemical.

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Part 1

Use of Tick Fever vaccine in New South Wales- an analysis of the major issues

1. Risks associated with using Tick Fever Vaccine

1.1 The Tick Fever Vaccine

Australian cattle producers have for many years been able to take advantage of the tick fever vaccine to protect cattle against *Babesia* and *Anaplasma* organisms that are transmitted by cattle ticks. The vaccine is important especially for dairy farmers and producers of British and European cattle, which are highly sensitive to *Babesia* and *Anaplasma* infections[1]. However producers of crossbreds, which have intermediate susceptibility to *Babesia*, and purebred tropically-adapted breeds of cattle such as Brahmans may also choose to vaccinate due to the innate susceptibility of these breeds to *Anaplasma* infection[2].

1.1.1 Vaccine history

The Australian vaccine against tick fever was developed in the late nineteenth century by CJ Pound, and subsequently used throughout Northern Australia. The vaccine was of profound importance for owners of susceptible cattle, as herds had been experiencing up to 70% mortality rates as tick fever spread down the east coast[3].

The original vaccine consisted of blood collected from an already-infected "donor" beast, and injected whole into the susceptible cattle. Due to the fact that unmodified live parasites were present in the vaccinated blood many of the vaccinated cattle developed reactions as they succumbed to tick fever, and losses were reasonably high. Moreover, it could not be guaranteed that the species of parasite in the donor was the same as that in the recipient animals, and since cross-protection between species is poor, cattle could still succumb. However the benefit of vaccination was sufficient to warrant these side effects, and the practice became widespread.

1.1.2 Vaccine manufacture

The vaccine currently used in Australia is manufactured at the CJ Pound Tick Fever Centre at Wacol in the western suburbs of Brisbane, owned and administered by the Queensland Department of Primary Industries. Instead of selecting a naturally-infected beast as donor, cattle are specially chosen from a closed herd and kept under strict supervision.

Cattle of a suitable age are splenectomised in order that infected red blood cells are maintained in circulation longer. These calves are cleared of contaminating haemoparasites using selective drug treatment[4]. These are then inoculated with laboratory strains of the three tick fever parasites *Babesia bovis, B. bigemina* and *Anaplasma centrale*.

Strains of *Babesia* and *Anaplasma* are selected initially from field isolates as vaccine strain candidates. Strains that exhibit good immunogenicity without excessive virulence are attenuated by passage in splenectomised calves and further tested for safety, efficacy and freedom from extraneous infectious agents. For example, the Dixie strain of *B. bovis* was isolated from a chronically infected bull in North Queensland and passaged rapidly in splenectomised calves. Various sub-isolates were taken and compared for protection and virulence, and the sub-isolate with the best protection and acceptable virulence (“calf passage 14”) was chosen as the vaccine strain[4].

Those that pass these tests are stabilised and stored for use as vaccine strains. Splenectomised calves are injected with the “stabilate” and the parasite levels are monitored by blood tests. When parasite numbers reach adequate levels, blood is drawn off from the calf under sedation. The calf is treated for the parasites and given supportive therapy.

Following collection the blood is titrated to ensure the correct number of parasites per 2.0mL dose-$1x10^7$ *Babesia bovis,* $2.5x10^6$ *B. bigemina* and $1x10^7$ *Anaplasma centrale.* Dilution is made with Phosphate Buffered Saline containing glucose and antibiotics, and the three aliquots mixed to provide the final “three germ” vaccine.

Both chilled vaccine, with a four day shelf life, and vaccine frozen in liquid nitrogen, with a five year shelf life, are available in Australia.

1.1.3 Number of doses sold in Australia

In the period January 2000 to April 2005 approximately 4.4 million doses of live tick fever vaccine were distributed from the Tick Fever Centre, Wacol for use throughout Australia. This equates to approximately 800,000 doses per year over the last five years.

1.1.4 Adverse events related to the use of live Tick Fever vaccine

Potential adverse events previously associated with the live Tick Fever vaccine are described below (see 1.1.4.1 to 1.1.4.5).

1.1.4.1 Loss of pregnancy

Due to the occasional incidence of high body temperature following inoculation with the live Tick Fever vaccine, the product label is required to carry a warning against using the vaccine on heavily pregnant animals. Reports to the Tick Fever Centre at Wacol on field use of the vaccine indicate that many producers have, however used the vaccine on heavily-pregnant animals. These cases mostly arise from drought-affected properties needing to move cattle due to lack of feed[5]. Producers were advised to keep the vaccinated animals under close observation, and treat cows if they showed the effects of tick fever. All of these recent cases passed without reported incident.

The evidence suggests that concern over the use of the vaccine in heavily-pregnant animals is probably over-cautious. However since it forms part of the APVMA-approved label recommendations, it is unlikely to be removed without trials being performed to confirm the safety of the vaccine for pregnant animals.

1.1.4.2 Vaccine reaction

The tick fever vaccine product label gives instructions for producers to treat “animal showing signs of severe reactions”. A vaccine reaction is considered to be an animal showing signs of clinical parasitism with one of the Tick Fever organisms, gained as a result of using the live vaccine.

Before the adoption of stabilised attenuated isolates of tick fever organisms in the commercial vaccine there were occasional reports, mostly anecdotal, of cattle showing tick fever signs as a result of vaccination. This has resulted in suspicion among people who are not regular users that vaccine use causes reactions.

An example is a well-publicised case of reaction to the *B. bigemina* component of the tick fever vaccine, (which took place about 1980). Bob Callow of QDPI investigated this case at Kingaroy, where 120 heifers were lost after vaccination with Y strain, as this was not properly attenuated. Subsequent investigations showed that this strain had actually increased in virulence due to passage in splenectomised calves. Since 1982 the G strain, which is properly attenuated, has been used, and no problems have been identified.

Due to publicity from this incident many producers in the northeastern Darling Downs needlessly order “Two-germ” vaccine (without *B. bigemina)* in the area even today despite no evidence the current strain is involved. In recent years 75% of all vaccine sold is Three Germ[6].

In a study designed to determine the extent of tick fever vaccine reactions Bock et al[7] isolated *Babesia bovis* organisms from cattle that were clinically affected with babesiosis soon after vaccination (within three weeks). A total of five different cases were investigated between September 1993 and March 1999. Of these five cases, only one case, in which two steers in Nanango Shire died, could be linked to infection with the vaccine strain.

In the other four cases the morbidity was caused by either other factors or natural (field) strains of *Babesia* that infected the cattle. The temporal relationship with time of vaccinations led the farmers and veterinarians treating the cattle to assume that the vaccine had caused these reactions.

Calves three to nine months of age show natural or "innate" resistance to tick fever organisms, and vaccination of calves in this age group rarely results in adverse reactions being reported. It is also recommended on the vaccine label that bulls are monitored for fever following vaccination, as a high fever can cause a temporary loss of fertility[4].

If cattle are found to have a reaction i.e. display signs of infection with one of the tick fever organisms following vaccination, it is routine to treat the animal with an appropriate babesicide such as Imidocarb (Imizol, Schering-Plough Animal Health, Imidox- Parnell Laboratories). Timely treatment usually results in rapid return to clinical normality[8].

1.1.4.3 Reversion to virulence

There is a possibility that any live vaccine administered to animals will regain virulence factors after a period of time in the host. Unpublished research conducted at the Tick Fever Centre, referred to in Bock et al (2004)[4], shows that the Dixie strain of *B. bovis* "is known to be transmissible by *Boophilus microplus* under laboratory conditions and to increase in virulence following tick transmission". The transmissibility of various clones of *B. bovis* in *B. microplus* was assessed by Timms et al (1990)[9]. Passage of certain clones in non-splenectomised calves resulted in reversion to virulence, but the clones could not be transmitted naturally in cattle.

It is concluded that field strains of *B. bovis* possess a range of virulence and infectivity (transmissibility). It could be further postulated that introduction of the vaccine (Dixie) strain into a field situation is unlikely to result in transmission to ticks, largely due to the fact that the parasitaemia stage is relatively short, and susceptible host ticks would need to feed on vaccinated cattle at precisely the right time period after vaccination for transmission to occur[5].

In a Queensland Department of Primary Industries trial performed at Mutdapilly on Herefords (Bock et al[6]), cattle were vaccinated with Dixie, inoculated with W isolate, then ticks introduced. No isolates of Dixie strain of *Babesia* were subsequently found in inoculated cattle.

1.1.4.4 Extraneous agents

Due to the nature of using a fresh or frozen live vaccine the potential exists for contaminating agents such as virus, bacteria or other haemoprotozoans to be included in the vaccine, and inoculated into cattle in the field.

In 1986 an outbreak of the viral disease Enzootic Bovine Leucosis, linked to the Tick Fever vaccine, affected several cattle producers, and cost the Queensland Government approximately A$7 million in compensation.

Since that time manufacturing techniques have been refined to preclude the risk of extraneous agents. Procedures known as "GMP" or "Good Manufacturing Practice have been instituted. These international standards of manufacture stipulate the type, number and frequency of Quality Assurance tests and measures that must be carried out before firstly a manufacturing plant can be licensed to produce commercial vaccine, and secondly before each individual batch of vaccine can be released for sale. The Quality Assurance procedures are detailed in Bock et al, (2004)[4].

Another major change in procedure is for a single closed herd to be used for the vaccine donor calves now, rather than sourcing donor calves from private herds. The herd is checked regularly for the presence of infectious agents such as viral diseases. Calves are vaccinated against common diseases, and treated with a combination of pharmaceuticals to clear them of haemoprotozoans before inoculation.

The GMP manufacturing site is audited every two years by officers of the Australian Pesticides and Veterinary Medicines Authority. Details of the APVMA's auditing processes for GMP facilities are available[10].

Frozen vaccine has lower risk than chilled or fresh vaccine due to the longer lag time between the time of manufacture and when it is released for sale. This gives extra time for conducting tests and releasing batches. Fresh and chilled vaccine needs to be distributed rapidly so that it can be transported to the farm and used within the four day lifespan.

1.1.4.5 "Lighting up" ticks

One of the reasons for Northern New South Wales cattle producers' objections to the introduction of tick fever vaccine has been the issue of "lighting up" ticks. This refers to the possibility of the vaccine strain of *Babesia* or *Anaplasma* infecting ticks present on a property that may not have previously carried protozoans.

In a Queensland Department of Primary Industries trial performed at Mutdapilly on Herefords (Bock et al[6]), cattle were vaccinated with Dixie strain of *B. bovis*, inoculated with W isolate, then ticks introduced. No isolates of Dixie strain of *Babesia* were subsequently found in inoculated cattle, while the 11 isolates from clinical cases identified by Polymerase Chain Reaction were all “wild” type[1], not Dixie.

The G strain of *B. bigemina* used in Australia is very poorly transmitted by ticks, and only has detectable parasitaemia for a short time making transmission in ticks a very unlikely event[4].

Anaplasma centrale, the organism used for vaccination against the naturally-occurring tick-borne disease *A. marginale,* is not transmitted by Australian ticks and therefore has no prospect of “lighting up” ticks.

Field observations after administration of several million doses of tick fever vaccine over the past thirty years support the idea that vaccine strains are able to confer protection to individual animals when inoculated, without becoming a naturally-transmitted strain in the field[5]. This is despite the fact that with eight hundred thousand head of cattle being vaccinated each year the population of vaccine strain “carriers” is very high. Moreover, natural tick infestations in the endemic areas of Northern Australia are also very high, giving ample opportunity for “lighting up” to occur.

In Northern New South Wales tick populations are very low, their presence triggering treatment and quarantine actions. The probability of vaccine strains “lighting up” autochthonous populations or introduced infestations of ticks if a NSW herd were to be vaccinated is therefore considered to be negligible.

1.1.4.6 Acute neonatal haemolytic disease

A potential risk exists for neonatal haemolytic disease if cows are repeatedly vaccinated with the tick fever vaccine. However due to the pattern of use adopted in Australia, which is to vaccinate cattle only once as calves, and seldom more than twice, the actual incidence of this complication appears to be very low.

Technological changes such as the introduction of a cell-free diluent, and reduction of the dose from 5mL to 2mL in 1984 have probably contributed to the low risk in recent years. Bock et al (2004) report that no cases of acute neonatal haemolytic disease have been confirmed in vaccinated cattle since 1976[4].

1.2 Timing of vaccination

To take advantage of natural immunity that is shown by calves of all breeds to tick fever it is recommended to vaccinate cattle between the ages of three and nine months[11]. Colostral immunity to the three tick fever infections is thought to last for two months, but is followed by a period of “innate immunity” that lasts until nine months of age. Calves vaccinated during this time period rarely show reaction to the vaccine.

In field use, repeat vaccination (a second vaccination) given either to calves during the three to nine month-old period of innate immunity, or a "booster" vaccination given to older cattle has not been associated with problems. This practice could ensure that cattle that missed out on adequate protection from the first inoculation gain protection from the second.

However repeated vaccination (more than twice) should be avoided, to prevent the chance of an animal reacting to the blood cell antigens contained in the vaccine.

1.3 Lack of efficacy of the vaccine

In the period 1995 to 2003 the combined total of reports relating to "lack of effect" of the live Tick Fever vaccine, as reported by the Australian Pesticides and Veterinary Medicines Authority, was ten possible and twelve probable events. The APVMA considered that due to the very low number of reports compared to the total number of doses sold there was no need for regulatory action[12].

1.3.1 Immunity following vaccination

Immunity to the vaccine strains of *Babesia* used in the Australian live tick fever vaccine was found to be high after a single inoculation[13]. Herds with confirmed *B. bovis* vaccine failures dropped off following the introduction of the Dixie strain in 1993. No difference was found between immunity gained from vaccination and that following natural exposure to *Babesia* organisms.

Immunity to *Anaplasma marginale* is gained using vaccination with *Anaplasma centrale,* a vaccine strain of organism brought into Australia from South Africa in 1934. Artificial challenge of individual cattle with *A. marginale* following vaccination with *A. centrale* sometimes result in clinical infection, but field evidence collected from diagnostic laboratory statistics suggest that herd immunity is solid and adequate[13].

1.3.2 Duration of immunity

Mahoney et al (1973) showed that cattle retain immunity to challenge infection with *Babesia bovis* and *B. bigemina* for at least four years, even if kept tick free in the interim[14]. Antibodies to vaccination strains of *Anaplasma* were found to be high on ELISA even nine years after vaccination, indicating long-lasting immunity to this organism also[13]. Field evidence supports the idea that most cattle remain immune to tick fever for life following a single vaccination[6].

1.3.3 Possible reasons for lack of efficacy

As alluded to in the APVMA's "Annual Report on Adverse Experiences", the large number of doses of vaccine used annually means that the product is administered to animals in many different situations across a wide range of cattle and management systems. Not all cattle will respond to inoculation with a vaccine, the response requiring an intact and functional immune system, absence of concurrent infection that could prevent the cattle mounting a response, adequate maintenance of the vaccine in a frozen or chilled state until use, then proper mixing and delivery of the full dose of the vaccine into the body.

Problems could occur at any of the above stages, and it is understandable that when such a large number of vaccine doses are used a few cattle will be left without protection as a result of problems either with the delivery or the animal's response. The number of lack of efficacy reports for the tick fever vaccine is similar or lower to that of other vaccines used on cattle in Australia[10].

1.4 Potential for adverse outcomes from use of the live tick fever vaccine

Potentially the live tick fever vaccine could have negative effects if cattle producers are unfamiliar with the product. Of particular concern would be the failure to observe cattle after vaccination, or provide proper treatment for any cattle showing signs of clinical tick fever.

Treatment of heavily pregnant cattle, while a potential hazard, is not considered by Tick Fever Centre personnel to be a high risk event due to anecdotal and clinical feedback indicating that the incidence of complications is probably low[5].

Protection against Babesiosis is not considered to be achieved until at least two to three weeks following inoculation, while protection from Anaplasmosis may take up to eight weeks.

Farmers vaccinating because of the appearance of tick fever on their neighbour's property would also need to ensure that cattle remained clear of infestation with ticks until this period had passed. This could be achieved by quarantine, especially by placing cattle in paddocks away from neighbour's fences, regular treatment with acaricides, and regular monitoring for the presence of ticks.

It should be noted that pour-on and injectable Macrocyclic Lactones, or the Tick Development Inhibitor Fluazuron, will not prevent tick fever from occurring, despite their lack of acaricide resistance and high efficacy against ticks. This is due to the fact that larval ticks are able to transmit tick fever organisms to the cattle before they are able to ingest sufficient chemical to affect them. In tick-endemic areas this feature is seen as an advantage because use of these products does not interfere with natural immunity derived from contact with wild strains of tick fever organisms conveyed by ticks. However in NSW it could mean that efforts to control ticks, while successful at achieving that aim, would not necessarily prevent the chance of tick fever occurring.

1.5 Summary

The live tick fever vaccine in use in Australia has, over the course of its approximately one hundred year history, been associated with several problems that have tempered the obvious advantages it conveys by protecting stock from death and morbidity.

The major problems encountered have been lack of efficacy, vaccine reaction and ensuing loss of pregnancy, haemolytic anaemia and transmitting extraneous agents. These potentially dangerous reactions have been dramatically reduced over the last three decades due to research to identify protective yet harmless vaccine strains, the adoption of biosecurity and manufacturing methods that would identify contaminants and eliminate them before the vaccine was marketed, and strict adherence to an externally-audited code of manufacturing.

Other problems such as reversion to virulence and lighting up ticks, while possible to simulate under laboratory conditions, are not found to be practical problems in the field. These issues do not represent genuine risks to cattle even in places like Queensland with ideal conditions for the expression of these side effects. The small number of ticks present in Northern New South Wales makes the probability of these issues causing clinical disease very low.

2. Risks associated with not using the tick fever vaccine

The tick fever vaccine is used by many cattle producers in the tick free and protected (control) zones of QLD to protect their herds, despite the low immediate threat of their cattle contracting tick fever. The use of the vaccine is especially suitable for stud breeders, those who keep cattle of high individual value, dairy farmers, producers who frequently sell cattle into the infected zone, exporters of live cattle, and others who have a low-risk approach to biosecurity.

However this option is not open to NSW cattle producers due to the current policy of only allowing vaccination of cattle after approval of the Chief Veterinary Officer or their delegate.

In this section we investigate the risk NSW cattle producers face by not having the tick vaccine available.

2.1 Current status of Northern New South Wales cattle herd

From the viewpoint of disease spread, the cattle herd of NSW has several distinct features that differentiate it quite distinctly from the Queensland cattle herd.

2.1.1 Breeds

Accurate figures relating to the breed composition of the cattle herd in various areas are not available. However some indications of the breed prevalence can be gained.

In a report on the northern Australian beef industry, Greg Bortolussi of CSIRO Livestock Industries, Rockhampton, examines the breed composition of northern herds over a five-year period in the mid-1990s[15]. Three hundred and seventy five producers in eight regions were surveyed. The author comments that beef producers in Queensland, the Northern Territory and Western Australia used breeds that met their market aspirations. British breeds and *Bos indicus* cross were much more common in the tick-free areas of Queensland (unweighted average of two tick-free areas 23.5% versus 10.8% in six tick-endemic areas), while pure *Bos indicus* cattle dominated in the six tick-endemic areas (unweighted average 54.5% versus 16.5% in the two tick-free areas). Climatic conditions, such as rainfall and humidity, may account for some of this variation.

First hand observations support a contention that the majority of cattle in Northern New South Wales are *Bos taurus.* It is estimated that at least 50% of cattle in the part of Northern NSW conducive to tick infestation are highly susceptible *Bos taurus,* with breeds such as Hereford and Angus most common [16]. The remainder are mostly crossbred, with varying degrees of suitability as tick hosts[17].

In comparison, only 5-10% of the cattle in the tick infected zone immediately to the north of the NSW-QLD border are estimated to be *Bos taurus,* with the majority crossbred and some pure *Bos indicus* cattle[18].

2.1.2 Exposure to Tick Fever- Endemic stability

NSW Department of Primary Industries monitors the incidence of new tick incursions by surveillance at saleyards (Murwillumbah, Lismore, Casino & Grafton) notification of ticks by producers, and monitoring of cattle passing through the Casino abattoir. DPI policy is to quarantine infected properties and treat cattle until ticks are eliminated. Because of this the incidence of ticks is very low in Northern NSW.

In the last ten years there have been approximately forty to eighty reports of ticks per year in Northern New South Wales[19]. All infestations are treated rapidly and neighbouring properties are inspected for ticks. Natural exposure to tick fever organisms is consequently very low, as the rate of infection with ticks varies highly, and may be as low as 0.04% for *B. bovis* and 0.23% for *B. bigemina* [20].

Tick fever outbreaks in NSW are infrequent and sporadic, but can be accompanied by heavy losses due to the susceptible nature of the NSW cattle herd.

Sserugga et al (2003) showed that even in areas of Queensland where calves were constantly exposed to reasonably high levels of tick infestation, and 73% of farmers recalled tick fever outbreaks, the natural exposure to tick fever was not high enough to cause herd immunity, and only 26% of surveyed farms had endemic stability to all three tick fever organisms. The authors suggested that vaccination be used to increase levels of herd immunity on dairy farms[21].

2.1.3 Vaccination history

NSW DPI report a high level of interest in producers bringing cattle into NSW from Queensland[19]. There was no restriction on the entry of cattle carrying *Babesia* and *Anaplasma* into NSW with the exception of the Tick Quarantine/ Tick Protected Area of NSW. Until 2004 when restrictions on cattle entering the Cattle Tick Protected Area NSW were lifted, cattle from Queensland entering that region were treated for tick fever. Consequently, cattle imported into New South Wales from the infected zone of Queensland may carry tick fever organisms from natural exposure or tick fever vaccination. These animals will be immune to infection with *Babesia* and *Anaplasma.*

Vaccination of local cattle does not take place routinely due to regulatory limitations on the availability of tick fever vaccine, and persistent mistrust among some producers regarding the tick fever vaccine. However if a farmer plans to sell a herd of cattle across the border into Queensland they could apply for approval from the Senior Field Veterinary Officer to vaccinate the entire herd.

2.2 Tick infestations in non-endemic areas of Queensland

There are currently about one hundred and twenty cases of tick infestations per year discovered in the tick free and control zones of Queensland. It is known that at least some of these cases are from cattle imported from the infected zone that have passed through treatment and inspection at the tick line[23].

No statistics are kept of the source of infestations in the free and control zones, but possible reasons, apart from ticks surviving treatment and evading detection by tick inspectors are-
a) trucks (washoff)- 2 cases confirmed in last ten years
b) deer- free movement of deer throughout SEQ
c) illegal movements- considered to be about 1% of outbreaks or 1-2 cases/year
d) straying cattle- due to damaged fences, floods etc.
e) on dogs, peoples' clothes etc.
f) mechanical- e.g. council slasher – one case confirmed in 1980s.
g) hay- thought to be mainly confined to opportunity growers, and professional hay makers are a low risk due to no cattle in paddocks
h) truck rollovers- unknown

2.2.1 Queensland Department of Primary Industries & Fisheries recommendations

The Ramsay model was devised to enable cattle producers to decide whether it was worth the expense of using tick fever vaccine, based on the serological prevalence of antibodies to tick fever organisms[22]. An economic assessment of the benefit of using the vaccine is also provided. Producers are advised to use the tick fever vaccine if their individual circumstances (discussed above) and an economic assessment indicate they would benefit. There is no policy in place to either encourage or discourage cattle producers in the tick free zone to use the vaccine.

2.2.2 Normal practice following outbreaks in tick free zone

It is not normal practice to vaccinate for tick fever[23] following the discovery of tick infestations or outbreaks of tick fever in the free zone of Queensland. The main reason is that immunity takes at least three weeks (for *Babesia)* to eight weeks (for *Anaplasma)* to develop. Efforts are directed into treatment of cattle for eradication of ticks and treatment of affected animals with antiprotozoals rather than to tick fever prevention.

2.2.3 Availability of vaccine

In the tick free zone of Queensland the use of tick fever vaccine is placed at the discretion of the cattle owners[23]. Those who market cattle into the tick zone for fattening or as stud animals are likely to use tick fever vaccine routinely on their calves at marking. Some cattle producers use tick fever vaccine to protect their herd from the potential of an outbreak of tick fever.

Producers can assess the risk of natural exposure based on the genetic makeup of their herd, historical data, or prevailing conditions of temperature, rainfall and proximity of tick-infested herds. They can order vaccine directly from the Tick Fever Centre or through local retailers or veterinary clinics. Approximately 800,000 doses per year of tick fever vaccine are used throughout Northern Australia.

2.3 Policy of New South Wales Department of Primary Industries

NSW has restricted access to tick fever vaccine, mainly as a response to public opinion. The history of tick fever vaccine regulation in NSW is detailed in a report to NSW DPI by Garry West (2005)[24].

2.3.1 Current NSW policies on tick fever vaccine

Use of the tick fever vaccine in NSW is regulated by the *Stock Diseases (General) Regulation 2004.* Section 58 states:
(4) The person may communicate the disease in the course of vaccinating stock with tick fever vaccine but only if:
(a) the stock is intended for export, and
(b) vaccination is carried out with the prior approval of an authorised officer for each animal to be vaccinated, and
(c) vaccination is carried out elsewhere than in:
(i) a cattle tick quarantine area, or
(ii) a tick fever protected area, and
(d) vaccinated stock is not permitted to enter:
(i) a cattle tick quarantine area, or
(ii) a tick fever protected area, and

(e) all stock to be vaccinated is, at the time of vaccination, individually identified in a manner approved by the authorised officer.

2.3.2 Changes in NSW DPI policies

For many years various recommendations have been suggested to allow the transfer of responsibility for tick control from the NSW government to producers' hands. In 1983 one proposal was for producers to be provided with tick fever vaccine and acaricides for them to treat cattle as they saw fit. This was met with vigorous opposition from farmers in Northern NSW[24].

The issue was addressed by the Cattle Tick Advisory Committee (CTAC) in 2000, who saw benefits in allowing tick fever vaccination if the risks of reversion to virulence could be allayed. CTAC and the Board of Tick Control suggested liberalisation of the tick fever vaccine in 2001 and 2002, with further minority opposition, and in 2005 the Board of Tick Control went as far as to recommend use of vaccine in the face of an outbreak as "an option for the producer". The final decision as to the appropriateness of vaccine use adjacent to an outbreak is to be left to the Chief Veterinary Officer of NSW.

2.3.3 Discussion

West (2005) comments in his report that the issue of tick fever vaccine use was contentious, due to mistrust among NSW farmers[24].

Keeping the tick fever vaccine out of the hands of NSW producers appears to be a moot point, as since 2004 cattle have been imported into NSW from the infected, control or free zones of Queensland without having been sterilised of tick fever infection. This means that there already exists a cohort of tick fever-positive cattle within NSW.

Use of the tick fever vaccine on individual farms to protect cattle, particularly dairy cattle, against potential outbreaks of tick fever would not de-stabilise the current situation. De-stabilisation has already occurred since 2004 due to the importation of cattle from Queensland that carry the tick fever organisms.

Rather, it could be said that since the theoretical dangers of reversion to virulence and "lighting up" local tick populations are remote or negligible when examined scientifically, the real effect of vaccination would be to enhance the overall immunity of the herd and contribute to a degree of protection against tick fever even for unvaccinated animals.

2.4 Tools available for Northern New South Wales cattle producers to protect their herds against ticks and tick fever

Despite drier than normal conditions over much of NSW and Queensland in the last five years ticks continue to infest cattle in NSW and make frequent incursions into NSW farms.

2.4.1 Resistant breeds of cattle

As noted by Bortoslussi[15], other factors being equal, beef producers in non-ticky country tend to choose breeds of cattle that are less resistant to ticks. NSW beef producers could take advantage of innately tick resistant breeds of cattle, as has been done in the tick-infected zones of Queensland, the Northern Territory and Western Australia. The use of genetic selection, including identification of desirable traits with gene markers and crossbreeding programs, have greatly enhanced the productivity of these tropical breeds over the last few decades.

2.4.2 Vaccines

If tick fever vaccine were available, a proportion of farmers who wished to insure against large losses due to tick fever in their herd could vaccinate either the entire herd, or just vaccinate calves and build up an immune herd over time. If calves were vaccinated between the age of three and nine months, the rate of tick fever vaccine reaction is very low. Given that the average age of cows at turnoff on dairy farms is approximately six years of age, most of the herd would be immune within a five year period.

Alternatively the entire herd, including older cattle, could be vaccinated all at once. Label recommendations include avoiding vaccination of pregnant females, so for a year-round calving herd, cows would need to be grouped together and vaccinated during the early part of the lactation. Given the extremely low rate of complications or side effects reported following use of the tick fever vaccine in recent years, this would be a genuine option for those who wished to have a rapid onset of herd immunity.

The TickGARD vaccine, developed by CSIRO and Biotech Australia and marketed in northern states and territories from 1995 to 2005 is no longer available. This subunit vaccine used an antigen, Bm86, directed at the tick's gut cells to decrease tick numbers by direct effect on the ticks and by decreasing their reproductive potential. It was used by mainly dairy farmers as a means of controlling tick numbers, but the lack of suitable manufacturing facilities led to its recent withdrawal[25].

2.4.3 Anti-protozoal agents

Babesicides such as Imidocarb (Imizol- Schering-Plough Animal Health, Imidox Injection-Parnell Laboratories) can be used to treat Babesiosis and Anaplasmosis, and are very effective at preventing loss if used in the early stage of infection. Injectable oxytetracycline can be used to treat cases of Anaplasmosis. Both of these drugs are available from veterinary practitioners.

Imizol has a long persistence in the body, and producers need to be aware of residue implications. A permit has been granted by the APVMA to allow the use of this drug in lactating dairy cows as long as a 14 day withholding period is observed[10]. Oxytetracyclines have a milk withholding period of 3 to 7 days, and a meat withholding period of 14 to 42 days, depending on the formulation selected[26].

Current permit (APVMA permit no. 7333) restrictions on Imidocarb stipulate that in Queensland, only clinically affected animals are to be treated, only at the therapeutic rate of 1.0mL per 100kg bodyweight rather than the sterilisation rate of 2.5mL/100kg, and milk must be withheld for fourteen days following treatment[27].

These options are only suitable for treating individual dairy cattle, and for whole herd protection other measures should be used.

2.4.4 Chemical acaricides

Dips have been used for many years in Northern NSW to treat dairy and beef cattle for ticks. Starting with arsenicals, then using DDT, and moving on to synthetic pyrethroids and organophosphates, the most common dip used today is amitraz. This is also the chemical used for knockdown of ticks at border crossings and tick line inspection points.

The major disadvantage of relying on chemical acaricides is the rapid development of resistance by ticks. The average time from introduction to resistance being detected, or the chemical being withdrawn from the market is just 7.5 years[28]. Recent findings have shown that the distribution of amitraz-resistant ticks is spreading, and the extent of this resistance will be quantified by surveys currently underway[29].

The ongoing rise in resistance to amitraz is likely to result in greater risk of ticks crossing the border in consignments of cattle destined either for slaughter or rearing in NSW.

2.4.5 Quarantine

Provisions for quarantine, either by restricting movement of cattle from a farm, preventing the use of paddocks adjacent an infected premise, or simply by the use of specific Vendor Declarations to notify buyers of the tick status of a property are currently widely used in NSW.

Farmers may voluntarily use quarantine measures at their own discretion, especially with regard to spelling or cropping paddocks near a neighbours property, treating all cattle with a tickicidal treatment on entry to the farm, destocking, or avoiding buying in cattle.

2.4.6 Tick knowledge

Cattle producers can use knowledge of the life cycle and biology of the tick to implement control measures specific to their own farm. Awareness of tick issues appears to be much higher among professional farmers than among small landholders who may just keep a few cattle as a hobby and to keep the grass in the paddocks down. This issue is addressed in Section 4 (below).

2.4.7 Integrated Pest Management

Combining several different measures for pest control in a given production system is known as Integrated Pest Management or IPM. In many cases the major motivation is to decrease the amount of chemical used, and subsequently to decrease the risk of chemical resistance occurring[30]. This approach to tick control is more appropriate to endemic situations. In NSW the commitment to eradication precludes strategies that tolerate any level of tick burden on cattle.

2.5 Summary

Despite tick fever vaccine being freely available to cattle producers in Queensland, and its use left to the individual herd owners' discretion, there have been no reports of tick fever outbreaks resulting from either improper or legitimate use of the vaccine. This provides some evidence to show that reversion to virulence or "lighting up" ticks would not occur if tick fever vaccine were used in NSW. Conclusive proof that these events would not occur however is very difficult to generate.

Northern coastal New South Wales, from an epidemiological viewpoint, provides a pool of cattle that are mostly highly susceptible to ticks. Further, because few have been vaccinated and there is no natural exposure, also highly susceptible to tick fever. The sudden introduction of large numbers of ticks could result in high mortalities due to this.

NSW cattle producers have some tools to prevent either ticks or tick fever causing economic and welfare consequences to their operations. The primary protection is quarantine measures, which have resulted in a low risk of ticks establishing from endemic areas. Use of acaricides has been successful in reducing tick numbers within NSW. If ticks were to become common, then the use of tick-resistant cattle, and Integrated Pest Management could become necessary.

Given the current low rate of tick fever outbreaks and the NSW government policy of eradicating ticks whenever they are detected, NSW cattle producers do not face high risks if they continue to have no access to the vaccine.

3. Value of vaccination in risk areas of New South Wales as a management option

Dairy producers in areas of NSW that frequently experience tick incursions would be the greatest beneficiaries of increased availability of tick fever vaccine. There are also tangible benefits for some beef cattle producers.

3.1 Risk for cattle producers in New South Wales

Farmers exposed to risk of tick fever outbreak due to the presence of ticks in adjacent areas have a risk of losing valuable cattle due to tick fever. Use of Imidocarb to protect cattle has limited application, especially for dairy farmers due to the expense of treatment and withholding milk from human consumption, and the fact that it can't be used to protect all animals.

Inspection and treatment for ticks also has limited usefulness, as the long-acting acaricides have a period when they allow larval attachment and feeding prior to the tick being killed. This means that these have limited scope for protection against tick fever. Short acting acaricides, such as amitraz, also have limited use in susceptible cattle, as the persistence of the chemical on the hide of cattle is very short (1-2 days), meaning that larval ticks will attach to the cattle and begin feeding within a week of treatment.

A practical means of establishing a protected herd in NSW could be to introduce stock that had already been vaccinated with tick fever vaccine from Queensland. Due to the adoption of Standard Definitions and Rules this would be a simple procedure, especially if cattle were brought in from the free zone of Queensland. In fact, a herd of cattle could be trucked across the border, vaccinated, then transported back into NSW. This would be legal, yet would circumvent the current restriction on sale of the tick fever vaccine in NSW.

3.2 How can the vaccine help?

Use of the tick fever vaccine would allow cattle producers to protect their herd against tick fever, and prevent the major economic effects of a tick fever outbreak. It would also enable stud cattle breeders or other producers to sell cattle into Queensland to vaccinate their calves at the most appropriate age, when side effects are lowest, rather than waiting until sale is confirmed before using vaccine.

3.3 How should vaccine be made available?

A practical means of making tick fever vaccine available in NSW is to restrict supply to private veterinary practitioners, or through the Rural Lands Protection Board veterinarians. The advantage is that diagnostic services, as well as design of vaccination programs, supply of babesicides and antibiotics and supportive treatment for sick animals could all be obtained from the same source as the vaccine.

Another option would be to make the vaccine available on order from rural retailers such as Landmark, CRT and Elders stores. A third possibility would be for farmers to be able to contact and order the tick fever vaccine themselves from the Tick Fever Centre at Wacol. All three options are available to cattle producers in other parts of Northern Australia.

3.4 Extension and promotion program

Any change in the policy of tick fever vaccine restriction in NSW would need to be accompanied by a widespread education campaign aimed at livestock producers.

Current efforts by NSW DPI to educate farmers are aimed at providing basic information on tick identification and raising awareness of tick control. The Rural Lands Protection Board play little role in tick awareness programs, despite their activities in other areas of livestock health and welfare[31].

If tick fever vaccine were to be made available through veterinary practices these should also have extension material available, so that relevant information on correct use of the vaccine is available at the point of sale.

3.5 Summary

The risks associated with vaccination, outlined above, are small and unlikely to occur. In contrast, the risk of tick fever outbreak in a susceptible herd adjacent to a tick incursion is real, and the consequences could be devastating.

The current incidence of tick fever outbreaks, involving at most several dozen cattle, does not warrant widespread vaccination programs to protect cattle. This is especially true if the NSW DPI continue to oversee and support eradication of ticks in the area. Free access to the tick fever vaccine would also enable greater market flexibility to cattle producers such as stud breeders who market cattle into the tick-infected zone.

4. Risks posed to tick management by the recent increase in small landholder community in Northern New South Wales

In places such as the Tweed Valley, Byron Bay hinterland, Wollongbar, Alstonville and the periphery of large towns such as Lismore and Casino, many properties that were formerly commercial dairy or beef farms have been sold as ten or twenty acre blocks that are used as “lifestyle blocks” by people who work elsewhere or have retired.

4.1 Awareness of tick fever, quarantine and control options among small landholders

Recent reports of tick infestations of cattle in NSW have drawn attention to the lack of awareness of ticks and tick fever among people who are not commercial farmers[24]. Since the actual level of awareness of ticks and tick fever among small landowners in Northern NSW is unknown, a survey to determine if the knowledge of ticks in this group of landholders could be conducted. Until that time any comment, however valid, on the role of small land owners is based on anecdote or personal opinion.

4.2 Extension by Rural Lands Protection Board

Through their newsletters and monitoring activities the Rural Lands Protection Board (RLPB) provide information on animal health and welfare issues, as well as broader issues such as pest control to landowners in Northern NSW[31]. Should the need arise, the RLPB could piggyback tick extension activities onto their existing programs with very few extra resources.

4.3 Licensing system for livestock owners

A suggestion to improve the compliance with quarantine and awareness of tick control issues is to enforce the licensing of all livestock owners. This could be based on the system in Queensland, where the presence of even a single ruminant requires the owner to register the property. Livestock owners could then be targeted with extension material to increase their awareness of ticks and tick fever, regardless of whether they were career farmers or small landholders.

5. Discussion

It has been shown that the most effective measure of preventing tick fever infections in high risk areas of Australia such as coastal Queensland is the use of the tick fever vaccine. Due to the low number of outbreaks of tick fever in NSW at present the need for this vaccine is not pressing. However the likely presence of tick fever organism-carrying cattle already in NSW means that the policy of restricting vaccine availability is largely redundant. There appears to be no cogent scientific argument why producers wishing to have access to the vaccine for their farm biosecurity programs should not have it made available.

Some cattle producers, particularly those who have lived through times of hardship caused by ticks, and who have supported tick eradication in Northern NSW for many years, are suspicious of attempts to liberalise supply of tick fever vaccine into NSW. Their attitude could be summed up as a suspicion that vaccine use is the “foot in the door” for NSW to abandon the policy of tick eradication, and implement a strategy of “endemic stability”[16].

Free access to the tick fever vaccine in NSW would pose negligible risk to the susceptible herd of cattle in NSW, and would probably have a beneficial effect by helping to improve the overall immunity and therefore decrease the probability of an outbreak. It would also benefit producers by opening up markets for them across the border in tick infected zones of Queensland.

Part 2

Quantitative risk assessment of the possibility of cattle ticks being spread if tick-positive cattle were permitted to travel from Queensland infected and protected zones direct to slaughter in New South Wales

1. Introduction

The cattle tick, *Boophilus microplus*, is distributed around the northern coastal areas of Australia as far south as the Queensland and NSW border, where it is held by quarantine boundary at an annual cost of $7m to the NSW government, in addition to grower costs (White et al. 2003).

Presently cattle in northern herds have a low natural immunity to the disease as a result of low tick numbers. Surveys (West, 2005) have indicated that outbreaks of tick fever in NSW were common up until 1968, with an average of 10 outbreaks per year. Since the 1970's outbreaks have only occurred every few years. Vaccines have been developed in order to control the disease in Northern Australia.

The primary objective of this risk assessment was to address the recommendations that were raised in the previous report for NSW DPI (West, 2005), specifically to assess the risk of cattle ticks being spread if untreated livestock were permitted to travel from Queensland cattle tick infected and protected areas direct to slaughter in NSW.

To achieve this we required a more precise characterisation of risk factors for cattle ticks being spread if untreated cattle travel from QLD into NSW. A literature search was conducted and experts were interviewed on the probability and severity of an outbreak of tick infestation as a result of cattle importation from QLD. To demonstrate the risk associated with cattle importation, a scenario tree for the risk was developed showing the pathway of introducing cattle from a range of environments in QLD into NSW abattoirs. The scenario tree was constructed for the risk associated with the entry and release of ticks:

- Probability of the source property being tick positive
- Probability of a tick positive consignment being transported into NSW
- Probability of ticks dropped during the transport

- Probability of ticks spread from the abattoir environment (holding yard, abattoir and hide retention) in NSW

The findings of this risk assessment will assist the NSW Government to make appropriate decisions in relation to the following:

- Abolish or maintain the current requirement for the importation of cattle from the protected and infected zones of QLD,
- Confirm if the recent tick fever outbreaks in NSW are related to the importation of cattle from QLD, and
- Inform cattle producers of the likelihood of risk associated with cattle importation from QLD

1.1. Distribution of Queensland cattle tick zones, number of cattle exported and location of concessional abattoirs in NSW

To enable us to develop the risk model, historical data were used to estimate the total number of cattle from a range of environments and production systems in QLD and the risk of carrying ticks into NSW. The source of cattle imported into NSW is the three cattle tick zones in QLD (Figure 1). The size, cattle population, tick infestation rate, climate and feeding management vary between these zones. Therefore, a different data set was used in the risk model for the protected and infected zones.

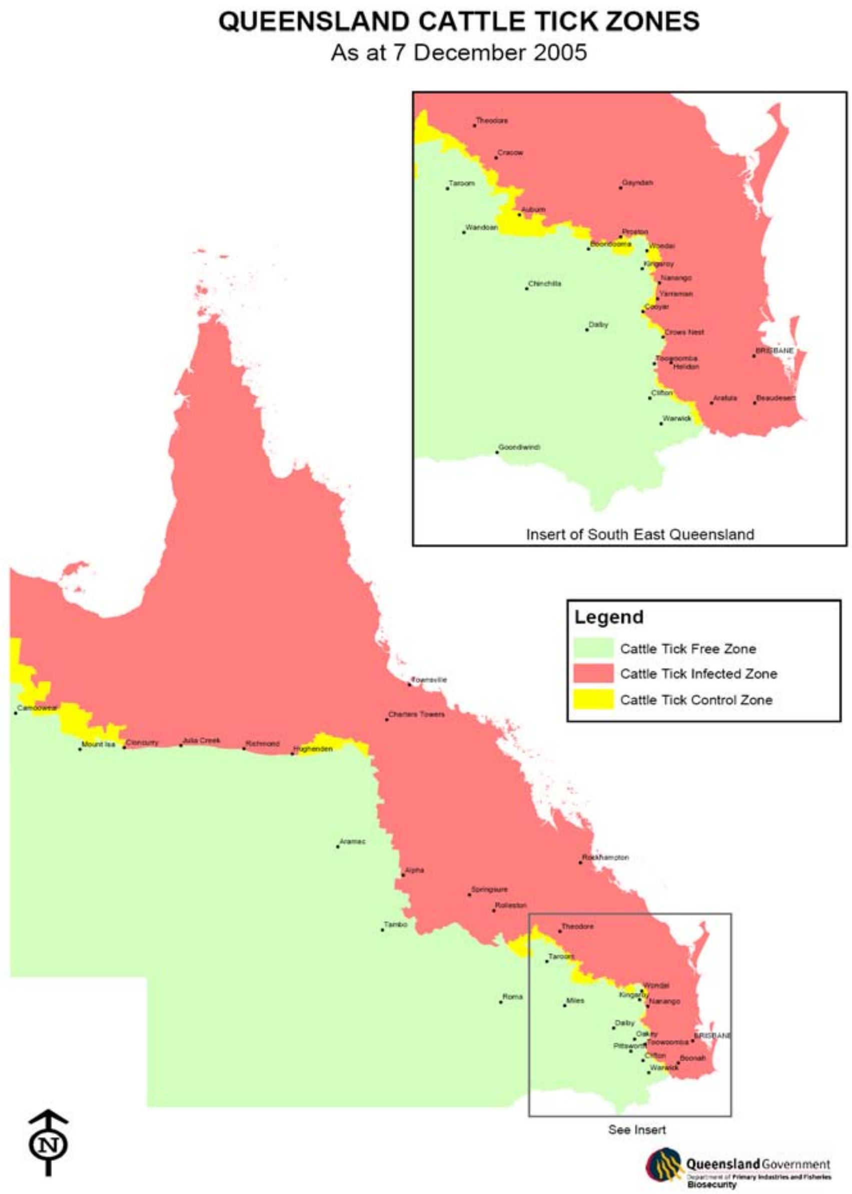


Figure 1. Queensland cattle tick zones

The total number of cattle transported from QLD properties into NSW abattoirs from July 2002 to June 2003 is shown in Table 1. These data show that more than 78% of cattle are from the free zone, and the remaining cattle are from the infected (2%) and protected zones (20%).

Table 1. Number of cattle transported from different zones of QLD into NSW from July 2002 to June 2003

Areas in QLD	Total number cattle	No of consignments
Free zone	110,451 (78)%	1869 (78%)
Infected zone	2,489 (2%)	43 (2%)
Protected zone	28,207 (20%)	478 (20%)
Total	**113,223 (100%)**	**2390 (100%)**

These cattle have been transported directly into commercial abattoirs throughout NSW (Appendix I). Table 2 shows the total number of cattle transported into nine concessional abattoirs in NSW. The locations of these abattoirs are shown in Figure 2.

Table 2. Number of cattle slaughtered in nine concessional abattoirs in NSW from July 2002 to June 2003

Destination abattoir in NSW	Total no of cattle	No of consignments
Free zone		
Casino	38,900 (35.2%)	970 (51.9%)
Cooma	192 (0.2%)	5 (0.3)
Grafton	4,448 (4%)	63 (3.4%)
Inverell	30,540 (27.7%)	342 (18.3)
Scone	636 (0.6%)	17 (0.9%)
Singleton	7,728 (7%)	96 (5.1)
Tamworth	13,900 (12.6%)	197 (10.5%)
Wagga	2,700 (2.4%)	36 (1.9%)
Wingham	4,159 (3.8%)	37 (2%)
Infected zone		
Casino	1,430 (57.5%)	30 (68.9%)
Grafton	612 (24.6)	6 (14%)
Inverell	301 (12.1%)	4 (9.3)
Wingham	66 (2.7)	1 (2.3%)
Protected zone		
Casino	11,120 (39.4%)	231 (48.3%)
Cooma	50 (0.2%)	2 (0.4%)
Grafton	10,512 (37.3%)	134 (28%)
Inverell	4,620 (16.4%)	77 (16.1)
Singleton	982 (3.5%)	14 (2.9%)
Tamworth	213 (0.8%)	4 (0.8%)
Wagga	138 (0.5%)	3 (0.6%)
Wingham	340 (1.2%)	7 (1.5%)

❶Cargil Meats, Wagga Wagga
❷Bindaree Beef, Inverell
❸Wingham Beef Export, Wingham
❹Northern Coop Meat, Casino
❺Ramsey Wholesale Meats, South Grafton
❻Cargil Meat, Tamworth
❼MonBeef, Cooma
❽EC Throsby, Singleton
❾Primo Meats, Scone

Figure 2. Location of nine concessional abattoirs in NSW

2. Quantitative risk assessment

2.1. Historical data on number of cattle, prevalence and distributions

To enable us to assess the risk of cattle tick spread in NSW, historical data on the number of cattle transported between July 2002 and June 2003, and the probability of cattle carrying ticks were used to quantify the risk of a tick positive consignment of cattle entering into NSW.

Quantitative data were not always available to support estimation of some of the probabilities assigned to the pathway steps considered in this analysis. Likelihoods assigned to these steps were subsequently based on expert opinion. Scientists and experts in the field of cattle ticks at QLD Department of Primary Industries and University of QLD were interviewed to collate data on the probability of tick distribution and survival in different environments (routes) during the transport to abattoirs in NSW.

There is limited information on the number of cattle transported interstate since 2003. Our survey and interviews with experts and industry showed that the total number of cattle imported from the free and protected zone remained unchanged during recent years (similar to the numbers for 2002-2003) but the size of the protected zone has been markedly reduced and some of the properties in the protected zone have moved into the free zone. However, it is anticipated that the number of cattle imported from the infected zone into NSW may increase if compulsory treatment or inspection are lifted. **For the purpose of this assessment, the risk of cattle carrying ticks into NSW was estimated for both situations if the requirement for treatment and inspection are met, and when these are lifted.**

There are also limited data on the number of cattle transported to the designated abattoirs in NSW since 2003. The data provided by NSW DPI indicates that the majority of cattle transported from the infected zone of QLD into NSW have been slaughtered in Casino, whereas other abattoirs prefer to source cattle from the protected and control zones.

2.2 Concessional abattoirs in New South Wales

The nine concessional abattoirs mentioned above are permitted to import cattle from Infected and Control (Protected) zones of QLD direct to slaughter, subject to the following conditions:

a) Consignments of cattle are either treated with an acaricide and visually inspected before entry into NSW, or alternatively are given a full inspection for ticks by palpation (without treatment).

b) Quarantine area- concrete pens with washdown draining to ponding systems so female ticks will die.
c) Animals held 3 days maximum in NSW.
d) DPI informed if any changes to protocol.
e) Audited once every 2 years
f) Until 2003 requirement was same as for transport to Free Zone of QLD- dip and inspection prior to transport.
g) Approved feedlots (within the Infected or Protected Zones) are exempt from the treatment requirements

2.3 Approved feedlots

About eighty approved feedlots in the Infected Zone of Queensland can send cattle directly to slaughter in the Free Zone (or NSW) due to the specifications of the feedlot. Key features are:
a) buffer zones of 10m around pens where cattle are kept (no stock allowed in this area), and
b) cattle must be in the feedlot for 35 days before they are eligible.

These conditions are based on unpublished research performed by QDPI in Beaudesert in 1993-1994 (Malcolm McLeod, QDPI&F, Kingaroy, pers. comm..)

2.4 Standard Definitions & Rules for Cattle Tick Control in Australia

The terms and conditions relating to zones for control of cattle ticks are detailed in a document prepared by the four Australian states that have cattle ticks (Western Australia, the Northern Territory, Queensland and New South Wales). Refer to Dunn et al (2000).

3. Risk model structure- Precision Tree Model

A scenario tree was constructed to show the pathway of introducing cattle from a range of environments and production systems in QLD into NSW abattoirs. Subsequently, this pathway was used to develop the risk model and calculate the probability of risk exposure and risk release using @Risk (Palisade, 2005).

This risk analysis comprised two components:

(1) **Entry** – the probability that a consignment of cattle entering NSW from Queensland contains at least one tick-positive beast; and
(2) **Release** – the probability that ticks from a tick-positive consignment are released into the NSW environment.

A third component, considered briefly in this report, is the probability of tick survival, following release.

The steps that have to be processed for cattle transported into NSW differed according to the zone of origin of stock:

1. Protected zone: Cattle from the protected zone are required to be treated, inspected and treated again at the property or “clearing facility centres” before being loaded on the truck and transported into NSW.

2. Infected zone: Cattle from the infected zone are required to primarily be treated by the owner, inspected and treated again at the “tick line facility centre” before being loaded on the truck and transported into NSW.

The aim of this analysis was to calculate the probability that tick(s) will be released into NSW following the importation of a tick positive consignment of cattle.

The distribution of ticks throughout NSW, if it were to occur, will be related to how imported cattle are handled during the transport and also quarantine facilities in the designated abattoirs. These have an important effect on the risk of introduction of ticks into NSW because some of the factors at these steps can cause the spread of ticks, if tick positive cattle are imported. Thus the major points that are expected to be the risk points in this analysis are where cattle are transported across the border into NSW (routes) and designated abattoirs in the Northeast of NSW. This technique of modelling is used for each zone separately, and then summing the probabilities for each region is used in each of the subsequent major areas of the model.

3.1. Risk assessment model

The quantitative model provided the following four important technical facilities:

- A framework upon which to base the logical structure of each assessment
- Evaluation of the effect of the number of cattle imported each year
- Accommodation of uncertainty in the likelihood estimate assigned to individual steps in pathways, and
- Use of sensitivity analysis to identify steps in each scenario, and thus focus information needs and where relevant, risk management

Quantitative data on a probability, or on estimate of other numeric quantities such as number of cattle imported, were modelled either as a point estimate or, more commonly as a distribution. The shape and parameters of these distributions depend on the nature of the variable being modelled and the completeness of available data.

3.1.1. Entry scenario

The pathway or ordered sequence of steps undertaken in sourcing, processing and exporting cattle up to the point where tick positive consignments of cattle enter NSW is termed the "entry scenario." The initiation step for the entry scenario is the sourcing of cattle from properties in QLD, whereas the endpoint is the arrival of a tick-positive consignment of cattle at the NSW border.

The steps of the entry scenario are summarised below (Figure 3).

- Entry step 1 (Entry 1): Ticks are present on the source property or farm
- Entry step 2 (Entry 2): Selected cattle for importation are tick positive
- Entry step 3 (Entry 3): Tick positive cattle remain in the consignment following routine processing (treatment) at the property of origin (cattle sourced from protected and infected zones only)
- Entry step 4 (Entry 4): Tick positive cattle remain in the consignment following Tick Line inspection and subsequent treatment (cattle sourced from protected and infected zones only)
- Entry step 5 (Entry 5): Tick positive cattle remain in the consignment during transportation

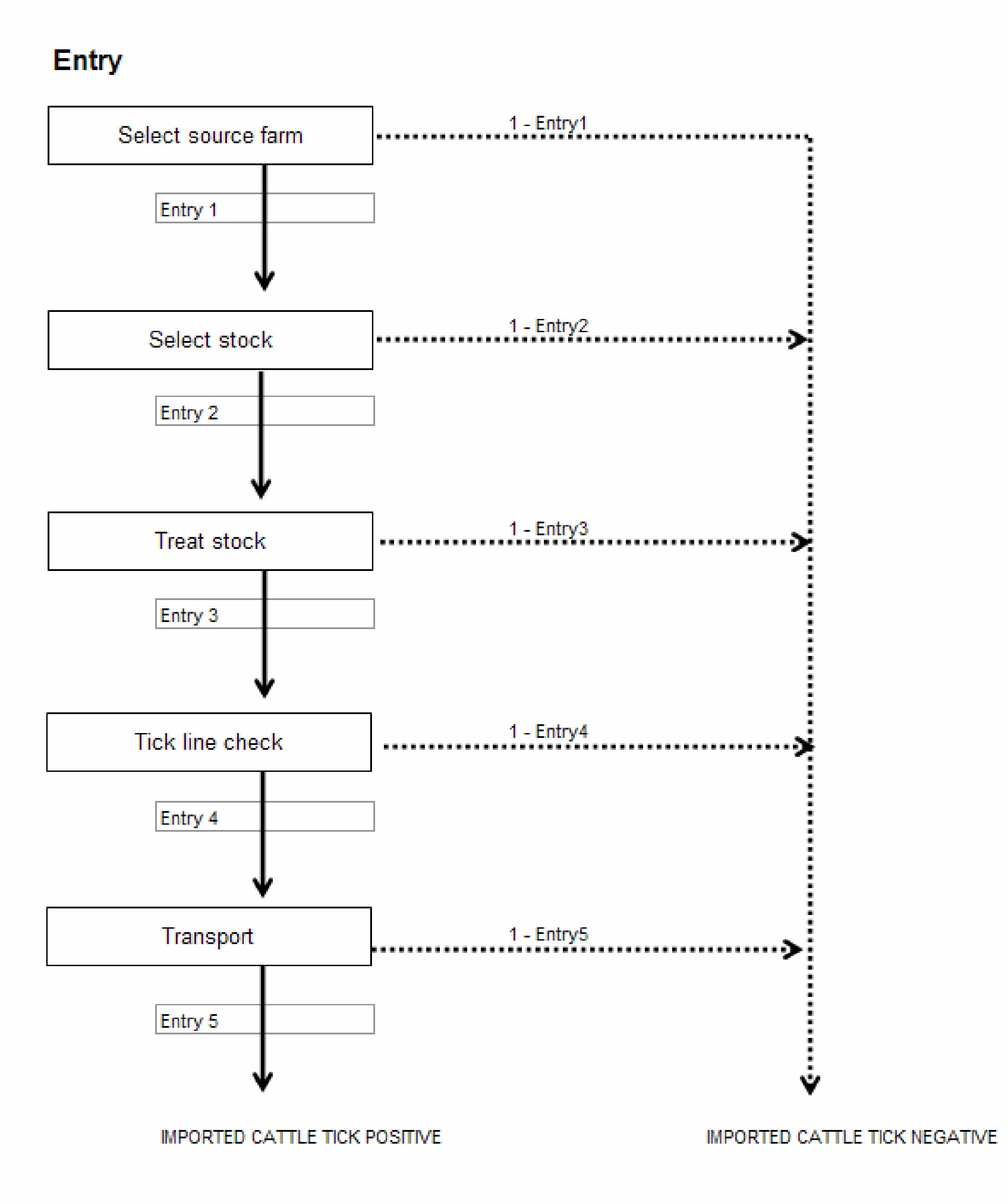


Figure 3: Entry scenario for cattle imported from QLD properties

Entry step 1 (Entry 1)

The likelihood assigned to the first entry step presented the prevalence of farms or properties in QLD that are tick positive. The prevalence of infested properties was estimated largely by the zone that property is located in. This likelihood was dictated largely by breed of cattle, climate and environment, farm management and tick epidemiology. In most cases, these factors interrelated and, as a result, there are areas within QLD within which the prevalence of infestation is higher (infected zone) and areas within which prevalence is low (protected zone), and some cases, in which ticks are known to be absent (unrestricted properties in free zone and approved feedlot properties).

Entry step 2 (Entry 2)

The likelihood assigned to the second entry step represented various factors that determine the prevalence of infestation amongst selected cattle from various properties. It was approached in each risk assessment systemically by considering the following questions where information was available.

- How likely is infestation of cattle at the time of selection?
- How likely is infestation on an individual herd within an infested property?
- How likely is it that tick positive cattle are selected from a herd for export?

Entry step 3 (Entry 3)

The likelihood assigned to the third entry step represented the ability of a tick to survive on cattle after routine processing (treatments, e.g. dip, pour on, etc.). This likelihood was dictated largely by whether the treatment is efficient, whether tick susceptibility is reduced (resistance issue), procedures used for treatment (e.g. dip versus pour on) and breed of cattle.

Entry step 4 (Entry 4)

The likelihood assigned to the fourth entry step represented factors relevant to the ability of tick-positive cattle to remain after inspection and subsequent treatment procedures (Tick Line). This step is also affected by the vigorousness of inspection and again susceptibility of ticks to different type of treatments at Tick Line facilities (including chemical resistance issues).

Entry step 5 (Entry 5)

The final step in the entry scenario represents the likelihood that a consignment of cattle entering NSW contains at least one tick positive beast. This step is influenced by the efficacy of treatment and those factors that have been described in previous steps.

Projected number of cattle exported into NSW

The number of cattle that might be imported from QLD if importation was to proceed for a prescribed period with or without routine treatment and inspection procedures (Tick Line) is an important factor in estimating the probability of exposure. The source of cattle (zone) is also an important factor in estimating the probability of exposure, as the climate and environment, infestation rate vary between these zones. The genetics of cattle imported can also affect the prevalence of tick exposure, as the number of ticks (infestation rate) vary between different breeds of cattle.

Table 3. Probabilities of tick positive cattle imported (exposed) from protected zone of QLD into NSW

	Input data – Protected zone Entry	**Min**	**Median**	**Max**
Entry 1	Probability that the source farm is tick positive	0.035	0.18	0.99
Entry 2	Probability that cattle selected for export are tick positive	0.007	0.088	0.99
Entry 3	Probability that tick positive cattle are present after treatment	0.001	0.05	0.15
Entry 4	Probability that tick positive cattle are present after Tick Line check	0.0001	0.003	0.01
Entry 5	Probability that tick positive cattle are present after transport	0.000075	0.0029	0.0099
nCAT	Number of cattle per consignment	5	48	120
nCON	Number of consignments per year	46	231	1155
nBt	Number *B. taurus* imported	22	4435	55440
nBi	Number *B. indicus* imported	81	3881	48510
nBtBi	Number *B. taurus* x *B. indicus* imported	288	13860	173250
ntBt	Number of ticks on *B. taurus*	7	72	232
ntBi	Number of ticks on *B. indicus*	0	1	5
ntBtBi	Number of ticks on *B. taurus* x *B. indicus*	3	17	32

Table 4. Probabilities of tick positive cattle imported (exposed) from infected zone of QLD into NSW

	Input data – Infected zone Entry	**Min**	**Median**	**Max**
Entry 1	Probability that the source farm is tick positive	0.5	0.72	0.99
Entry 2	Probability that cattle selected for export are tick positive	0.1	0.36	0.99
Entry 3	Probability that tick positive cattle are present after treatment	0.001	0.05	0.15
Entry 4	Probability that tick positive cattle are present after Tick Line check	0.0001	0.003	0.01
Entry 5	Probability that tick positive cattle are present after transport	0.000075	0.0029	0.0099
nCAT	Number of cattle per consignment	5	76	120
nCON	Number of consignments per year	34	170	850
nBt	Number *B. taurus* imported	17	1292	10200
nBi	Number *B. indicus* imported	119	9044	71400
nBtBi	Number *B. taurus* x *B. indicus* imported	205	15504	122400
ntBt	Number of ticks on *B. taurus*	14	144	465
ntBi	Number of ticks on *B. indicus*	0	3	10
ntBtBi	Number of ticks on *B. taurus* x *B. indicus*	7	34	65

Calculating the probability of entry (importation)

Calculations focused on the proportion of imported consignments that were tick positive. From this, and from an analysis of the projected number of cattle imported into NSW, the expected number of tick positive cattle was calculated.

The probability of entry (importation) was an estimate derived from a simulation of the probabilities at each step in the entry (importation) scenario (Figure 3). The calculation was based on the probability that imported cattle have been tick positive. If it can be assumed that the infestation status of individual cattle is largely independent of other cattle, then this will approximate the proportion of imported cattle that are infested.

The Pert distribution which has three parameters (minimum, most likely and maximum values) was used for the distributions of probabilities of the entry and release scenarios (except for Release scenario 1; see Figure 6). The main advantage of Pert distribution is that it allows values that are considered more likely to occur to be modelled as such. Risk estimates for each of the 2000 simulations were tabulated and results presented as the median risk estimate and its 95% confidence interval.

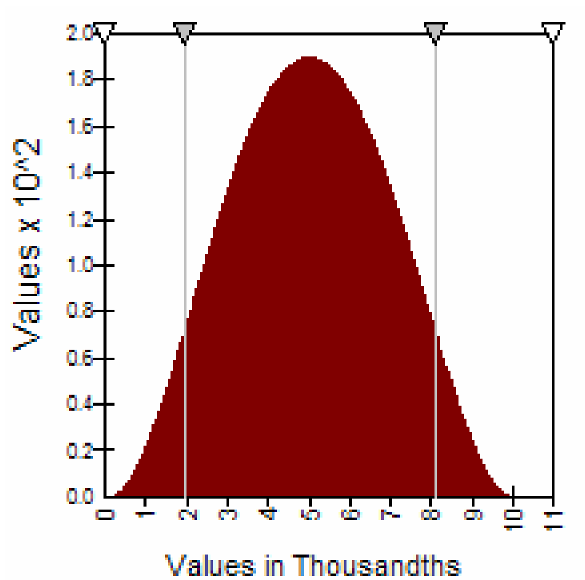


Figure 4. Pert distribution

The number of ticks entering NSW was estimated based on: (1) the number of cattle in a consignment; (2) the proportion of the consignment that are carrying ticks; and (3) the breed composition of the consignment.

Details of the calculations to determine the number of tick positive cattle that might enter NSW following treatment and Tick Line check and transport are provided in Appendix II. This table shows that the probability of importation was derived from probabilities attributed to 5 individual pathways. These pathways, numbered 1 to 5, were obtained from an analysis of the exposure scenario in Figure 3. The overall probability that imported cattle were infested was the sum of the probabilities associated with each individual pathway.

Details of the probability components for entry are provided in Appendix II.

3.1.2. Release scenario

Probability of tick release

The aim of this part of the risk analysis was to identify and quantify the probability of ticks being released into NSW following the entry of a tick positive consignment of cattle into the state. The pathways of distribution of cattle in NSW are shown in Figure 5. There are five key points at which ticks may be released are as follows: (1) during transportation of cattle from the Queensland border to a receiving abattoir, (2) during unloading and cleaning of trucks in holding yards, and (3) during stay in holding yard, (4) slaughter in the abattoir and (5) up to the point where hides are processed.

Definitions for each component of the release scenario are summarised below (Figure 5).

- Probability of release 1 (Rel 1): the probability that ticks released from a truck en route to abattoir
- Probability of release2 (Rel 2): the probability that ticks are released via truck washout following unloading at abattoir
- Probability of release3 (Rel 3): the probability that ticks are released from the abattoir holding yard
- Probability of release 4 (Rel 4): the probability that ticks are released via effluent from abattoir
- Probability of release 5 (Rel 5): the probability that ticks are released via hides post slaughter

The model structure has accounted for exposure occurring via one or more of these pathways. For example, from a single consignment ticks may be released by escaping from a truck en route to the abattoir *and* escape during truck washout and escape of ticks from hides.

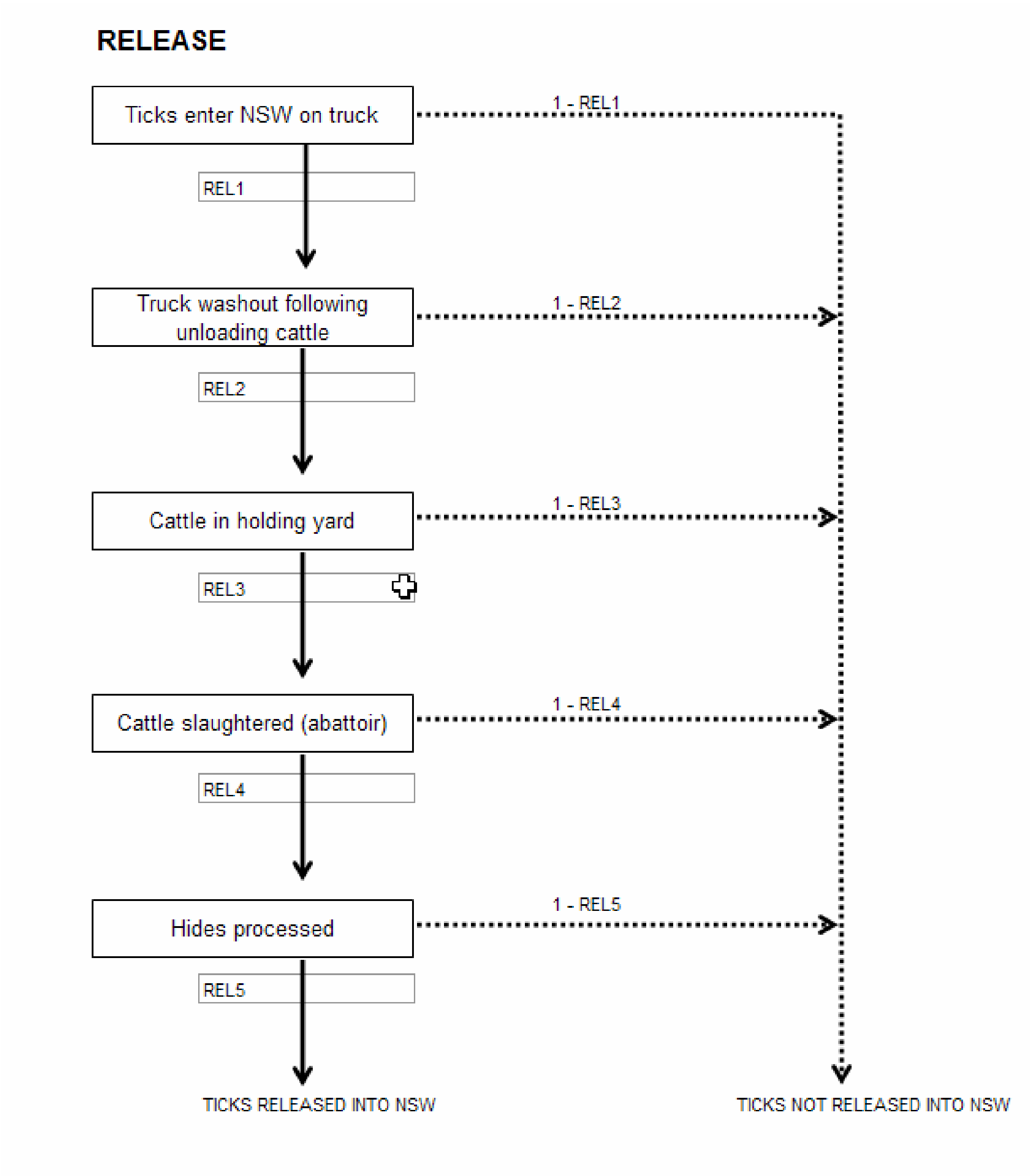


Figure 5: Release scenario for cattle imported into NSW

Probability of release 1 (Rel 1)

This represents the probability of ticks falling off a truck, during transportation in NSW, on the road or road sides during the stop times. Other factors that may determine the probability of tick release during the transport are duration of trip, stock routes, suitability of environment, operator factors and holding QDPI certificate of inspection and treatment. This also includes the likelihood of ticks to spread into the nearby farms in the case of accidents, when cattle are required to be held in nearby paddocks.

The Australian Livestock Transport Association has some guidelines on Animal Welfare requirements during transport; however, this guideline fails to provide a standard operating procedure for the transportation of cattle suspected of being tick positive or for emergency (e.g. accident) situations. To estimate the probability of release en route to the abattoir, a truncated log normal distribution was used (Figure 6). This allowed the probability of release to be close to zero on the majority of occasions, with the occasional very high probability of release (which might occur, for example, following a rare event such as a truck accident).

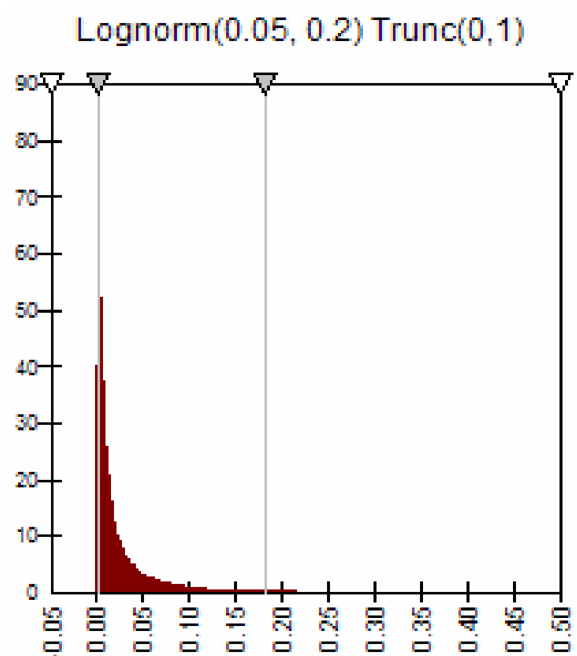


Figure 6. Log normal distribution used for Release Step 1

Two routes could be used in NSW by truck companies bringing cattle to Casino abattoir (Figure 7):

1. The preferred route form the QLD border to Casino abattoir is
   Tweed Heads to Ballina along Pacific Highway.
   Ballina to Lismore then Casino along Bruxner Highway

2. The non-preferred route is
   Rathdowney to Woodenbong along Mt Lindesay Highway
   Woodenbong to Kyogle
   Kyogle to Casino along Summerland Way

Climex (CSIRO Australia) data were used for these routes to estimate the survivability of ticks, if these fall off the truck

Figure 7: Map of North and East coast of NSW

Australian Livestock Transport Association (ALTA) should have standard operating procedures to handle livestock in the case of accidents. Unloading cattle in nearby paddocks due to accident could have a severe impact on the spread of tick in NSW.

NSW RTA database was interrogated to find the number of truck crashes along the stretch of road from Tweed Heads to Casino, travelling along the Pacific

Highway south to Ballina and then from Ballina to Casino along the Bruxner Highway (see map supplied). In the 5 year period April 1999-March 2004 there were 139 heavy-vehicle accidents, or approximately 28 per year along this stretch of road. For the purpose of this exercise we assumed 1% of heavy vehicles on this road were livestock transport vehicles. From abattoir figures, assume average consignment is 50 head/truck, and an accident resulted in all cattle being released from the truck and impounded in nearby paddock. An estimate of 14 cattle per year (28x0.01x50) released.

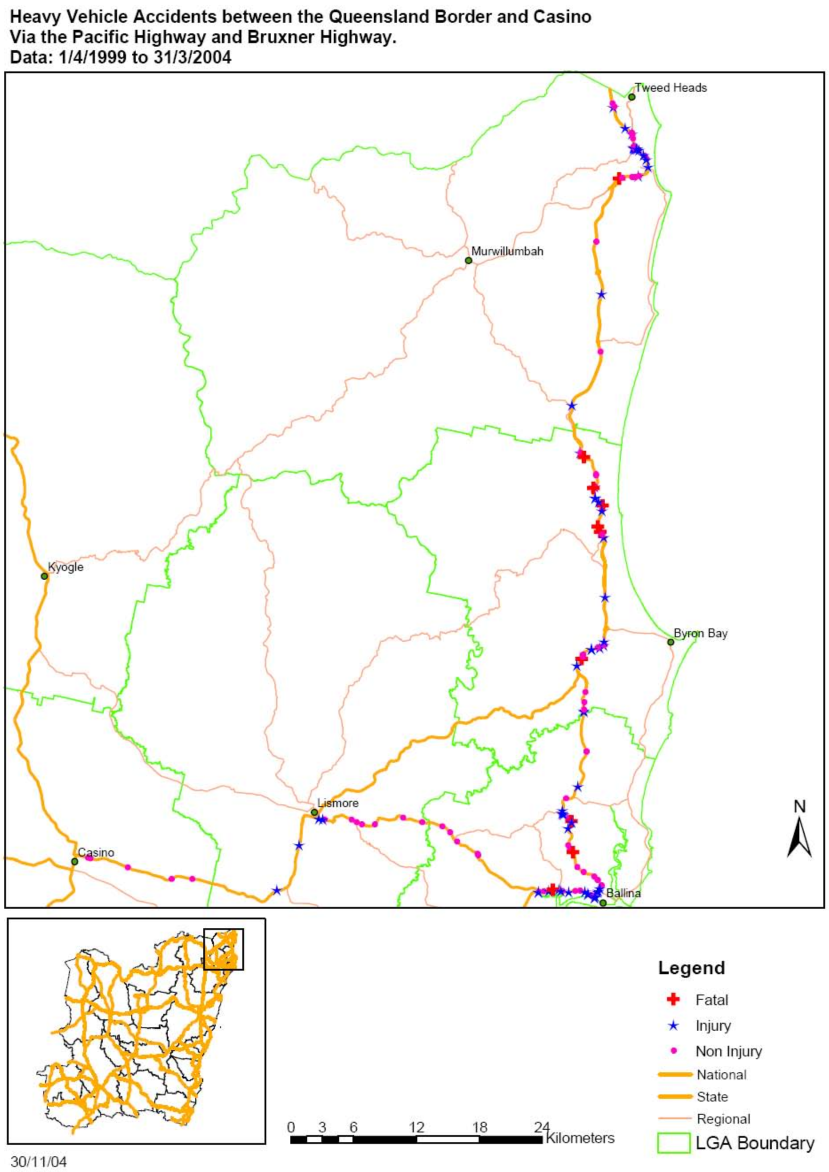


Figure 8. Heavy vehicle accidents between the QLD border and Casino via the Pacific HWY and Bruxner HWY (1999-2004) – RTA map and figures

Probability of release 2 (Rel 2)

This represents the probability that ticks might be released when trucks are washed out following cattle unload in the holding yard of the abattoir. This is a routine procedure for the truck drivers to clean and wash their trucks after unloading cattle in the holding yard. The truck's wash out will be directed into holding yard effluent.

Probability of release 3 (Rel 3)

This represents the proportion of ticks that may be released from the holding yard of the abattoir. Cattle are held in the holding yard before slaughter, there is a possibility that ticks may fall off on the ground and establish an infestation in the holding yard. The probability of tick release from the holding yard is determined by the presence of other forms of transfer (staff and dogs), interruption in slaughter process (e.g. breakdown), quarantine facilities and the quality assurance (e.g. wash down of holding yard) that are practiced in individual abattoir. The period of time that cattle are held in holding yards is also determined by animal welfare issues, however, slaughter may be delayed due to other factors such as public holidays and staff strike.

Probability of release 4 (Rel 4)

This represents the proportion of ticks that might be released via abattoir effluent. The probability of tick release into abattoir effluent is dictated largely by the presence of quarantine facilities for effluent and the quality assurance procedures that are practiced in the abattoir.

Probability of release 5 (Rel 5)

This represents the proportion of ticks that might be released via hides that are produced as a by product of processing. The probability of tick release are largely determined by the efficacy and type of treatment, location of hide treatment (on – site or off-site), disposal and treatment procedures, interval from slaughter till treatment, quarantine facilities and the quality assurance that are practiced in the abattoir.

Table 5. Estimates of probability of ticks released via various pathways into NSW

	Release	Min	Median	Max
REL 1	Probability ticks released from truck en route to abattoir	0.001	0.01	0.1
REL 2	Probability ticks released via truck washout following unload at abattoir	0.0001	0.005	0.01
REL 3	Probability ticks released from abattoir holding yard	0.0001	0.005	0.01
REL 4	Probability ticks released via effluent from abattoir	0.0001	0.005	0.01
REL 5	Probability ticks released via hides and skins post slaughter	0.0001	0.005	0.01

Calculating the probability of release

The probability of release was an estimate of the probability that ticks would be deposited in NSW following entry of a tick positive consignment of cattle from Queensland. Details of the probability combinations for release (as shown in Table 5) are provided in Appendix III.

4. Suitability of environment for tick survival

The third and final component of these analyses was to estimate the probability of tick survival and establishment following entry and release into the state

To achieve this objective we used the dynamic simulation model for predicting the geographical distribution of plant and animal species, CLIMEX (Sutherst and Maywald, 1985, Sutherst, Maywald, and Skarratt 1995). Climatic data for 229 locations throughout Australia were loaded into Climex and for each location a parameter termed the Ecoclimatic Index (EI) calculated for the cattle tick. Within Climex, EI is a continuous variable scaled between 0 and 100. An EI close to 0 indicates that the location of interest is not favourable for long-term survival of cattle ticks. EI values of 100 are only achievable under constant and ideal conditions for tick establishment. EI values of greater than 30 identify locations where climatic conditions are favourable for tick establishment. For the purpose of this risk analysis, we interpreted the raw EI values as the percentage probability of tick survival, if release were to occur.

Cattle tick EI values for the 229 Australian locations with climate details provided with Climex were plotted and Kriging techniques used to interpolate EIs between locations. This provided a surface of EIs, allowing us to estimate the probability of survival of cattle ticks at any location throughout Australia – not just the sampled locations. For this risk analysis, this allowed us to identify specific locations throughout NSW (for example, segments of major truck routes) suitable for tick survival and establishment.

A final assessment of the probability of tick entry, release, and establishment in NSW would therefore equal the product of the estimated probabilities for entry, release and survival. For this report we acknowledge that the spatial distribution of areas suitable for tick survival will vary throughout the year and between years, and for this reason we have omitted this final calculation from our analyses. A useful extension to this project would be to retrieve monthly climatic data for eastern Australian locations and compute the kriged EI surface for each month. This would allow the minimum and maximum geographical extent of locations suitable for tick survival to be more precisely defined.

Figure 9 is a grey-scale map showing the distribution of EI (divided by 100) for *Boophilus microplus*. Superimposed on this map are contour lines delineating areas where EI values are greater than 0.30 and greater than 0.05. These contour lines identify those areas of NSW where there is a possibility of tick establishment, following entry and release.

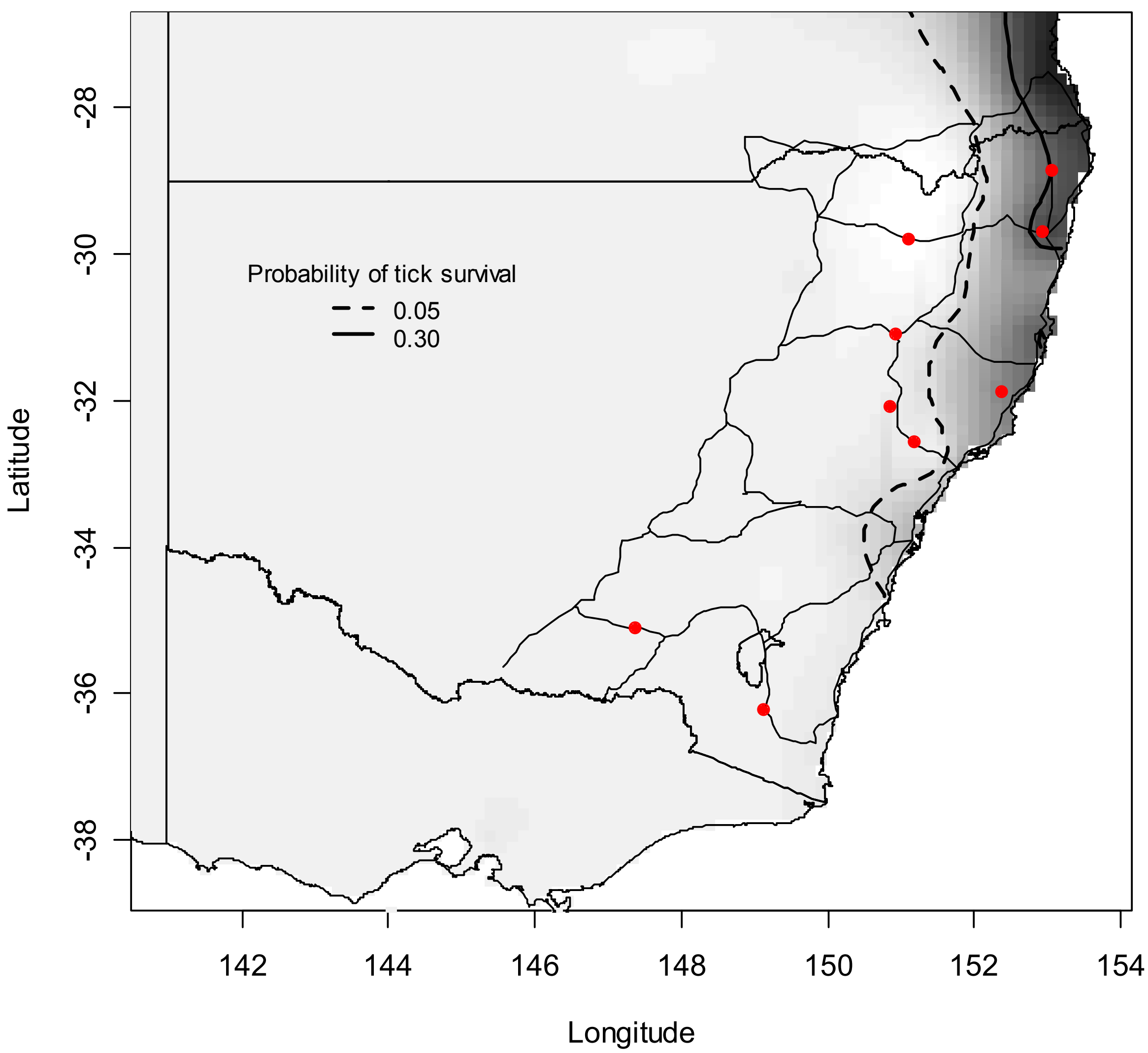


Figure 9: Map of NSW showing the distribution of EI values for *Boophilus microplus*. Contours identify locations where EI values are greater than 0.30 (solid lines) and greater than 0.05 (dashed lines). Points identify the location of receiving abattoirs throughout NSW.

5. Analytical methods

The risk of tick entry and release into NSW were calculated using the median probability estimates presented in Tables 3 to 5 (above). To provide an indication of the uncertainty in our final estimate of risk, a stochastic approach was used where the risk model was simulated 1000 times using @RISK, and for each simulation a random number drawn from the prescribed distribution for each variable.

The seed was a number that initialised the selection of numbers by the random generator within @RISK. A random sampling seed was used on each occasion a simulation was run.

6. Tick risk assessment results

The number of cattle likely to be imported if granted market access into NSW, forms an important part of the risk assessment. This is because quantitative risk assessment methods express risk in terms of tick introduction per consignment of cattle imported. The risk of tick introduction is then directly proportional to the number of cattle imported.

The number of tick positive cattle likely to be imported if market access is granted

for untreated cattle has been assessed through the following means:

- Examining data on imports of cattle form QLD into NSW for the past 3 years
- Examining data on the routes that used by the transport companies and quality assurance and regulation on handling emergency situations
- Examining data on the abattoirs in NSW sourcing cattle from QLD
- Examining data on number of tick fever outbreaks in NSW during recent years

Tables 6 to 8 are a summary of probability and number of ticks that may release en route to abattoir, in truck washout, holding yard washdown, abattoir effluent and hide processing section.

Table 6. Cattle consignments entering NSW from the protected zone of QLD, probability of tick release into the environment and estimated number of years per release of ticks

Outcomes	**Expected no of tick releases per 100,000 consignments**	**Estimated no of years per one release**
The unit of interest is a consignment (typically a truckload of cattle)	**Median (95% Confidence Interval)**	**Median (95% Confidence Interval)**
Proportion of tick positive consignments entering NSW	0.0002 (0.0.0001 – 0.0272)	130,000 (57,000 – 520,000)
Proportion of tick positive consignments entering NSW and releasing ticks at any stage after entry into NSW environment	0.0001 (0.00001 – 0.0.0018)	330,000 (151,000 – 1,400,000)
Components of release scenario		
Proportion of consignments releasing ticks released on the road to the abattoir	0.00003 (0.000001 – 0.0013)	11,000,000 (5,000,000 – 47,000,000)
Proportion of consignments releasing ticks via truck washout following unloading at slaughterhouse	0.00001 (0.000001 – 0.00014)	28,000,000 (12,000,000 – 115,000,000)
Proportion of consignments releasing ticks from abattoir holding yard	0.00001 (0.000001 – 0.00015)	27,000,000 (12,000,000 – 113,000,000)
Proportion of consignments where ticks are released via effluent from abattoir	0.00001 (0.000001 – 0.00014)	28,000,000 (13,000,000 – 120,000,000)
Proportion of consignments where ticks are released via hides and skins post slaughter	0.00001 (0.000001 – 0.00014)	28,000,000 (13,000,000 – 120,000,000)
Estimated numbers of ticks entering NSW each year	0.0081 (0.00023 – 0.1485)	

Current estimated number of consignments/year = 354

Table 7. Cattle consignments entering NSW from the infected zone of QLD, probability of tick release into the environment and estimated number of years per release of ticks under current regulations

Outcomes	**Expected no of tick releases per 100,000 consignments**	**Estimated no of years per one release**
The unit of interest is a consignment (typically a truckload of cattle)	**Median (95% Confidence Interval)**	**Median (95% Confidence Interval)**
Proportion of tick positive consignments entering NSW	0.0150 (0.0013 – 0.0992)	26,000 (12,000 – 110,000)
Proportion of tick positive consignments entering NSW and releasing ticks at any stage after entry into NSW environment	0.0006 (0.00004 – 0.0079)	670,000 (310,000 – 3,000,000)
Components of release scenario		
Proportion of consignments releasing ticks released on the road to the abattoir	0.0002 (0.000001 – 0.0070)	2,200,000 (1,100,000 – 11,000,000)
Proportion of consignments releasing ticks via truck washout following unloading at abattoir	0.00007 (0.000001 – 0.0005)	5,400,000 (2,500,000 – 24,000,000)
Proportion of consignments releasing ticks from abattoir holding yard	0.00007 (0.000001 – 0.0005)	5,600,000 (2,500,000 – 24,000,000)
Proportion of consignments where ticks are released via effluent from abattoir	0.00007 (0.000001 – 0.0006)	5,700,000 (2,600,000 – 25,000,000)
Proportion of consignments where ticks are released via hides and skins post slaughter	0.00007 (0.000001 – 0.0006)	5,500,000 (2,500,000 – 24,000,000)
Estimated numbers of ticks entering NSW each year	0.07 (0.004 – 0.72)	

Current estimated number of consignments/year = 261

Table 8. Cattle consignments entering NSW from the infected zone of QLD, probability of tick release into the environment and estimated number of years per release of ticks if current regulations are lifted

Outcomes	**Expected no of tick releases per 100,000 consignments**	**Estimated no of years per one release**
The unit of interest is a consignment (typically a truckload of cattle)	**Median (95% Confidence Interval)**	**Median (95% Confidence Interval)**
Proportion of tick positive consignments entering NSW	93.77 (13.59 – 287.30)	4 (2 – 18)
Proportion of tick positive consignments entering NSW and releasing ticks at any stage after entry into NSW environment	3.22 (0.38 – 40.21)	120 (52 – 500)
Components of release scenario		
Proportion of consignments releasing ticks released on the road to the abattoir	0.95 (0.028 – 37.820)	400 (160 – 1700)
Proportion of consignments releasing ticks via truck washout following unloading at abattoir	0.42 (0.051 – 1.717)	900 (410 – 4000)
Proportion of consignments releasing ticks from abattoir holding yard	0.43 (0.053 – 1.657)	890 (400 – 4000)
Proportion of consignments where ticks are released via effluent from abattoir	0.43 (0.055 – 1.633)	890 (400 – 4000)
Proportion of consignments where ticks are released via hides and skins post slaughter	0.42 (0.050 – 1.700)	920 (420 – 4300)
Estimated numbers of ticks entering NSW each year	402 (31.95 – 2723.6)	

Current estimated number of consignments/year = 261

6.1. Probability of tick-positive cattle entry and tick release in NSW

6.1.1. Proportion of tick positive consignments entering NSW

The computed probabilities and estimates that are presented in this report were based on the historical data, current estimates on infestation rate in different zones, expert judgments and current regulations (treatment and Tick Line inspection). It was also assumed that the effectiveness of treatments (chemicals) and treatment procedures (e.g. dip, pour on, etc.) remained constant over the years. It is intended that the issue of tick resistance to the chemicals is not accounted for in this assessment. However, since the efficacy of the Acaricide products in the market are unlikely to remain constant (resistance issue), it is suggested that the finding of this study should be interpreted in the light of possible changes in the infestation rate and resistance to chemical.

It is important to note that this report provides an estimate of tick release into the environment. While an outbreak of tick fever is possible from such release, the probability of tick fever outbreak must be lower than that of tick release alone.

Definition: negligible risk = less than one release per 100,000 years.

Protected zone: If cattle were imported from the protected zone the probably of an incursion (tick positive cattle entering NSW) would be 0.0002 per 100,000 consignments per year (Table 6). These data indicate that with the current number of consignments per year (354 consignments per year) the likelihood of an outbreak following the importation of tick positive cattle from the protected zone, would be negligible.

Infected zone under current regulations: If cattle were imported from the infected zone under current surveillance regulations (treatment and Tick Line inspection), the probably of an incursion (tick positive cattle entering) would be 0.02 per 100,000 consignments per year entering NSW (Table 7). These data indicated that with the current number of consignments per year (261 consignments per year), the likelihood of an outbreak following importation of tick positive cattle from the infected zone, would be negligible.

Infected zone if current regulations lifted: If cattle are imported from the infected zone and if the current surveillance regulations were lifted (no treatment and no Tick Line inspection), the probability of an incursion would be 93.8 per 100,000 consignments per year entering NSW (Table 8). Assuming the current number of consignment per year (261 consignments per year), there is a possibility of an outbreak following the importation of tick positive cattle from the infected zone of QLD once every 4 years. This risk would increase if, as anticipated the number of consignments increased following lifting of regulations.

6.1.2. Proportion of cattle consignments entering NSW and releasing ticks into the environment (including abattoirs)

Cattle that are imported into NSW, from different zones of QLD, are transported into the abattoirs across NSW. In this risk assessment, nine major abattoirs were considered as the main destination for the imported cattle (Figure 2).

Protected zone: If cattle were imported from the protected zone the probability of tick positive cattle entering NSW and releasing ticks at any stage into the NSW environment would be 0.0001 per 100,000 consignments per year (Table 6). This indicates that with the current number of consignments per year (354 consignments per year) the likelihood of ticks being released into the NSW environment and the likelihood of occurrence of an outbreak, due to the importation of tick positive cattle from the protected zone, would be negligible.

Infected zone under current regulations: If cattle were imported from the infected zone under current surveillance regulations (treatment and Tick Line inspection), the probability of tick positive cattle entering NSW and releasing ticks at any stage into NSW environment would be 0.0006 per 100,000 consignments (Table 7). This indicates that with the current number of consignment per year (261 consignments per year) the likelihood of ticks being released into the NSW environment and the likelihood of occurrence of an outbreak, due to the importation of tick positive cattle from the infected zone, would be negligible.

Infected zone if current regulations lifted: If cattle were imported from the infected zone and if the current surveillance regulations were lifted (no treatment and no Tick Line inspection), the probability of tick positive cattle entering NSW and releasing ticks at any stage into the NSW environment would be 3.22 per 100,000 consignments per year (Table 8). **This indicates that with the current number of consignments per year (261 consignments per year) the likelihood of ticks being released into the NSW environment and the likelihood of occurrence of an outbreak following release of ticks, due to the importation of tick positive cattle from the infected zone, would be once every four years.**

Once the likelihood of exposure and release of ticks were established in the environment (abattoir) in NSW, then the effect of climate and humidity conditions on the probability of ticks remaining viable were assessed, using Climex software (Climex, V2, CSIRO Australia) (Figure 9). Climex data provided a measure of the suitability of locations of towns for tick survival. These data indicated that the climate and environment at the abattoirs that are located in Casino (Northern Coop Meat), South Grafton (Ramsey Wholesale Meats) and Wingham (Wingham

Beef Export) were more likely to be favourable for tick survival and establishment than the other abattoirs.

6.2. Components of tick release in NSW abattoirs (release scenario)

The risks associated with each component of the release scenario are detailed in Tables 6 to 8. These include the probability of tick release on the road and in a abattoir environment (holding yard washdown, abattoir effluent and hide processing section) in NSW. The likelihood of ticks being released in the abattoir environment is negligible.

The probability of ticks released en route to the abattoirs in NSW is presented here:

6.2.1. Probability of tick surviving and being released en route to abattoir in NSW

Protected zone. If cattle were imported from the protected zone the probability of tick-positive cattle entering NSW and releasing ticks en route to the abattoir would be 0.00003 per 100,000 consignments per year (Table 6). These data suggest that with the current number of consignments per year (354 consignments per year) the likelihood of ticks released en route to the abattoir and occurrence of an outbreak following release of ticks, due to the importation of tick positive cattle from the protected zone, would be negligible.

Infected zone under current regulations. If cattle were imported from the infected zone under current surveillance regulations, the probability of tick positive cattle entering NSW and releasing ticks en route to the abattoir would be 0.0002 in 100,000 consignments per year (Table 7). These data suggest that with the current number of consignments per year (261 consignments per year) the possibility of ticks being released en route to the abattoir and occurrence of an outbreak following release of ticks, due to the importation of tick positive cattle from the infected zone, would be negligible.

Infected zone if current regulations lifted: If cattle are imported from the infected zone and if the current surveillance regulations were lifted (no treatment and no Tick Line inspection), the probability of tick positive cattle entering NSW and releasing ticks en route to the abattoir would be less than 0.95 per 100,000 consignments per year entering NSW (Table 8). These data suggest that if the current regulations were lifted and with the current number of consignment per year (261 consignments per year) the likelihood of possibility of ticks released into NSW environment and occurrence of an outbreak following release of ticks, due to the importation of tick positive cattle from the infected zone, would be one in every 400 years.

Climex data indicated that the North east coast part of the preferred route (Figure 7- Tweed Heads to Ballina along Pacific Highway, and then from Ballina to Lismore then Casino along Bruxner Highway) would probably be more “favourable conditions” for tick survival if ticks were released in this environment. It appeared that the alternative route (Figure 7- Rathdowney to Woodenbong along Mt Lindesay Highway, Woodenbong to Kyogle and then Kyogle to Casino along Summerland Way) would provide slightly more “unfavourable conditions” for tick survival.

The risk assessment and Climex data indicated that if cattle were imported from any area of “QLD cattle tick infected zone” under current surveillance regulations, the probability of ticks being released on the road and an ensuing outbreak would be negligible. If the current regulations on treatment and Tick Line inspection were lifted when cattle were imported from the infected zone, while the risk may still be low, the likelihood of occurrence of an outbreak following release of ticks would be much greater than previous scenarios (Tables 7, 8).

Truck accident data

It is possible that a truck accident could occur along the route to one of the major abattoirs (e.g. Casino). If the preferred route was used, the probability of ticks being released into the nearby farms or properties would be greater. However the presence of suitable hosts for cattle ticks along both routes would impact greatly on the relative risk of using these routes. This would require acquisition of data on the number of cattle, distribution of cattle breeds and location, which lies outside the scope of the current study.

7. Risk management and conclusions

Table 9 is a summary of risk of cattle consignments entering and releasing ticks in NSW.

Outcomes	Level of risk of tick release for cattle sourced from different zones of QLD		
	Protected	Infected	
		Under current regulations	Current regulations lifted*
Proportion of tick positive consignments entering NSW	Negligible	Negligible	V High
Proportion of tick positive consignments entering NSW and releasing ticks into the environment	Negligible	Negligible	Low
Components of release scenario			
Probability ticks released en route to abattoir	Negligible	Negligible	Low
Probability ticks released via truck washout following unload at abattoir	Negligible	Negligible	Low
Probability ticks released from abattoir holding yard	Negligible	Negligible	Low
Probability ticks released via effluent from abbatoir	Negligible	Negligible	Low
Probability ticks released via hides and skins post slaughter	Negligible	Negligible	Low
Estimated numbers of ticks entering NSW each year	Negligible	Negligible	V High

Negligible risk = less than one release per 100,000 years

Probabilities ≥0.5 and ≤5 per 100,000 consignments = low risk
Probabilities ≥5 and ≤10 per 100,000 consignments = medium risk
Probabilities ≥10 and ≤ 50 100,000 consignments = high risk
Probabilities ≥50 per 100,000 consignments = very high risk

Number of ticks are imported per year ≥1 and ≤5 = low risk
Number of ticks are imported per year ≥5 and ≤10 = medium risk
Number of ticks are imported per year ≥10 and ≤100 = high risk
Number of ticks imported per year ≥100 = very high risk

***** Scoring was based on the data under current regulations in the infected zone

7. Conclusions

The data obtained from this risk assessment indicate that under the current regulations and surveillance system and with the current estimates on infestation rate in three cattle tick zones of QLD, the probability of tick positive cattle entering into NSW and ticks being released into the environment (farms and cattle properties) would be negligible. As previously suggested in the results section, the interpretation of these data should be in the light of a dynamic life cycle of ticks under changing climate and temperature conditions, and resistance to chemicals. Possible changes in the regulations and surveillance strategies in QLD could also impact on the risk associated with cattle importation from QLD into NSW.

The sensitivity test on data from the infected zone, following lifting of quarantine procedures, shows that the probability of tick positive consignments entering NSW and ticks released in the environment could increase significantly (Tables 11,12). This indicates that current regulations, treatment and Tick Line inspection, are effective and able to control tick release and establishment of ticks when cattle are imported from the infected zone.

Part 3

Overview of risk to NSW cattle from Cattle Ticks & Tick Fever

1. Background- Introduction of ticks and tick fever to Australia

Tick fever (*Babesiosis* and *Anaplasmosis*) and tick infestation (*Boophilus microplus*) cause economic loss in cattle in northern Australia, through death, weight loss, fertility decline, hide damage, treatment and regulatory costs. Various control options are used including chemicals to kill ticks, resistant cattle genotypes, regional tick eradication programs and movement controls, vaccination for ticks and tick fever, and grazing (pasture) management.

Cattle ticks and the accompanying intracellular parasites that cause tick fever were introduced into northern Australia along with their host stock, probably as early as 1829. The introduction of cattle into the Northern Territory region between 1829 and 1849 from Timor and possibly Bali, where the parasites were enzootic, has been detailed in a report (Angus, 2003). This report indicated that this probably led to the establishment of these parasites in the Top End, and their survival was enhanced by the introduction of susceptible British breeds of cattle into the Darwin area from 1866.

Disease caused by tick fever or ‘redwater’ was first recorded around Darwin in 1870, in working bullocks transported to Darwin by sea from NSW. The construction of the overland telegraph line from this time, relying on the use of bullocks for transport, helped distribute ticks and tick fever further. Redwater was noted as affecting cattle brought into the Roper River area of the Northern Territory by the Duracks in 1885. Angus provides further anecdotal evidence of redwater outbreaks in northern herds as early as 1845.

Outbreaks of redwater were recorded in mobs of cattle being droved from the Wave Hill region of the Northern Territory to the Kimberley region of Western Australia in 1885, following the discovery of gold at Halls Creek and the need to supply miners with beef. Large movements of naïve cattle from Queensland into the Roper River district saw mortalities as high as 24%.

From the 1880s ticks and their accompanying disease spread backwards along the stock routes from the Northern Territory into western Queensland. Seddon[1] described the ensuing rapid spread of ticks and tick fever from the initial focus in the Northern Territory, across the country adjoining the Gulf of Carpentaria by

1892, to Cape York by 1894, and to the east coast towns of Cairns and Townsville by 1895.

Quarantine lines were hastily established to prevent the introduction of ticks into southern and eastern Queensland, which had large cattle populations. The lack of success of these lines was apparent however, in the need to drastically re-draw them from the original 1892 and 1894 lines, boxing in the northwest corner of Queensland, to the 1895 line which divided north and south Queensland with a line drawn parallel with Mackay, to the 1896 line drawn below Rockhampton. By 1898 zones were established to protect southern and southeast Queensland, the parasites and accompanying disease having spread as far south as Bundaberg.

Herds of cattle were decimated in the face of the parasites. Reports from the Gin Gin area in 1898 note 60% to 70% mortality in newly infected cattle. In contrast, cattle inoculated along the lines of Pound's recommendations suffered losses of only 3–5%.

The NSW government closed the NSW–Queensland border to cattle imports in order to prevent the introduction of cattle tick to the state. Cattle ticks were noted on the Queensland side of the border in 1902, and despite the best efforts of stock inspectors, including double fencing, inspection and dips, had spread into NSW by 1906. Distribution was enhanced by bullock teams travelling in the northeast corner of the state, and had spread to Kyogle by 1909, and as far south as Coffs Harbour by 1932.

The distribution of ticks has changed little since then, except for the control of ticks in NSW. In fact, the current distribution of cattle ticks (2005) closely resembles the distribution in 1906. This would indicate that the rapid spread of cattle ticks between 1880 and 1905 across the tropical north coast of Australia and down the warm humid east coast of Queensland into NSW, closely follows the limits of the natural habitat of the tick.

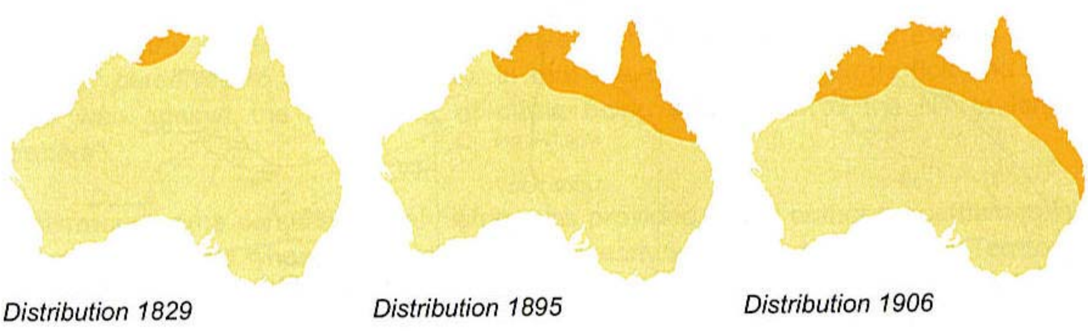


Figure 1: Maps of Australia illustrating spread of cattle tick *Boophilus microplus* on a time-course scale. (modified from drawings supplied by Tick Fever Research Centre, Wacol, Queensland).

2. Hazard identification

2.1. Aetiological agents

Tick-born diseases are an important constraint in many countries because they limit livestock productivity. In general, epidemiological studies have shown that tick-borne pathogens often occur together in both vertebrate hosts and tick vectors. The cattle tick (*Boophilus microplus*) is the most serious external parasite of cattle in Australia, causing economic losses to the cattle industry. Tick fever is a disease of cattle caused by the haemoparasites; *Babesia bovis*, *Babesia bigemina* or *Anaplasma marginale*. The disease is endemic in northern Australia and follows the distribution of the tick vector *Boophilus microplus*. The one-host ixodid tick, *Boophilus microplus,* is the vector of 3 of the 4 parasites comprising Australia's tick fever complex of diseases (Roberts, 1970). These disease organisms are the protozoans *Babesia bovis*, the most pathogenic species, and *Babesia bigemina*, both of which cause babesiosis or redwater, and *Anaplasma marginale* which causes anaplasmosis. It is estimated that more than 600m cattle worldwide are exposed to babesiosis and anaplasmosis. The fourth tick-fever organism compromising Australia's tick-fever complex is the relatively benign protozoan *Theileria buffeli* (Dodd, 1910). Although not normally a problem (Legg, 1935), *Theileria buffeli* may occasionally cause acute haemolytic disease (Rogers and Callow 1966). *Boophilus microplus* is the most important tick parasite of cattle in the world in terms of the economic loss it causes, which, in Australia, has been estimated to be approximately $180 million per year (MLA, 2005). It has been also estimated that more than 7m cattle are potentially exposed in endemic regions (Chudleigh, 1991). McLeod and Kristjanson (1999) estimated that annual mortality associated with anaplasmosis and babesiosis in Australia in 1998 resulted in production losses of $22m despite spending $8.5m on acaricides and vaccines.

Although vaccines against tick fever have been used in Australia for up to a century, vaccines containing attenuated strains of *Babesia bovis* and *Babesia bigemina* as well as *Anaplasma centrale* grown in splenectomised calves have been only used in Australia since 1964 to immunise cattle against the disease. Use of tick fever vaccine in endemic parts of Australia is a risk management strategy based on the likelihood of exposure, the value and the susceptibility of the stock.

2.1.1. NSW status

The tick is distributed around the northern coastal areas of Australia as far south as the Queensland and NSW border, where it is held by a quarantine boundary at annual cost of $7m to the NSW government, in addition to grower costs (White et al. 2003). Its potential southernmost distribution is limited by insufficient thermal accumulation during the winter (Sutherst, 1987) but it is estimated to be able to colonise an area several hundred kilometers south of the QLD-NSW bolder and so presents a current risk that could increase under global warming. Inland the distribution is limited by dryness.

In the late 1890s there was considerable concern at the movement of cattle tick southwards through QLD towards the NSW border. Various preventive steps were taken. These included the building of the border fence west from Point Danger, experiments with inoculation against tick fever and the banning of the importation of cattle from many areas of QLD. The legislative backing for these controls was under the Stock Diseases (Tick) Act, 1901. Despite these precautions the cattle tick entered NSW in 1906 and has been the subject of control ever since.

Presently cattle in northern herds have a low natural immunity to the disease as a result of low tick numbers (and therefore little exposure of calves to the three tick fever parasites). Surveys (summarised in the Tick Fever Inquiry by Garry West, 2005) indicated that outbreaks of tick fever in NSW were common up until 1968, with an average of 10 outbreaks per year. Since the 1970's outbreaks have only occurred every few years. Vaccines have been developed in order to control the disease in Northern Australia. West reviewed the outbreaks of tick worry and tick fever in NSW as follows:

1989- Yeoval: 13 cattle died of tick fever and or tick worry. It was found out that the ticks and tick fevers were introduced by an illegal introduction of calves from the tick infected area of QLD.
1995- ? : One cow was diagnosed with tick fever at post-mortem. No tick was found at the property and all cattle were serologically negative for tick fever.
1997- North west of Kyogle: Tick fever was detected on two properties heavily infested with cattle ticks. The properties were close to the National Park which adjoined the QLD border. A total of 59 cows died in these properties as a result of tick fever.
1998- ? : One cow died as a result of tick fever. No tick was found at the property and no report of further loss was recorded.
2005- Old Koreelah and Carool: Two outbreaks have been recorded at two different locations. 13 cows (out of 800) died in Old Koreelah. There were five cattle tick infested properties in the Tweed valley. At least 52 properties in the Tweed Valley have been quarantined after 21 deaths on three properties. Both *Babesia bigemina* and *Anaplasma* were detected in these properties.
At Carool tick fever has been detected on two adjoining properties. Mortality on one property was 5 out of a small herd of 19 cattle, and on the neighbouring property the number of deaths was 3 from a herd of 70 cattle. *Babesia bovis* and *Anaplasma* were both recovered in these properties. Sporadic deaths were also reported over a period on one of these properties.

There is limited information on the exact protozoal cause of tick fever outbreaks (e.g. *Babesia bovis, Babesia bigemina or Anaplasma marginale*) occurring in NSW. Therefore, it can be very difficult to confidently confirm the cases as babesiosis or anaplasmosis, as each have different ecology in the environment.

Currently the use of vaccine is neither common nor popular in NSW to control the outbreak of tick fever. The cattle producers in NSW are fully not convinced that use of tick fever vaccine is the best option for them. Some cattle producers believe that sterilisation of incoming cattle which may be tick fever carriers could be an option, whilst the majority considered the introduction of an Animal Health Statement would be adequate to assist producers assess the risk.

The most useful measure of risk to industries under changes such as climate, regulatory control or chemical resistance is their vulnerability. This is estimated from a combination of their exposure and sensitivity (impacts in the absence of any intervention) and the capacity of the industry to adapt to the changes. When the option to change breed was available, the beef industry in different areas had very low vulnerability to climate change. The uncertainties surrounding the sustainability of the other options that are currently available means that *B. taurus* producers are much more vulnerable to climate change. As there is a restricted range of chemicals available to treat cattle ticks for movements compared with on-farm control, the greatest risk from cattle ticks, in the event of failure of chemical control, is in the southern States where non-immune cattle will be exposed to the ticks and tick-borne diseases for the first time.

Intermittent outbreaks of cattle tick, with epidemics of tick fevers, could occur even where the climate is unsuitable for permanent persistence of large tick populations. This is largely a result of an expansion of the area at risk and the dependence of the industry on chemical acaricides. Within the cattle tick endemic area, cattle owners depending on *B. taurus* cattle for either beef or dairy production are the most vulnerable to changes in climate. As eradication depends so much on the use of chemicals there is perceived to be a high risk to the NSW policy of maintaining the tick-free status.

2.1.2. QLD status

Queensland has been and is the State most affected by the ticks, therefore, most research and surveys over the past 100 years have been carried out in QLD at State and Federal laboratories and universities. The cattle tick infected area of QLD comprises the coastal areas east of the Great Dividing Range and north of the Great Northern Rail line. Cattle ticks are also found in the northern areas of Western Australia and Northern Territory. Outbreaks of cattle ticks can and do occur in tick free areas of QLD, being more common in the marginal areas adjacent to the infected areas.

In over 1100 confirmed tick fever outbreaks in QLD, on average 1 out of every 20 animals at risk died of the disease. There are about 250 confirmed outbreaks of tick fever in QLD each year with many more unconfirmed or not reported. A recent outbreak caused almost $50,000 in stock losses, veterinary fees and mustering costs. Most outbreaks occur in animals 18-36 months of age.
In 1892, the QLD government established tick quarantine boundaries from the 20°S parallel of latitude on QLD's western border to 22°S parallel of latitude on the coast. In 1893 this line was extended further south to 24°S parallel of latitude at Port Curtis. Progression of the disease down the QLD coast was rapid. By 1897, it had reached the southeast QLD and by 1906, despite double fencing and strict surveillance, had entered NSW. In 1896, "The Queensland DIP" was formulated for cattle dip. This method was extremely successful at ridding cattle of ticks without a deleterious effect on cattle.

Records of the outbreaks of tick fever in QLD (Rogers, 1971) showed that 140 outbreaks of *B. bovis* (*Babesia argentina*) were recorded, five due to *B. bigemina*, and 37 attributable to *Anaplasma marginale* in northern QLD from 1964 to 1971. More outbreaks (30) were recorded in 1968 than any other year. The lowest number occurred in 1969 and 1970, when only 14 outbreaks were confirmed in each year. The distribution varied from year to year, but more outbreaks occurred in May than any other month followed by October, August and September in that order. Only 17.8% of outbreaks occurred during the summer months. British breed cattle were affected in 93 of 118 outbreaks compared with 25 for Brahman cross-bred (up to 50% Brahman) cattle.
Clinical disease attributable to *B. bigemina* infection was confirmed on five occasions. Only one cow was affected in four of these occasions, but one cow died and two were sick in the fifth outbreak (Rogers, 1971).

Until 1970, thirty seven outbreaks due to *Anaplasma marginale* were recorded, five of which occurred following the introduction of susceptible cattle into tick-infested areas. Thirteen of the outbreaks involved cows less than 2 years of age, but 20 outbreaks involved cattle more than 2 years old.
It was concluded from the survey of Rogers (1971) that:

- The incidence and seasonal distribution of outbreaks due to *B. bovis* has not altered greatly from that recorded by Johnston (1968), except that more outbreaks occurred in spring than in winter. The distribution varied in some years possibly associated with rainfall pattern. Summer outbreaks tended to follow rain in the preceding spring, and few outbreaks occurred in the latter half of the year when summer rains failed.
- Most outbreaks involved British breed cattle. *B. indicus* and *Zebu* cattle are considered to have a high natural resistance.
- More outbreaks involved cattle in the 10-24 month age group than in any other group, followed by those 25-36 months old. Calves up to and including 9 months of age were affected much less frequently.

- There was poor immunity of cattle due to their prolonged exposure to tick populations which were too low to result in infection. Therefore, these cattle were more susceptible to reinfection.
- The low percentage of outbreaks of babesiosis due to *B. bigemina* and also low morbidity and mortality indicated that *B. bigemina* cannot be regarded as a significant pathogen in the area.
- A greater proportion of older cattle developed clinical anaplasmosis than was the case with *B. bigemina* infections.

Anaplasmosis occurs in those areas of northern and eastern Australia infested by the cattle tick *Boophilus microplus* but it has only been studied in any detail in QLD (Rogers and Shiels, 1979). The seasonal distribution of outbreaks of Anaplasmosis differs from that of Babesiosis in that the majority of outbreaks occur during the autumn and winter (of 204 outbreaks; 14% in summer, 42% in autumn, 36% in winter and 8% in spring) (Conell, 1974). Maximum populations of *B. microplus* develop during autumn and the extension of outbreaks over winter is probably associated with the relatively long pre-patent period following tick-induced infections. The age distribution of 277 outbreaks is as follows; 6.9% were less than 1 year old, 37.9% were 1 to 3 years old, and 55.2% were greater than 3 years of age. The 79.5% of 259 outbreaks affected female cattle, however, this could be due to higher proportion of females in the population. The results of Complement-Fixing Antibodies (CFA) in the three tick-infested zones are given in Table 1.

Table 1. Prevalence of Complement-Fixing Antibodies (CFA) in cattle in *Boophilus microplus* infested areas of QLD

Zone	% reactors	No of sera
North QLD	47.2	1939
	63.1	531
Central QLD	52.3	1638
South QLD	30.2	1388

A cross-sectional study was conducted on young dairy cattle, between 6 and 15 months in QLD using serological methods to determine features of farms with and without endemic stability, the relationships between farm management practices and endemic stability and effectiveness of tolerating a few ticks on cattle as a method of natural vaccination (Serugga et al. 2003). They reported that on 73% of farms, confirmed clinical cases of tick fever were recalled by the farmer, indicating that tick fever was a threat on most dairy farms.

The majority of herds in the study (54 of 64) did not have sufficient numbers of seropositive animals aged between 6 and 15 months to have a low risk of tick fever. Region had an effect on the likelihood of endemic stability for all tick fever organisms. Cattle in far-north QLD were more likely to be seropositive to *B. bovis* and *B. bigemina*. Leaving a few ticks on cattle in order to induce endemic stability could increase the likelihood of endemic stability to *A. marginale*. However, in practical terms, it was ineffective, because only 26% of these farms had endemic stability against all three organisms. The investigators of this study came to the conclusion that given the low proportion of farms that have endemic stability to the tick fever organisms and the high likelihood of clinical disease, vaccination is recommended to protect dairy cattle from tick fever throughout tick infested area of QLD.

In QLD tick fever vaccines are commonly used and are the most reliable and practical tools for long-term control of the disease. Vaccines have been produced at the Tick Fever Centre of the DPI&F in a number of different forms. The choice of vaccine depends on the circumstances and potential benefit expected from the vaccine.

1. Chilled tick fever vaccines- are available in bivalent or trivalent forms and are supplied ready to use. Chilled vaccines are most commonly used by QLD cattle producers.
    a. Trivalent (3-germ) vaccine protects against all three organisms that cause tick fever (*Babesia bovis*, *Babesia bigemina* and *Anaplasma marginale*).
    b. Bivalent (2-germ) protects against two causes of tick fever (*Babesia bovis* and *Anaplasma marginale*). This vaccine is popular for *Bos indicus* and cross-bred cattle in ticky areas.
2. Frozen tick fever vaccines (Combavac 3 in 1)- is supplied as a trivalent form of vaccine and has a long shelf life (5 years) and suitable for on-site storage at properties and distributors. Many large QLD cattle producers prefer this form of vaccine.

Vaccination with *Anaplasma marginale* is employed either as a routine preventive measure in young cattle or in the face of an outbreak. Oxytetracycline and imidocarb have been used successfully to control the disease.

2.2. TickGARD®PLUS vaccine

One of the non-chemical control methods that have been developed to control cattle tick is vaccination. TickGARDPLUS vaccine was a commercially available vaccine used as an aid in the control of *B. microplus*. Jonsson et al. (2000) evaluated the efficacy of TickGARDPLUS against B. microplus in lactating Holstein-Friesian cows in QLD. It was reported that the vaccine reduced moderate tick populations on lactating dairy cattle in the field. This reduction was affected via reduced yield of engorged ticks, reduced egg production by engorged ticks and reduced hatchability of eggs. Antibody titres, were also low after tertiary vaccination.

However, when strategic plans for the control or eradication of tick populations are developed, the effectiveness of the vaccine from an epidemiological point of view is questioned. This vaccine was commercially available for more than a decade and was widely used by cattle producers in Northern Australia, but did not have a significant impact on cattle tick populations. It is no longer available for cattle producers in Australia but remains on the market in Cuba, Mexico and South America.

2.3. Tick Line

All cattle entering NSW from the tick-infected area of QLD must be treated for cattle ticks before leaving their property of origin. These cattle are then inspected for the presence of cattle ticks at border surveillance, either inside QLD by QLD DPI officials or on the border by NSW DPI staff. If any cows are found to have ticks, these are returned to the property of origin for further treatment. If none are found, these are then treated one more time before proceeding to NSW. All cattle on the tick fever affected properties are undergoing a treatment program to kill ticks and ensure that the tick fever parasite does not spread to other cattle. The following factors at the Tick Line can contribute to the success of this program:

a) Types of treatments
b) Effectiveness of treatment (e.g. resistance to acaricides)
c) Quality assurance (experience of individual inspectors)
d) Quarantine facilities
e) QDPI Certificate of Inspection & Treatment

2.4. Regulations for transporting and selling livestock

The Australian Model Codes of Practice for Welfare of Animals have been prepared for the Standing Committee on Agriculture and Resource Management (SCARM) by representatives of State and Federal Departments with the responsibility for agriculture and/or animal welfare, CSIRO, and other relevant committees with the SCARM system. This Code of Practice is intended as a guide for people who are involved in transporting cattle. It emphasises the responsibilities of the cattle producers, livestock transporters, livestock transport drivers, attendants and railway officials.

In the Code of Practice there are some guidelines about the cleanliness of the floors, loading rates for cattle of various liveweights, and resources required for the watering, feeding, welfare of cattle pre-loading, during loading, transportation and unloading cattle. All required documentations such as Waybill, National Vendor Declaration (NVD) and travel Permit should also be provided by the cattle producer before transporting cattle to different regions within state and interstate.

These documentations will be according to the States Code of Conducts. Issues related to the animal welfare have been adequately addressed in the regulation.

2.4.1. Regulations for transporting and selling livestock in NSW

For transporting cattle into NSW a National Vendor Declaration and Waybill are required. This NVD incorporates the Livestock Production Assurance (LPA) declaration.

2.4.2. Regulations for transporting and selling livestock in Queensland

The *Stock Act 1915* requires travelling alpaca, buffalo, camels, cattle, deer, goats, guanacos, horses, llamas, sheep and vicunas to be accompanied by a waybill. Waybills are completed by the actual owner or authorised agent of the owner or the occupier of the holding of the origin of the stock. Combined National Vendor Declaration (NVD)/Waybills are generally used when stock are moved to saleyards or to slaughter. Waybills describe the livestock being travelled. They are available in duplicate form, with the original to be retained at the destination for two years while the duplicate remains at the property of origin for a period of two years.
Most livestock movements will only require a Waybill but the following movements require a Travel Permit as well:

- **Livestock travelling from the Cattle Tick Infected Area of Queensland to the Cattle Tick Protected or Free Areas of Queensland.**
- **Livestock travelling to interstate destinations.**

There are 4 separate documents that may be required to move livestock in QLD:

1. Queensland Travel PERMIT (issued by an Inspector of Stock). (Permits are issued with specific conditions that MUST be complied with.)
2. Queensland Livestock movement System- Move Easy WAYBILL. (may include National Vendor Declaration Waybill)
3. Cattle Tick Preliminary Treatment OWNER DECLARATION
4. Cattle Tick INSPECTION/TREATMENT DECLARATION. (Issued by an Inspector or Approved Person)

I) Conditions of cattle movement from **tick infected area** into Protected or Free Areas are;

1. Queensland Livestock Movement System- Move Easy WAYBILL. (may include National Vendor Declaration Waybill)
2. Cattle Tick Preliminary Treatment OWNER DECLARATION
3. Cattle Tick INSPECTION/TREATMENT DECLARATION. (Issued by an Inspector or Approved Person)

For cattle movement into NSW border one extra document is required

4. Travelling STOCK Statements (TSS)

II) Conditions of cattle movement from **cattle tick Protected (including provisionally protected) Areas** are;

1. All restricted (infected, Provisionally Clean, First Removed or Second Removed) properties in Protected (or Provisionally Protected) are subject to movement conditions
2. Stock from Clean Non-Restricted properties in the Protected Area have the same movement conditions as apply to Free Area properties.

III) Conditions of cattle movement from **cattle tick Free Area** to any destinations within in QLD or NSW are;

1. Queensland Livestock movement System- Move Easy WAYBILL. (may include National Vendor Declaration Waybill)

For cattle movement into NSW border one extra document is required

2. Travelling STOCK Statements (TSS)

3. Clinical signs

3.1. Tick worry

Heavy infestation of cattle ticks causes loss of condition and even death because of tick worry and loss of blood. When cattle are heavily infested, ticks can be found anywhere on the body. On a lightly infested animal the main places ticks are found are the escutcheon, tail butt, belly, shoulder, dewlap and ears. Hides of heavily infested cattle are damaged by tick bites and their value reduced. In severe cases hides may unsaleable.

3.2. Tick fever

3.2.1. Babesiosis

Babesiosis is caused by two organisms in Australia, *Babesia bovis* and *Babesia bigemina*. Of the two species, *B. bovis* is by far the most important, causing about 80% of outbreaks and an even higher percentage of deaths. Both *Babesia* species are single cell organisms that develop in the red blood cells of cattle and are transmitted in Australia by the cattle tick *Boophilus microplus*.

i) Transmission of *B bovis* takes place when engorging adult female ticks pick up the infection; pass it on to their progeny (larvae or eggs) which, in turn, pass it on when feeding on another animal.

ii) Transmission of *B bigemina* is also from one generation of ticks to the next with engorging adult ticks picking up the infection and nymphal and adult stages of the next generation passing it on to other cattle.

Disease caused by ***Babesia bovis*** is normally severe and large numbers of cattle can get sick and die. Clinical signs of affected cattle include:

- Fever (higher than 40^{o}C) for several days
- Loss of appetite, depression, weakness and reluctance to move
- Red urine (haemoglobinuria) and at the latter stage anaemia and jaundice
- Abortion
- Diarrhoea
- Death within days of the onset of fever
- Nervous signs sometimes develop in a condition known as cerebral babesiosis.

Disease caused by ***Babesia bigemina*** is usually less severe but can develop very rapidly.

- Sudden and severe anaemia, jaundice and death can occur with little warning
- Red urine is present earlier and more consistently than in *B bovis* infections.
- Nervous signs are not seen.

Cattle that recover from either infection may take several weeks to regain condition but recovery is usually complete. Surviving bulls may have reduced fertility for several weeks. In mild infections, signs are less obvious and sometimes even difficult to detect. Calves often show no symptoms after infection.

3.2.2. Anaplasmosis

Anaplasmosis in cattle is caused by *Anaplasma marginale* that invades and multiples in red blood cells. As the disease progresses, infected and even uninfected red blood cells are destroyed mainly in the liver and spleen, resulting in an increasing anaemia and even death in severe cases.

Anaplasmosis is only found in the northern and eastern parts of Australia where the cattle tick is present. Any stage of the cattle tick's life cycle can become infected after feeding on an animal carrying *Anaplasma* organisms in its blood stream. The organism multiplies in the tick and will pass to later stages of the tick

life cycle. However, it doesn't appear the infection is passed on to the eggs in *Anaplasma marginale*. Consequently, the next generation of ticks will not be infected unless they also feed on a carrier cow. Therefore, an infected stage of the tick must transfer to a susceptible animal for transmission to occur. Because the adult male tick is more mobile and lives longer than other stages, it is the most likely stage to transmit the disease.
The severity of clinical signs is age related, but acutely affected cows will show:

- Rapid loss of condition
- Transient fever (40^{o}-41^{o}C at peak infection)
- Weakness and respiratory distress particularly after exercise
- Depression and loss of appetite
- Mucous membranes pale (anaemia) then yellow (jaundice)
- Urine is often brown due to bile pigments, but may be red as in babesiosis
- Severely affected cattle may die.

4. Life cycle and ecology of tick

The cattle tick spends the parasitic stage of its life on the one host. This stage takes about 21 days during which time tick changes from a minute larva to a nymph and finally an adult. Adult females feed slowly for about a week, filling rapidly with blood at the end of that time. Ticks then drop onto pasture, lay up to 3000 eggs and die. Eggs then hatch to produce larvae which then infest the pasture until picked up by a suitable host or eventually die. This non-parasitic stage can vary from approximately 2 months in summer to 6 to 7 months over winter and is adversely affected by extremes in temperature and moisture levels. Males feed occasionally, but do not fill with blood (engorge). Male ticks wander over the cow's body for several months, mating with females. There are four stages in the cattle tick cycle (Figure 2).

Eggs: Eggs hatch into larvae after two to six months; hatching is fastest in warm weather. Cold weather kills eggs; this determines where ticks are found.
Larvae: Larvae or 'seed ticks' hatch from tick eggs on the ground and swarm up blades of grass where they may survive for up to eight months before finding a suitable host. Once attached to a host animal, they feed by sucking blood for five to six days. They then moult and transform into nymphs.
Nymphs: Nymphs feed on blood for another six to eight days and then moult to become adults.
Adults: Females feed for 7 to 12 days, engorging rapidly with blood at the end of that time. They then drop off into the pasture, where they lay up to 3000 eggs and then die.

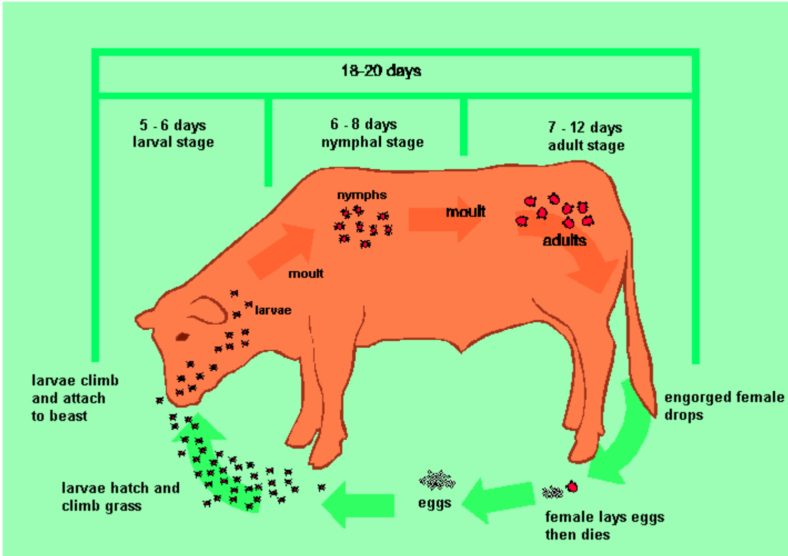


Figure 2. Life cycle of ticks (Source: WA Agriculture Department)

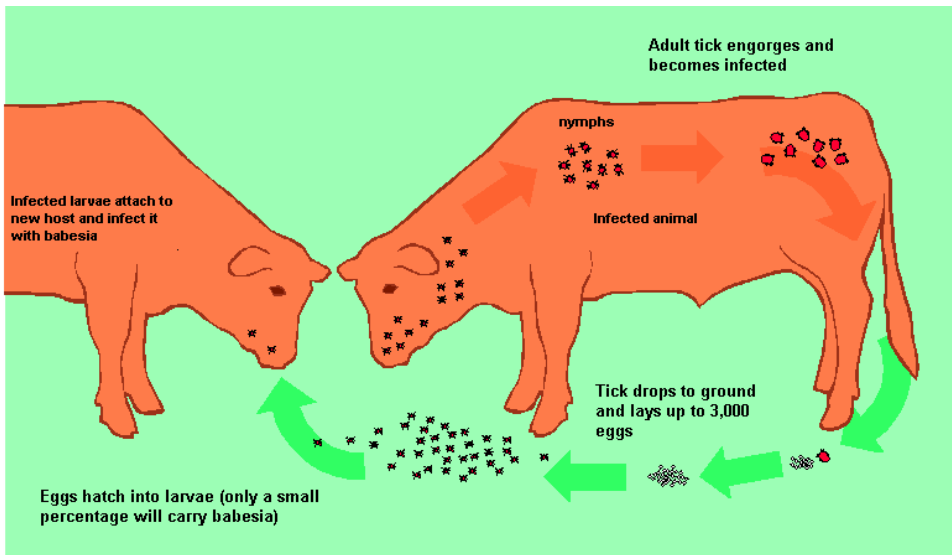


Figure 3. Babesia are taken from an infected animal when female ticks engorge with blood and transfer Babesia through tick eggs to the larvae. The disease spreads when larval ticks attach to a new host, infecting it by injecting saliva carrying the organisms (Source: WA Agriculture Department)

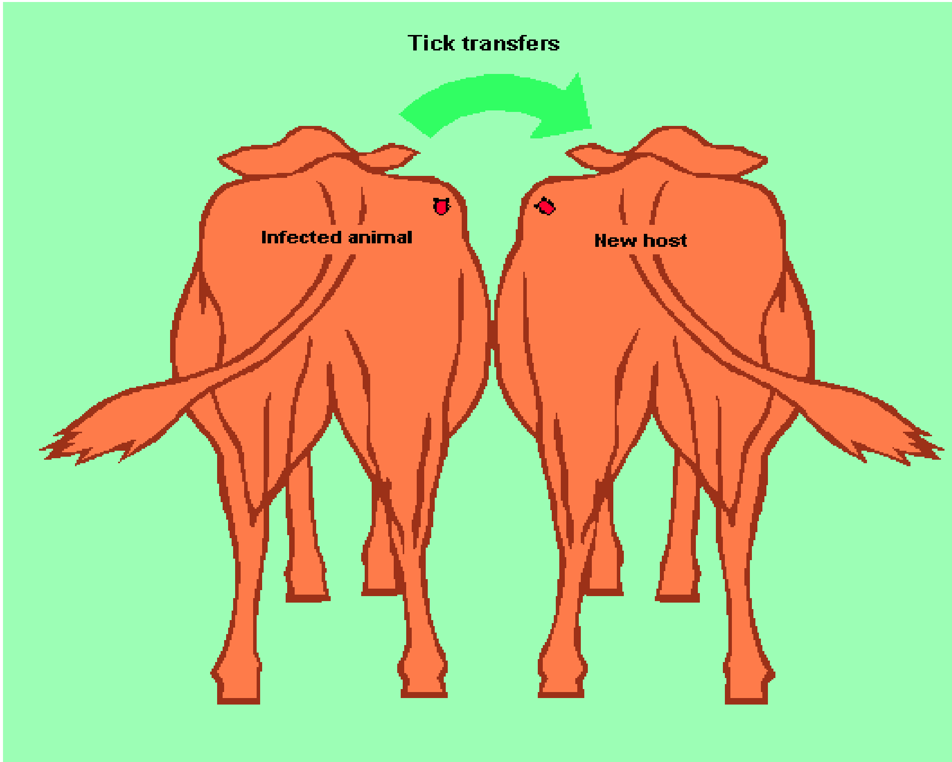


Figure 4. *Anaplasma* is transmitted when infected ticks are transferred directly from one animal to another. These parasites are not transmitted from one generation of ticks through the eggs to the next generation (Source: WA Agriculture Department)

There are four major influences on tick populations (Figure 5):

i) The effect of pasture micro-climate on the development and survival of free-living stages

ii) The effect of cattle density and movement on the host-finding rate

iii) The effect of host resistance on ticks

iv) The effect of antiparasitic drugs (dipping) on the survival of parasitic ticks

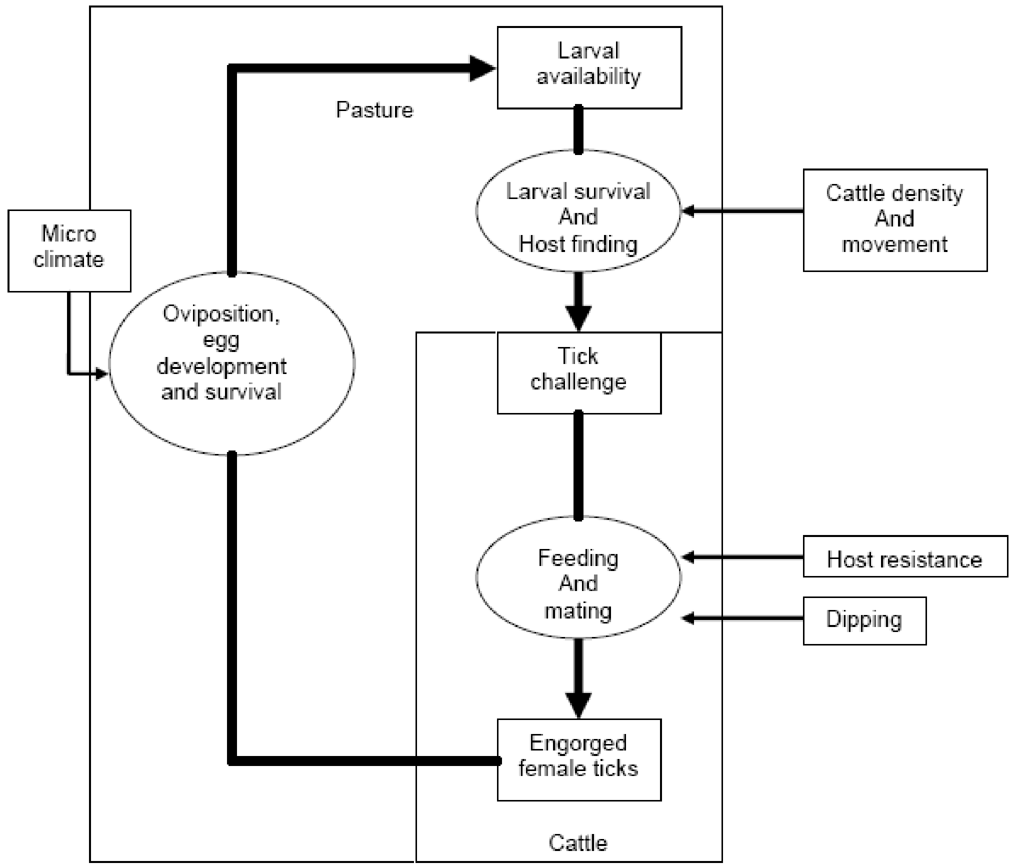


Figure 5: Structure of the cattle tick model, illustrating how climate and management affect core population processes (in oval enclosures) (Source: Norton et al. 1983).

4.1. Seasonal incidence

Temperature and humidity can be risk factors, as good seasons increase tick numbers. Distribution of the cattle tick is primarily limited by climate. Ticks are rarely found in areas receiving less than 500ml of rain and average temperature of less than 16^{o}C. Season of the year when cattle move into NSW is a risk factor.

- ***Southern QLD***:
  - Ticks which fall between mid April and late June produce virtually no progeny.
  - Engorged female ticks dropped in early autumn (e.g. March) can produce larvae that will survive the winter and eventually result in a spring rise in tick numbers.

- ***Central and North QLD***: Ticks lay viable eggs all year round.
    - o Central QLD- there is a slowing down during winter
    - o North QLD- wet season interferes with tick production.

summer:
50% of the larvae survive for 2 weeks,
10% of the larvae survive for 4 weeks
Winter:
50% of the larvae survive for 3-4 weeks
10% of the larvae survive for 6-11 weeks

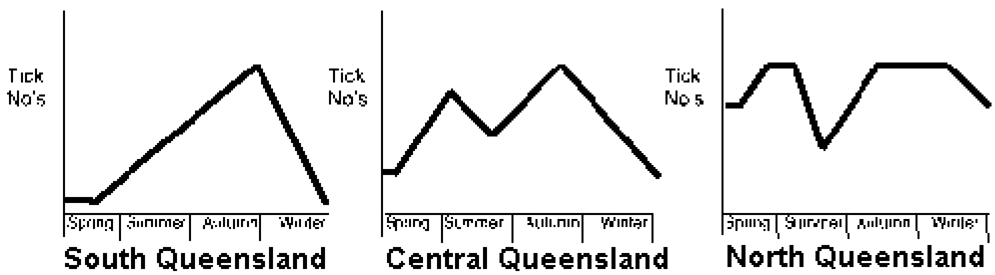


Figure 6: Tick populations in QLD during different seasons (Source: QLD Department of Primary Industries)

4.2. Ecology of cattle ticks

The sizes and seasonality of tick populations depend on the survival of ticks through the three life-cycle processes:

i) free-living development

ii) host finding

iii) parasitic feeding and mating

4.2.1. Survival rate of free-living ticks

Several factors can cause a reduction in reproductive potential of engorged female ticks in natural conditions (Sutherst et al. 1988a). In the natural environment, when engorged female ticks are dropped on grass, the ticks are free to select their oviposition sites and are subject to predation throughout the period of their development in the pasture.

- Predation of female
- Failure to find suitable oviposition site
- Reduced fecundity
- Egg mortality
- Low viability of larvae due to stress of eggs

- Mortality of newly hatched larvae under field conditions
- Failure of larvae to ascend pasture

4.2.2. Host-finding by cattle tick

The total proportion of larvae finding a host could be expressed as a function of the product of the host-finding rate and the median duration of survival of the larvae. Despite the pervasive impact of cattle density and movement on the cattle tick life system, in most situations it is the effect of host-finding rate that is likely to have the major impact on tick population dynamics (Norton et al. 1983).

At stocking rates of about two cows per hectare the cattle can pick up between 30 and 70% of the larvae in a week, whereas with five cows per hectare the pick up is between 50 to 85%. Each cow can effectively pick up all the ticks from an area of 0.022-0.075 hectare each day. Low temperature can reduce these rates (Sutherst et al. 1977). Sutherst et al. (1977) developed a model to investigate the sensitivity of the host-finding component of the tick's life system to the parameters controlling the process. Figure 5 shows the details of this model.

- In south-east QLD; two head per hectare, larvae pick up from pasture is between 30 and 70% in a week.
- In south-east QLD; Five head per hectare, larvae pick up from pasture is between 50 to 85% in a week.
- Each cattle beast can effectively pick up all the ticks from an area of 0.022-0.075 hectare each day.
- Other reports (Norton et al., 1983) indicate that if stocking rate in south-east QLD is between 2-3 hectare per animal, host-finding rate will be around 20% per week.
- Host-finding rate and stocking rate are expected to fall in an approximately linear fashion.
- Pasture spelling. Cattle enter into NSW will directly be sent to the abattoir- therefore pasture spelling will be irrelevant.

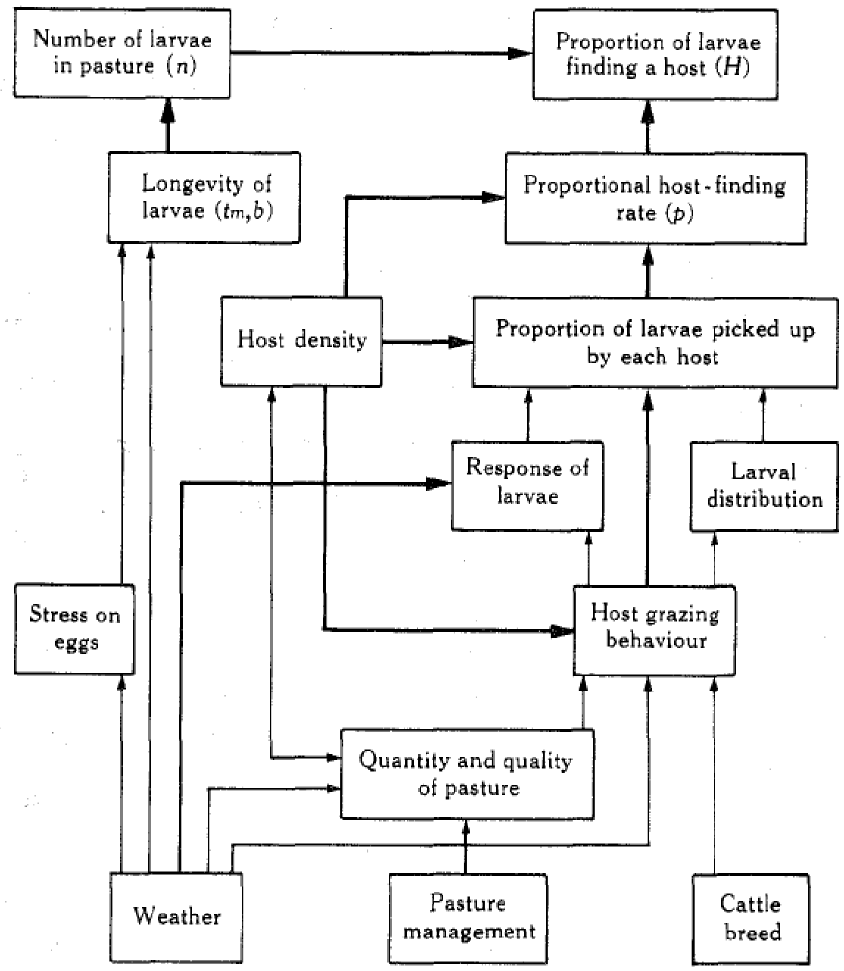


Figure 7. Conceptual model of subcomponents of host finding developed by Sutherst et al. 1977 (Aust. J. Zool. 1977)

The potential for controlling ticks by reducing stocking rate will depend on the current level of stocking and its relationship to host-finding rate. The usual stocking rate in south-east QLD, of 2-3 ha per head, is estimated to be associated with a host-finding of around 20% per week. If this stocking rate is reduced, e.g., 25%, the host-finding rate can be expected to fall in an approximately linear fashion, to 15% per week (Norton et al. 1983). A reduction of 25% in stocking rate can reduce the host-finding rate from 0.2 to 0.15.

4.2.3. Survival rate of parasitic feeding ticks

The survival of parasitic ticks on various types of cattle (*B. indicus*, *B. taurus* and cross-bred) has been measured under field conditions using artificial infestations of known numbers of tick larvae (Sutherst et al. 1988a,c; Bourne et al. 1988). Tick population increases exponentially with increasing *B. taurus* content in cattle, associated with higher survival rates of parasitic stages. Cattle with lower resistance not only allow more ticks to survive, they also contaminate the pastures with many more engorged ticks, leading to a cumulative build up in tick populations.

4.3. Effects of temperature and humidity on tick life cycle in QLD and NSW

Studies of Sutherst et al. (1988a,b,c) on free living stages of cattle tick in two regions of QLD, central and southern) during November 1977 to May 1982 showed that engorged ticks produced more larvae throughout the year in central QLD, despite laying fewer eggs. The colder and longer winter in southern QLD greatly reduced tick reproduction. Failure of engorged ticks to survive predation and find a favourable oviposition site, egg mortality and loss of larvae in the pasture accounted for most of the reduction in the potential number of larvae produced. Reduced oviposition was also important during winter time.

The survival rate of tick eggs through to hatching is related to the initial age of the eggs, the severity of the treatments and the duration of exposure. There is a relationship between desiccation and weight loss of eggs and, secondarily between weight loss of eggs and mortality. Mortality rate of eggs increases with weight loss of eggs until it reaches 100% when the weight loss is about 35%. Low temperatures are increasingly detrimental to eggs as these reduce from 14 ^{o}C to 5^{o}C. Freshly laid eggs are more susceptible to both low temperature and desiccation than are older eggs (Sutherst and Bourne, 2005).

Larvae emerging from eggs that are stressed by either cold or desiccation live for a shorter time under optimal conditions than those larvae from eggs under optimal conditions. Larvae from eggs with the same hatching rate have the same viability, whether the stress is induced by desiccation or low temperature (Sutherst and Bourne, 2005).

Laboratory studies of Hitchcock (1955) on the effects of temperature and relative humidity on the non-parasitic stages of *B. microplus* showed that larvae longevity is influenced markedly by temperature and humidity. A maximum of 240 days was recoded at 22^{o}C and 90% humidity. This study also showed that larvae are able to recoup water losses sustained at low relative humidity by absorption from the atmosphere during the subsequent period of high relative humidity (Hitchcock, 1955).

A model of the survival of larvae of the cattle tick, *B. microplus*, on pasture in south-eastern and central QLD was developed by Utech et al. (1983). They demonstrated that in summer 50% of the larvae survived for 2 weeks and 10% survived for 4 weeks. Comparable values for winter were 3-4 and 6-11 weeks, respectively.

4.3.1. Tick biology in southern QLD

- Population of ticks on cattle is high in summer and autumn and low in winter and spring.
- Female ticks dropping on pasture during April and July produce no progeny. The reproductive failure combined with the dying out of larvae and protracted developmental period, reduces the larvae population to very low levels during the months of August-October (Snowball, 1957).
- Ticks dropping on pasture from late July to the following autumn produce progeny. Ticks dropping during late winter and early spring will hatch at about the same time in the late spring which will lead to a "spring rise" in tick population on cattle (Snowball, 1957)
- It appears likely that engorged female adults dropped in the **early autumn** represent the **most important stage** in the over-wintering of the species in this area (Snowball, 1957).

4.3.2. Observations on the biology of ticks in south-eastern QLD and northern NSW

- In elevated areas of south-eastern QLD and northern NSW there is an overlapping of the distribution of three species of ticks which infest cattle. Apart from the indigenous tick *Ixodes holocyclus* Neumann, there are two species of introduced ticks, *Haemaphysalis (Kaiseiana) longicornis* Neumann and *Boophilus microplus* (Canestrini) (Sutherst and Moorhouse, 1972).
- *Ixodes holocyclus* is indigenous to Australia (Roberts 1960) and differs from the other two species (*Haemaphysalis longicornis* and *Boophilus microplus*) in that it does not require a bovine host to support it; cattle appear to be accidental hosts. A further difference is the activity in winter of all stages of this species, but particularity the nymphs. The rate of development of all stages of *Ixodes holocyclus,* is also much slower than that of the other two species (Ross, 1924).
- The one-host tick, *B. microplus*, is strongly host-specific and require cattle for its survival. Although the larvae are active, the fed females and the eggs are unable to develop in the cooler months, so *B. microplus* survived the winter by a very slender margin of safety, being dependent upon the chance persistence of some larvae until late in the winter.
- In the area of south-east QLD and north NSW *Haemaphysalis longicornis*, also appear to be dependent upon cattle, as only cattle and dogs are recorded as hosts (Sutherst, 1970). This tick is much less host-specific than *B. microplus* (Myers, 1924) and the dependence upon cattle is probably due to insufficient numbers of alternative hosts. Unlike the other ticks, *H. longicornis*, is found in all stages during the winter.

- Both *I. holocyclus* and *H. longicornis* are well adapted to conditions similar to those at Mt. Tamborine, while *B. microplus* is close to that limit of its range set by low temperature of long duration (Sutherst and Moorhouse, 1972).
- Ecological studies of *B. microplus* in north coast district of NSW during 1962-1965 by McCulloch and Lewis (1968) showed:

i) The maximum longevity, from the dropping of the female parent in the field to the death of the last larva, of the non-parasitic stages of the cattle tick in northern NSW would be around 7.5 months. The majority of larvae die within 6 months of the parent leaving its host.

ii) In the warmer parts of the former Tick Quarantine Area in Northern NSW, ticks falling in favourable situations may lay eggs in any month. The winter climate may slow the development but does not prevent it. The tick population in NNSW is at its lowest level in September.

iii) The cattle tick could probably survive as a pest as far south as Newcastle.

iv) The time of year for the start of an eradication campaign would not be of first importance. Strategic dipping program for the ecological control of cattle ticks, the optimum time would be early October in the areas most favourable to the ticks.

v) The longevity of ticks reported from 1917 till 1962 ranges between 133 to 319 days, with an average of not more than 200 days.

vi) The “spring rise” of ticks would probably not occur until late October in the Tweed area and late November west of the (Richmond) Range and that engorged females would probably not produce viable progeny when dropped after mid- and early March respectively.

vii) Wollongbar ticks could reproduce after falling from cattle in any part of the winter, provided they can find relatively warm situations such as pasture with a north-easterly aspect. Those ticks falling in shade in April to July would die without laying or have their eggs killed by cold.

viii) In the Wollongbar region, winter temperatures are not fatal to larvae. Ticks are abundant and active on the grass in June, July and August, but number of ticks decline to the lowest at the end of September.

ix) In the Pretty Gully region, near the western boundary of the Tick Quarantine Area during the early spring, there is a definite break of some 4 months in which tick eggs, if laid, fail to hatch. However, the natural populations would survive as eggs laid by ticks which had found hosts in July, August and September.

x) In Wollongbar and Pretty Gully regions, the tick populations have not been affected by drought.

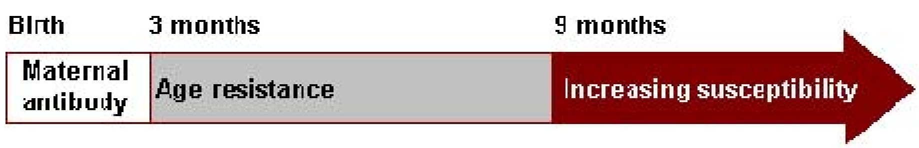
xi) The mild winters and relatively moist summer of the coastal strip indicate that *B. microplus* could survive permanently some hundreds of kilometre south of Grafton.

xii) Efforts at quarantine which appear to have held the line near Grafton would probably have failed had not the climate been relatively unfavourable to the tick.

xiii) At Tabulam tick at the ecology site are less restricted by winter cold than at Pretty Gully, but markedly more damaged by dehydration in the spring and summer.

4.4. Age resistance

Calf exposure to infected ticks is one of the keys to natural tick fever protection. The age of cattle at the time of first exposure to tick fever determines how severe the disease is likely to be. The older they are, the worse it is likely to be. Calves from immune mothers receive temporary protection (maternal antibody) against tick fever through the colostrum. The protection lasts about 3 months. In most calves this is followed by an age resistance that stays with the animal until about 9 months of age. Calves exposed to tick fever when the age of resistance is high rarely show clinical signs and develop a solid long-lasting immunity. If this happens to all calves, tick fever will be a problem, but calves have to be exposed to all 3 parasites (*B. bovis*, *B. bigemina* and *A. marginale*) (QLD Department of Primary Industries)



4.5. Number and survival rate of parasitic ticks on different breeds of cattle

The resistance of cattle to *Boophilus microplus* varies with cattle breed, sex, age and lactation and with season and nutrition (Sutherst and Utech, 1981). This variation can have large effects on the sizes of natural populations of cattle ticks (Sutherst et al., 1979; Mahoney et al. 1981). A summary is given in Table 2 of the mean numbers of standard ticks on each breed of cattle in two regions with mean percentage survival of artificial infestation of 20000 larvae. The survival of parasitic ticks on various types of cattle has been measured under field conditions using artificial infestations of known numbers of tick larvae (Sutherst et al. 1988c). The factors affecting resistance of cross-bred herds could be the proportion of *B. indicus* genes, lactation, age interacting with nutritional conditions, and seasonal cycle which differ in timing at different locations, and rainfall during the week of tick infestation.

Table 2. Mean daily numbers of standard ticks per beast from natural infestation, with the mean percentage survival (S) of 20000 larvae from artificial infestations of parasitic stages of the ticks for infested (I) and census (C) herds at Craighoyle and Willowbank from 1978 to 1981 (T herd for 1978, TTZ herd from 1979 to 1981)

	Z(C)	**TZ(C)**	**TZ(I)**	**TTZ(I)**	**T(I)**
			Craighoyle		
Mean ticks beast^{-1} day^{-1}	5	67	62	79	465
% survival of parasitic ticks	1.2	2.9	3.2	2.9	12.5
			Willowbank		
Mean ticks beast^{-1} day^{-1}	0.5	6	15	37	203
% survival of parasitic ticks	0.8	3.4	2.5	5.7	20.5

Z: *B. indicus*. TZ: *½ B. indicus, ½ B. Taurus*. TTZ : *¼ B. indicus*, *¾ B. taurus*. T : *B. taurus*

Findings of Bourne et al. (1988) in central and southern QLD showed that:

- Tick numbers increases exponentially with decreasing *B. indicus* content.
- The pure *B. indicus* (Zebu) cows carried an average of five ticks per cow per day in central QLD and only one tick in southern QLD.
- The 50% *B. indcus* (Zebu) breed herds carried 65 ticks per cow per day in central QLD and 11 ticks in southern QLD.
- The 25% *B. indicus* (Zebu) breed herds carried 79 ticks per cow per day in Central QLD and 37 ticks in southern QLD
- The pure *B. taurus* cows carried 465 tick per cow per day in Central QLD and 302 ticks in southern QLD

They concluded that changes in the tick burden on the herds can be explained mostly by changes in survival rates of parasitic ticks in central QLD and by changes in availability of larvae on pastures in southern QLD.

*4.6. Hosts of cattle tick **Boophilus microplus***

Boophilus microplus is well known in Australia as a parasite of cattle. However, it has frequently been found on horses, sheep and deer. It has also been collected, less frequently, from bufalloes, pigs, marsupials (Kangaroo and wallaby) and domestic dogs (Seddon, 1951; Roberts, 1952). Horses can carry large numbers of ticks, usually only a few engorged female ticks are recovered, which could be due to hypersensitivity reaction which causes heavy mortality. In addition, when experimental hosts were prevented from grooming themselves, ticks could mature on some laboratory animals (mice and rabbits) (Riek, 1959). Development of ticks on mice was slower than on cattle. Similarly Callow and Hoyte (unpublished data) demonstrated that *B. microplus* could mature successfully on goats.

Other domestic animals, mentioned above, are sometimes in more or less close association with infested cattle, and hence might act as casual hosts of the tick. Hoyte (1964) showed that very few ticks can mature on the adult dogs only, the yield of adult female ticks was very low and variable (0.01% in dogs; compared with 4.5% in cattle), more time was needed to mature on dogs than on cattle, and size and egg production were also reduced. Their data also showed that no ticks can mature on young foxes and dingoes. Hoyte (1964) concluded that for controlling the cattle tick, the presence of dogs represents no risk to success, where eradication is the aim; dogs can represent some risk to the success of the eradication plan.

5. Risk assessment

In this section those factors that can affect the risk of entry and exposure will be discussed. The analytic part of this risk assessment will be discussed in the next chapter.

5.1. Risk of entry

5.1.1. Cattle

5.1.1.1. Source of cattle in QLD

Under the Stock Act, QLD is divided into five main tick areas for movement control purposes. The protected areas are marginal areas which are generally free of ticks but can become infected when seasonal conditions are favourable. Before entering tick free, protected or eradication areas stock from the tick infected area must be inspected clean and treated under the supervision of an Inspector of Stock. Similarly there are restrictions on inter-state stock movement. The number of cattle entering into NSW from different areas of QLD farms are required to enable us to assess the risk of cattle tick to NSW cattle.

5.1.1.2. Feeding systems

Cattle entering into NSW may come from different feeding systems. Risk of carrying ticks in grazing cattle is much greater than those in feedlot situations.

5.1.1.3. Age of cattle

Older cattle carry more ticks than younger cattle.

5.1.1.4. Sex of cattle

Male cattle carry more ticks than females.

5.1.1.5. Breed of cattle

British and European breed cattle are more susceptible to tick fever than Brahman breeds. *Bos indicus* cattle have significant resistance to *Babesia bovis* and *Babesia bigemina*. Nearly 20% (1 in 5) confirmed tick fever cases involve *Bos indicus* type cattle. Bos Indicus type cattle are very susceptible to *Anaplasma marginale*. Number of cattle from different breeds that are transported from QLD to NSW can contribute to the risk factors for tick fever;

a) *Bos taurus*

b) *Bos indicus* (carry less ticks than British and European animals)

c) Cross-bred (½ *B. taurus*, ½ *B. indicus*)

d) Cross-bred (¼ *B. taurus*, ¾ *B. indicus*)

e) Dairy

5.1.1.6. Stressed cattle

Conditions that cattle are kept under can influence the number of ticks on the animal. For example poor body condition and pregnant cattle carry more ticks than well conditioned non-pregnant cattle.

5.1.2. Tick factors

5.1.2.1. Number of ticks carried by different breeds of cattle

The resistance of cattle to *B. microplus* varies with cattle breed (Sutherst and Utech, 1981). The number of ticks carried by cattle carried in different breeds. Sensitivity test will conducted with different figures.

Table 3. Tick numbers for different breeds

Breeds	**(ticks/day)**	
	MLA estimates (2005)	**Bourne et al. 1988 (under experimental conditions)**
Bos taurus	14 – 41	302 – 465
Bos indicus	1 – 5	1 – 5
Cross-bred (½ *B. taurus*, ½ *B. indicus)*	7 – 21	11 – 65
Cross-bred (¼ *B. taurus*, ¾ *B. indicus*)	-	37 – 79
Dairy	14 – 41	302 – 465

5.1.2.2. Survival rate of free-living ticks

Sutherst et al. (1988a) highlighted the factors (see ecology of ticks) that can cause a reduction in reproductive potential of engorged female ticks in natural conditions. To be able to asses the risk of ticks dropped off cattle, it is required to have some estimates on the survival rate of free-living ticks in different environments.

5.1.2.3. Host-finding factor

Stocking rate can contribute to the tick pick up by cattle (Each cow can effectively pick up all the ticks from an area of 0.022-0.075 hectare each day).

Table 4. Percentage of larvae picked up by cows/week

No of cows/hectare	**Larvae pick up (%/week)**
	(Sutherst 1977)
2	30 – 70
5	50 – 85
No of hectare/cow	**(Norton et al. 1983)**
2-3	20

5.1.2.4. Survival rate of parasitic feeding ticks

The survival of parasitic ticks on various types of cattle has been measured under field conditions using artificial infestations of known numbers of tick larvae (Sutherst et al. 1988b,c; Bourne et al. 1988).

Table 5. Survival rate of parasitic ticks

Breed	**Survival rate of parasitic tick Mean & range (%)**
	(Sutherst et al. 1988c)
Bos taurus	12.5 (12.5 – 20.5)
Bos indicus	1.0 (0.8 – 1.2)
Cross-bred (½ *B. taurus*, ½ *B. indicus*)	2.9 (2.5 – 3.2)
Cross-bred (¼ *B. taurus*, ¾ *B. indicus*)	4.3 (2.9 – 5.7)
Dairy	12.5 (12.5 – 20.5)

5.1.2.5. Number of infected ticks

One infected tick is sufficient to transmit the infection but only a very small number of ticks actually carry the disease.

Table 6. Number of infected ticks with different protozoa

Protozoa	**Region**	***Infected ticks (% & N) - QLD DPI***

Babesia bovis	The Infected Area	(0.02%) 1 in 5000
	Protected Area	
Babesia bigemina	Infected Area	(0.2%) 1 in 500
	Protected Area	
Anaplasma marginale	Infected Area	
	Protected Area	

There are no data on the number of infected ticks with *Anaplasma marginale*. Losses due to anaplasmosis can be as high as 20-30%, although mortality of 5-10% in newly infected herds are more common.

5.1.3. Season or month of year of different regions in QLD and NNSW

Distribution of the cattle tick is primarily limited by climate. Ticks are rarely found in areas receiving less than 500mL of rain and average temperature of less than 16^{o}C. Season of the year when cattle move into NSW is a risk factor.

5.1.4. Presence of other hosts for cattle tick on the transport route and abattoir

Other domestic and wildlife animals can also carry cattle ticks. Ticks can also mature and reproduce on some of these species (see ecology of cattle ticks). However, the duration and survivability of cattle ticks in other species are different. These hosts have the potential to contribute in the risk of spreading ticks in the NNSW region.

5.1.5. Transport companies

Australian Livestock Transport Association is responsible for the transport of live cattle across Australia. The following factors can contribute to outbreaks. The transport companies and some of the drivers were interviewed to collate information;

a) Number of cattle transferred per truck (density rate)
b) Quarantine facilities
c) Quality assurance
d) Hygienic and disposal facilities
e) Truck design
f) Animal welfare issues for transporting cattle (e.g. need to water)
g) Operator factors (drivers)

h) Number and duration of stops for resting

i) Duration of trip

j) Truck breakdown (RTA)

5.1.6. Routes of transport

a) Proximity of road to farms

b) Stock routes

c) Surveillance

5.2. Risk of exposure

5.2.1. Risk of exposure en route to abattoir

This risk is related to the probability of ticks falling off a truck, during transportation in NSW, on the road or road sides during the stop times. Those factors that may determine the probability of tick release during the transport are duration of trip, stock routes, suitability of environment, operator factors and holding QDPI certificate of inspection and treatment. This also includes the likelihood of ticks to spread into the nearby farms in the case of accidents, when cattle are required to be held in the nearby paddock.

5.2.2. Risk of exposure in abattoir

Cattle entering the NSW border will be directed into one of the abattoirs in NSW. The risk of spreading the tick during the slaughter will be discussed here, and these risk points are at holding facilities, abattoir, and hide retention and treatment.

5.2.2.1. Holding yard

Cattle are held in the holding yard for a short period of time, before they are slaughtered. If cattle in the holding yards carry ticks, there is a possibility that the ticks can spread out of holding facilities. Following risk points need to be checked:

i) Holding times determined by animal welfare

ii) Transfer on staff/dogs

iii) Holding yard facilities (e.g. watering facilities.

Following factors may facilities these risks

i) Delay to slaughter

ii) Interruption in slaughter process (e.g. breakdown)
iii) Suitability of environment in the yard for tick spread (e.g. temperature)
iv) Proximity to farms or sale yards
v) Quality assurance
vi) Quarantine facilities
vii) Other opportunities for spread (e.g. public holidays, staff strikes, etc.)
viii) Washdown from abattoir holding yards

5.2.2.2. Abattoir

Risks points in the abattoir during the slaughtering process are;

i) Effluent
ii) Transfer on staff

Facilitating factors for these risk points are:

i) Suitability of environment for tick spread
ii) Quality assurance
iii) Quarantine facilities

5.2.2.3. Hide retention and treatment

When cattle are slaughtered, the hides will be washed and treated. The following risk points should be considered during this process:

i) Hides disposal and treatment
ii) Effluent
iii) Transfer on staff
iv) Interval from slaughter till treatment

The following are the facilitating factors for these risk points:

i) Staff experience
ii) Efficacy and type of treatment
iii) Disposal and treatment procedures
iv) Quality assurance
v) Quarantine facilities

Appendix I

Table 1. Number of cattle transported into NSW from free zone of QLD (2002-2003)

Destination abattoir in NSW	Consignment	No of cattle
ADELAIDE	2	56
ARMIDALE	1	25
BOGGABILLA	2	103
BOOYONG	3	370
CASINO	970	38900
COFFS HARBOUR	1	12
COOMA	5	192
COONAMBLE	1	120
DUBBO	2	618
ECHUCA	1	16
EVERSON	1	64
FORBES	21	1250
FREDERICKTON	10	340
GEPPS CROSSING	1	192
GRAFTON	63	4448
INVERELL	342	30540
KEMPSEY	4	225
KILLARNEY	2	48
KYNETON	2	148
MUDGEE	4	262
MURRAY BRIDGE	1	29
NARACOORTE	2	476
REPTON	4	266
SCONE	17	636
SHEPPARTON	1	105
SINGLETON	96	7728
SWAN HILL	2	200
TAMWORTH	197	13900
TNGALA	1	63
TONGALA	13	418
WAGGA	36	2700
WARRNAMBOOL	22	1740
WINGHAM	37	4159
YANCO	1	100
YUNGAN	1	2
Total	**1869**	**110451**
Percentage of total Cattle transported from QLD to NSW	**78.20%**	**78.25%**

Table 2. Number of cattle transported into NSW from infected zone of QLD (2002-2003)

Destination abattoir in NSW	Consignment	No of cattle
CASINO	30	1430
GRAFTON	6	612
INVERELL	4	301
MUDGEE	1	59
TONGALA	1	21
WINGHAM	1	66
Total	**43**	**2489**
Percentage of total Cattle transported from QLD to NSW	**1.80%**	**1.76%**

Table 3. Number of cattle transported into NSW from protected zone of QLD (2002-2003)

Destination abattoir in NSW	Consignment	No of cattle
CASINO	231	11120
COOMA	2	50
GRAFTON	134	10512
INVERELL	77	4620
MUDGEE	6	232
SINGLETON	14	982
TAMWORTH	4	213
WAGGA	3	138
WINGHAM	7	340
Total	**478**	**28207**
Percentage of total Cattle transported from QLD to NSW	**20.00%**	**19.98%**

Appendix II

Table 1. Calculations of entry probability

Description of Probability	**Calculations for different zones**		
	Infected		
	Current regulations	**Current regulations lifted**	**Protected**
Probability consignment tick positive	0.0000002	0.0011	0.0000001
Number of tick positive consignments per year	0.0000620	0.28786	0.0000179
Proportion *B. taurus*	0.05	0.05	0.20
Proportion *B. indicus*	0.35	0.35	0.18
Proportion *B. taurus* x *B. indicus*	0.60	0.60	0.63
Number *B. taurus* per consignment	3.57	3.57	10.56
Number *B. indicus* per consignment	25.02	25.02	9.25
Number *B. taurus* x *B. indicus* per consignment	42.90	42.90	33.03
Number tick-positive *B. taurus* imported per year	0.0002	1.0291	0.0002
Number tick-positive *B. indicus* imported per year	0.0016	7.2037	0.0002
Number tick positive *B. taurus* x *B. indicus* imported per year	0.0027	12.3493	0.0006
Total number of ticks on tick-positive *B. taurus*	0.0390	180.9507	0.0166
Total number of ticks on tick-positive *B. indicus*	0.0057	26.4137	0.0002
Total number of ticks on tick-positive *B. taurus* x *B. indicus* per year	0.0922	428.1095	0.0102
Total number of ticks on tick-positive cattle	0.1369	635.4739	0.0271

Appendix III

Table 1. Calculations of release probability

	Description of Probability	Calculations of probabilities
P1	= REL1 * REL2 * REL3 * REL4 * REL5	0.0000000001
P2	= REL1 * REL2 * REL3 * REL4 * (1 - REL5)	0.0000000052
P3	= REL1 * REL2 * REL3 * (1 - REL4) * REL5	0.0000000052
P4	= REL1 * REL2 * REL3 * (1 - REL4) * (1 - REL5)	0.0000010232
P5	= REL1 * REL2 * (1 - REL3) * REL4 * REL5	0.0000000052
P6	= REL1 * REL2 * (1 - REL3) * REL4 * (1 - REL5)	0.0000010232
P7	= REL1 * REL2 * (1 - REL3) * (1 - REL4) * REL5	0.0000010232
P8	= REL1 * REL2 * (1 - REL3) * (1 - REL4) * (1 - REL5)	0.0002029358
P9	= REL1 * (1 - REL2) * REL3 * REL4 * REL5	0.0000000052
P10	= REL1 * (1 - REL2) * REL3 * REL4 * (1 - REL5)	0.0000010232
P11	= REL1 * (1 - REL2) * REL3 * (1 - REL4) * REL5	0.0000010232
P12	= REL1 * (1 - REL2) * REL3 * (1 - REL4) * (1 - REL5)	0.0002029358
P13	= REL1 * (1 - REL2) * (1- REL3) * REL4 * REL5	0.0000010232
P14	= REL1 * (1 - REL2) * (1- REL3) * REL4 * (1 - REL5)	0.0002029358
P15	= REL1 * (1 - REL2) * (1- REL3) * (1 - REL4) * REL5	0.0002029358
P16	= REL1 * (1 - REL2) * (1- REL3) * (1 - REL4) * (1 - REL5)	0.0402493889
P17	= (1 - REL1) * REL2 * REL3 * REL4 * REL5	0.0000000006
P18	= (1 - REL1) * REL2 * REL3 * REL4 * (1 - REL5)	0.0000001205
P19	= (1 - REL1) * REL2 * REL3 * (1 - REL4) * REL5	0.0000001205
P20	= (1 - REL1) * REL2 * REL3 * (1 - REL4) * (1 - REL5)	0.0000238919
P21	= (1 - REL1) * REL2 * (1 - REL3) * REL4 * REL5	0.0000001205
P22	= (1 - REL1) * REL2 * (1 - REL3) * REL4 * (1 - REL5)	0.0000238919
P23	= (1 - REL1) * REL2 * (1 - REL3) * (1 - REL4) * REL5	0.0000238919
P24	= (1 - REL1) * REL2 * (1 - REL3) * (1 - REL4) * (1 - REL5)	0.0047386081
P25	= (1 - REL1) * (1 - REL2) * REL3 * REL4 * REL5	0.0000001205
P26	= (1 - REL1) * (1 - REL2) * REL3 * REL4 * (1 - REL5)	0.0000238919
P27	= (1 - REL1) * (1 - REL2) * REL3 * (1 - REL4) * REL5	0.0000238919
P28	= (1 - REL1) * (1 - REL2) * REL3 * (1 - REL4) * (1 - REL5)	0.0047386081
P29	= (1 - REL1) * (1 - REL2) * (1- REL3) * REL4 * REL5	0.0000238919
P30	= (1 - REL1) * (1 - REL2) * (1- REL3) * REL4 * (1 - REL5)	0.0047386081
P31	= (1 - REL1) * (1 - REL2) * (1- REL3) * (1 - REL4) * REL5	0.0047386081
P32	= (1 - REL1) * (1 - REL2) * (1- REL3) * (1 - REL4) * (1 – REL5)	0.9398344417
P total	= P1 + P2 + … + P32	1.0000000000

Appendix IV

Risk Model

Cattle movement scenario
A scenario tree was developed using PrecisionTree 4.5.4. (Palisade, USA), based on two assumptions:

i) Cattle transported by trucks may carry ticks and enter into NSW and are slaughtered in commercial abattoirs
ii) Cattle transported by trucks may not carry ticks and enter into NSW and are slaughtered in commercial abattoirs

A questionnaire was developed to collect information that is required for this process.

NOTE: Cattle from different regions of QLD were processed/treated differently before entering into NSW. Cattle producers from all zones obtain travel permits to enable them to move their cattle into NSW.

a) **Free zone**- cattle from unrestricted properties of the QLD free zone are not required to be treated at the property or at the tick line before movement. The owners need to obtain the required documents from QLD and NSW DPIs, and cattle then can be transported into NSW without further treatments at the tick line. Cattle from quarantine properties of the QLD free zone will be required to be treated, similar to those properties in the infected zone.
b) **Protected zone**- Cattle that are transported from the QLD Control zone are required to be processed at the property or clearing facility centre, before being transported into NSW;
    - Pre-treatment- cattle must be treated for ticks at the property (dip or pour ons)
    - The final clearance of a clean inspection and supervised treatment can be either on property in the control zone or at a clearing facility centre.
    - Inspection - cattle must be inspected manually by QLD DPI&F Stock Inspector or an Approved Person.
    - Treatment - cattle must be treated again after inspection at the property or clearing facility centre (Tick Line)
    - Certificate of Inspection or Treatment (or a Travel Permit) will be issued by DPI&F Inspector or Approved Person indicating all procedures have been conducted and cattle are clean and tick-free.

- These cattle can then cross the border into NSW without further treatment

c) **Infected zone** - cattle that are transported from the infected zone are required to receive preliminary treatments on the property and final clearance procedures are undertaken at the tick line, before transport into NSW;

- Pre-treatment - cattle must be treated at the property (dip or pour-ons)
- Preliminary Treatment Owner Declaration – the owner or person in charge will complete a declaration indicating cattle have been treated for ticks by the owner.
- Inspection - cattle are required to be presented to an Inspector or Approved person at the clearing facilities for a manual inspection, and
- Supervised treatment - Cattle will be treated again at the tick line centre
- Certificate of Inspection or Treatment (or Travel permit) will be issued by DPI&F Inspector or Approved person indicating all procedures have been conducted and cattle are clean and tick-free
- These cattle can then cross the border into NSW
- Note that cattle destined for slaughter at one of the nine concessional abattoirs can opt for manual inspection (by palpation) without treatment, or visual inspection and treatment.

QUESTIONS:

1. For each of the 3 QLD areas supplying cattle to NSW, how many **stock** are transported on each truck movement? (List min, median, and max).

(Figures provided by Peter McGregor, NSW DPI database)

Areas	**Min**	**Median**	**Max**
Free zone	5	40	120
Control zone	5	48	120
Infected zone	5	76	120

2. For each of the 3 QLD areas supplying cattle to NSW, how many **truckloads** of stock will travel to NSW each year? (List min, median, and max).

Areas	**Min**	**Median**	**Max**
Free zone *(2003 NSW DPI)*	194	970	4850
Control zone	46	231	1155

(2003 NSWDPI)			
Infected zone *(2005 NSW DPI)*	34	170	850

Note that since 2003 figures were provided the control (protected) zone has been markedly reduced in size, so that many of the areas supplying cattle in 2003 are now in the Free Zone. It is also anticipated that numbers of cattle from the infected Zone will markedly increase (estimated five fold by NSW DPI) if compulsory treatment or inspection were lifted.

3. For each of the 3 QLD areas supplying cattle to NSW, what proportion of **farms** are tick positive? (List min, median, and max)?

Areas	Min	Median	Max
Free zone	50/15,000	150/15,000	250/15,000
Control zone	70/2,000	350/2,000	2,000/2,000
Infected zone	12,500/25,000	18,000/25,000	25,000/25,000

Estimate from QLD DPI, based on known properties under quarantine in free zone, and assumptions on level of infested properties in control and infected zones.

4. For each of the 3 QLD areas, 2 feeding systems and 4 breeds supplying cattle to NSW, what proportion of **cattle** on tick-positive farms carry ticks? (List min, median, and max):

4.1. For cattle entering NSW border from different areas of QLD:

For grazing cattle, based on QDPI estimates

Areas	Min	Median	Max
Free zone	10	50	100
Control zone	20	50	100
Infected zone	50	75	100

4.2. For cattle entering NSW border from different feeding systems in QLD of different regions (Grazing, feedlot)

Estimates from David Scarabelotti, Green Mountain Trading, Casino and Terry Serrone, Casino abattoir

Feeding systems	Min	Median	Max
Grazing	10	85	100
Feedlot	0	15	50

4.3. For cattle entering NSW border from different genetic composition of: *B. taurus*, *B. indicus*, 1/2 *B. taurus*, ½ *B. indicus*.

Feedlot

Breeds	Min	Median	Max

B. taurus	0	5	50
B. indicus	0	10	50
½B. taurus + ½ B. indicus	15	85	100

Grazing

Breeds	Min	Median	Max
B. taurus	0	5	50
B. indicus	25	60	100
½B. taurus + ½ B. indicus	10	35	100

5. For each of the 3 QLD areas with different feeding systems (grazing, feedlot) and different genetic compositions, how many **ticks** will be on each head of stock?

5.1.a *Bos taurus*

Areas	Min	Median	Max
Free zone	1	14	46
Control zone	7	72	232
Infected zone	14	144	465

5.1.b *Bos indicus*

Areas	Min	Median	Max
Free zone	0	0	1
Control zone	0	1	5
Infected zone	0	3	10

5.1.c *½ Bos taurus and ½ Bos indicus*

Areas	Min	Median	Max
Free zone	0	0	1
Control zone	3	17	32
Infected zone	7	34	65

These figures are derived from estimates supplied by QDPI, along with experimental and field figures derived from several sources-e.g. MLA (2005), Bourne et al. 1981

5.2. Grazing systems

5.2.a Feedlot cattle (all breeds)

Note that even in the infected Zone, many feedlots (n=80) are known as "approved feedlots" and have facilities and operations that give them equivalent status to the Free Zone. This involves double fencing, ten metre perimeter, >35 days in feedlot. The specifications are based on research performed by QDPI (see "Technical Report- Survival of the cattle tick in an *approved feedlot situation"-). This trial was conducted on Santa Gertrudis, Hereford and Santa X Hereford heifers.*

Areas	Min	Median	Max
Free zone	0	0	1
Control zone	0	0	1
Infected zone	0	1	10

6. To what abattoirs in NSW are QLD stock sent to? (List towns).

NSW Concessional abattoirs meat imports from QLD cattle tick infected zone Jan 05 to Jan 06

Abattoir	Location	Contact	no. consign-ments	no. head
Cargil Meats	Wagga Wagga	Tammy Vincent	0	0
Bindaree Beef	Inverell	Bronson McLean	1	20
Wingham Beef	Wingham	Alex McGregor	0	0
Northern Coop Meat	Casino	Garry Burridge	161	12,264
Ramsey Wholesalers	South Grafton	Paul Allen	0	0
Cargil Meats	Tamworth	Tony Burke	0	0
MonBeef	Cooma	Tony Dorahy		
E C Throsby	Singleton	David Tudor	0	0
Primo Meats	Scone	Scott Blake	3	234
TOTAL			**165**	**12518**

NSW Concessional abattoirs meat imports from QLD cattle tick infected zone June 02 to June 03

CASINO	30	1430
GRAFTON	6	612
INVERELL	4	301
MUDGEE	1	59
TONGALA	1	21
WINGHAM	1	66
TOTAL	**43**	**2489**

Note that in the last year only Casino abattoir appears to be importing large numbers of cattle from the infected Zone. This is backed by reports from QDPI that the vast majority of permits issued to transport cattle from infected Zone to NSW were going to Casino abattoir. Reports from other abattoirs (contacted above) indicate that they prefer to source cattle from approved feedlots, or Western Queensland saleyards outside of the infected zone, as this gives them the assurance that a consignment of cattle will not be held up on the border. (Cattle from IZ presented at these saleyards have been pre-cleared for tick-free status). This situation would be likely to change if the requirement for inspection or treatment were lifted.

CATTLE MOVEMENTS

7. In the last 2 years what proportion of ticks from “infected and control zones” cattle survived **after treatment**/s? (List min, median, and max).

Data from NSW DPI
In the last 2 years a single consignment has been found to have ticks at destination after passing through treatment and inspection procedures. Out of eight head of stock four were infested, with medium level of ticks (estimate min 20 ticks/head, median 40 ticks/head, max sixty ticks/head).

8. What proportion of ticks will survive on cattle when cattle are loaded on a **truck**? (List min, median, and max).
Estimate Min 75%, Median 95%, Max 100%
Note: These questions will allow estimations of tick numbers entering the truck

9. What proportion of ticks will fall off the cattle onto the **truck’s floor**? (List min, median, and max).
Estimate based on tick biology, where female ticks engorge in the 24 hour before dropping. Life cycle average is 20 days. Therefore approx. 5% of ticks on body of cattle will drop off per day. (Note it is thought that the engorged female ticks will generally drop off between the hours of 0600 and 0900- see Wharton & Utech 1970)

10. What proportion of ticks will fall off the truck on the **road** or **road sides**? (List min, median, and max).

Assume that to fall away the truck the tick would need to bounce off the animals, sides or floor, or be kicked by a beast as it fell.
Estimate Min 0%, Median 1%, Max 10%

11. What proportion of ticks will **survive** in the **truck’s washout**? (List min, median, and max).
Estimate Min 0%, Median 5%, Max 10%.
Note that the concessional abattoirs in NSW have procedures in place to ensure that truck washout is directed towards appropriate collecting ponds that would preclude the survival of female ticks. The only way that we can envisage that would allow tick survival would be if untrained operators used high pressure hoses to clean trucks and blasted ticks from the truck’s floor into nearby grass.

12. What proportion of ticks that fall off the truck will **survive** on the **road or side roads** during the rest times (stops)? (List min, median, and max).
Assume that ticks falling from trucks during transport or rest stops along major roads will fall onto tarmac or gravel (90%) or onto grass at verge (10%). Further assume that tick larvae hatching from gravid female that survives on

grass verge survive according to trials reported by McCulloch & Lewis 1968- survival time of tick larvae on pasture in NNSW- Min 1m, Median 5m, Max 7.5m. The probability of cattle coming into contact with surviving tick larvae on grass verge of major road is low (Min 0%, Median 0%, Max 1%).

Note: These questions will allow us to know where the ticks are deposited
ABATTOIR

13. What is the probability of 'contact' occurring between Queensland cattle and NSW cattle or other tick hosts (e.g. dog) after arrival at a commercial abattoir? (e.g. industrial action resulting in cattle for slaughter being put out to pasture). (List min, median, and max).

Note that research conducted by Hoyte 1954 shows the reproductive potential of ticks attaching to dogs is very low (0.01%). Procedures currently in place at NSW concessional abattoirs preclude mixing of QLD IZ cattle with local cattle. Breakdowns in procedures could occur due to industrial action, animal welfare considerations or non-compliance, but the degree of auditing and quality control standards in NSW abattoirs would make the possibility unlikely.
Min 0%, Median 0%, Max 1%

14. What is the probability of 'contact' occurring after slaughter at a commercial abattoir (e.g. improper disposal of hides and skins). (List min, median, and max).

Skins taken from cattle at Casino abattoir are processed on site, and not exposed to the environment until fully tanned.
Min 0%,Median 0%, Max 1%

15. What is the probability of cattle ticks (including eggs, larvae and adults) to survive in the Washdown from abattoir holding yards.

Note that the concessional abattoirs in NSW have procedures in place to ensure that truck washout is directed towards appropriate collecting ponds that would preclude the survival of female ticks. The only way that we can envisage that would allow tick survival would be if untrained operators used high pressure hoses to clean trucks and blasted ticks from the truck's floor into nearby grass.
Min 0%, Median 0%, Max 1%

16. What is the probability of 'contact' occurring between cattle ticks in the washdown from the abattoir holding yards (if survive) and cattle or other ticks hosts (e.g. dog).

Min 0%, Median 0%, Max 1%

ACCIDENTS

17. What is the possibility of a truck crash releasing cattle between the QLD-NSW border and the abattoir?

NSW RTA database was interrogated to find the number of truck crashes along the stretch of road from Tweed Heads to Casino, travelling along the Pacific Highway south to Ballina and then from Ballina to Casino along the Bruxner Highway (see map supplied).
In the 5 year period April 1999-March 2004 there were 139 heavy-vehicle accidents, or approximately 28 per year along this stretch of road.
Assume 1% of heavy vehicles on this road were livestock transport vehicles.
From abattoir figures, assume average consignment is 50 head/truck, and an accident resulted in all cattle being released from the truck and impounded in nearby paddock.
An estimate of 14 cattle per year (28x0.01x50) released.

Appendix V

Glossary

Confidence Interval	Confidence intervals indicate the strength of evidence. Where confidence intervals are wide, they indicate less precise estimates of effect. The larger the trial's sample size, the larger the number of outcome events and the greater becomes the confidence that the true relative risk reduction is close to the value stated.
Consignment	A truck loaded with cattle and transported into NSW
Deterministic	The term deterministic indicates that there is no uncertainty associated with a given value or variable
Probability distribution	A probability distribution is the proper statistical term for a frequency distribution constructed from an infinitely large set of values where the class size is infinitesimally small.
Entry scenario	Describing the biological pathways necessary for entry of animals and humans to the hazards released from a given source, and estimating the probability of the exposure occurring, either qualitatively or quantitatively'.
Free zone	Cattle from unrestricted properties of the Cattle Tick Free Zone of Queensland and approved feedlot properties within the infected Zone are not required to be treated or inspected at the tick line before transported into NSW.
Infected zone	Cattle from the Cattle Tick infected Zone of Queensland are required to primarily be treated by the farmer, inspected and treated again at the "tick line facility centre" before loaded on the truck and transported into NSW.
Iteration	An iteration is one recalculation of the user's model during a simulation. A simulation consists of many recalculations or iterations. During each iteration, all uncertain variables are sampled once according to

	their probability distributions, and the model is recalculated using these sampled values.
Log normal distribution	Allows the probability of release to be close to zero on the majority of occasions, with the occasional very high probability of release. Specifies the actual mean and standard deviation of the generated log normal probability distribution.
Monte Carlo	Monte Carlo refers to the traditional method of sampling random variables in simulation modelling. Samples are chosen completely randomly across the range of the distribution, thus necessitating large numbers of samples for convergence for highly skewed or long-tailed distributions.
Pert distribution	The Pert distribution has three parameters (minimum, most likely and maximum values) used for the distributions of probabilities
TICK positive cattle	Cattle that carry at least one tick
Probability	Probability is a measure of how likely a value or event is to occur. It can be measured from simulation as frequency by calculating the number of occurrences of the value of an event divided by the total number of occurrences. This calculation returns a value between 0 and 1 which then can be converted to percentage by multiplying by 100.
Protected zone (Control zone)	Cattle from the protected Zone – the zone in between the infected and free zones of Queensland - are required to be treated, inspected and treated again at the property or "clearing facility centres" before being loaded on the truck and transported into NSW.
Random number seed	The seed is a number that initialises the selection of number by a random number generator. A random number seed will generate the same series of random numbers each time a simulation is run.
Risk	The term risk refers to uncertainty or variability in the outcome of some event or decision.
Risk analysis	Risk analysis is a general term used to describe any method used to study and understand the risk

	inherent to a situation of interest. Methods can be quantitative and/or qualitative in nature.
Release scenario	Description of the pathway or ordered sequence of steps undertaken or pathways necessary for a an organism to release into a particular environment, and estimating the probability of that complete process occurring either qualitatively or quantitatively.
Simulation	Simulation is a technique whereby a model, using tools such as an Excel worksheet, is calculated many times with different input values with the intent of getting a complete representation of all possible scenarios that might occur in an uncertain situation.
Stochastic	Stochastic models include a factor to account for risk or chance. These provide a distribution around an estimate.

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