Small Ruminant Research 136 (2016) 227–237

Contents lists available at ScienceDirect

Small Ruminant Research

journal homepage: www.elsevier.com/locate/smallrumres

A stochastic simulation model for brucellosis eradication in goat flocks in an area with high flock prevalence but low animal prevalence

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ARTICLE INFO

Article history:
Received 29 September 2014
Received in revised form 4 February 2016
Accepted 6 February 2016
Available online 11 February 2016

Keywords:
Brucellosis
Goat
Simulation model
Eradication

ABSTRACT

Since 2009, the Thai national brucellosis eradication programme has been implemented with the strategy of test-and-slaughter and compensation paid for positive brucellosis goats. Nakhon Pathom is a province located in the west of Thailand. Due to a high volume of goat movement, brucellosis in goat is still problematic with a high prevalence of 31% at the flock level and 1–2% at the goat level. The stochastic simulation model was created to predict the success of the programme, as defined by when goats were free from brucellosis (true prevalence = 0). The scenarios regarding the decisions about the routine testing interval of the test-and-slaughter programme, and the testing for brucellosis before introducing new goats into a flock were simulated. The dynamic and uncertainties of reproductive performance, abortion rate, survival rate, transmission per contact, transmission per mating, vertical transmission rate, level of brucellosis prevalence, and age to sale for young and breeding goats were included in the model. The results indicate that testing for brucellosis before introducing new goats from a flock with an unknown brucellosis status and introducing replacement goats from a brucellosis-free flock were very important for the success of the eradication programme. Furthermore, a short testing interval of the test-and-slaughter regime was also able to eradicate brucellosis-positive flocks faster than a long testing interval.

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1. Introduction

Brucellosis in goats is caused by *Brucella melitensis* and is widely spread throughout the world (Diaz Aparicio, 2013). Brucellosis can cause dramatic economic losses in terms of abortion, infertility and increased kid mortality (Singh et al., 1994; Diaz Aparicio, 2013). Brucellosis in livestock is also able to transmit infection to wildlife animals (Serrano et al., 2011). Risk factors for brucellosis include large flock size, introduction of new goats into a flock, management systems, pregnancy status, and goat age and sex (Coelho et al., 2007; Islam et al., 2013; Bamaiyi et al., 2014). In Thailand, the prevalence of goat brucellosis was 0.7% at the individual level and 6.4% at the flock level (DLD, 2013). However, in positive flocks, brucellosis prevalence varies widely among farms, from 1% to 35%. Since 2009, a national eradication programme with the test-and-slaughter regime and compensation policy has been continuously conducted by the Livestock Development Department (DLD), Ministry of Agriculture and Cooperation, Thailand. A serum positive goat, as determined by a serial ELISA test and a complement fixation test (CFT), is slaughtered. In case of positive flocks, all goats are retested every three months. Once there are no more positive results in the flock, a flock is declared to be a brucellosis-free at level B. After one year, a goat flock is declared to be free from brucellosis at level A, if every goat tests negative for brucellosis in at least two consecutive tests.

Nakhon Pathom province is in the west of Thailand where goat traders collect animals from both inside and outside the province in order to sell them to the southern part of Thailand. The official test-and-slaughter programme has been regularly implemented in the area for many years. Due to a high prevalence at a flock level along with a high volume of goat movement and an inability to monitor brucellosis status for all animal movements, brucellosis situation remains a problem in this area. In practice, the success of the eradication programme depends on several factors, and several strategies can be applied (Minas et al., 2007). The decision to test for brucellosis before introducing new goats into a flock and the testing interval of the test-and-slaughter programme can be made before implementation. However, other risk factors related to brucellosis, including the amount of contact with infected goats, number of mating of infected goats, abortion and population structure,

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http://dx.doi.org/10.1016/j.smallrumres.2016.02.005
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dynamically changed over time and they are difficult to determine. Due to the uncertainty of the large number of risk factors, local veterinarians require knowledge to support their work to successfully conduct the test-and-slaughter programme. For bovine brucellosis control, a simulation model proved to be useful in various situations when predicting the brucellosis status with certain (England et al., 2004) or uncertain inputs (Yamamoto et al., 2008). In this study, a stochastic dynamic simulation model was created in order to predict the success and time to achieve a brucellosis-free status (true prevalence = 0) after the test-and-slaughter programme started in Nakhon Pathom province and to explore the most important factors for a successful eradication mission.

2. Materials and methods

2.1. Data collection

The current status of brucellosis in small ruminant flocks was serologically surveyed in Nakhon Pathom province. The survey was conducted on 32 flocks with 897 adults from October 2012 to September 2013. Blood collection was performed twice to determine the brucellosis status at the beginning and the end of project. The brucellosis status was determined by a serial iELISA test (98% of specificity and 87% of sensitivity) and a complement fixation test (CFT) (95% of specificity and 86% of sensitivity) performed at the Western Veterinary Research and Development Center, DLD, Ministry Agricultural and Cooperatives. The goat population distribution in each flock, including the age and sex of goats, was recorded during a visit. The age to sale of young goats and the age to cull of breeding females and males at the end of their productive lives were determined by face-to-face interviews using a set of questionnaires.

2.2. Model

A Monte Carlo stochastic-simulation model was developed in Excel (Microsoft Corporation, Redmond, WA, USA) with @Risk add-in software (Palisade Corporation, Ithaca, NY, USA). The model used the flock level as a basis with scenarios to predict when brucellosis could be eradicated from a flock. The model was dynamic, and the structural model is as shown in Fig. 1. A structure of model composed of a population-dynamic model and infectious-transmission model in one flock. For kids, after birth, survival kids were sold when they reached the age for sale. A female goat was estimated for a dynamic of pregnancy and lambing. Once abortion was observed, a number of kids per year were adjusted. To control and eradicate brucellosis, a test-and-slaughter programme was implemented. At each time step, the positive brucellosis goats and the goats at the end of their productive lives were replaced with other breeding goats from other flocks (Fig. 1 and Table 1). The model was run at a specific time step (i, $i = 0$ representing the start of the test-and-slaughter programme). The testing interval of the test-and-slaughter programme (months) was varied over different scenarios. The time step of model (T) was run depending on testing interval of the test-and-slaughter programme setting at 3, 6, 9, 12 months and randomly from 3 to 12 months. When the number of goats was estimated for any event in each time step, a binomial distribution (Binomial (n, p)) with the number of goats (n) and the probability to occur of that event (p) was used. The probability of each event was randomly sampled from the stochastic values in Table 1. The model was run for 120 time steps, with 10,000 iterations for each scenario.

2.3. A population-dynamic model

In a flock, the goat population (Pop_i) consisted of adult females ($Female_i$), adult males ($Male_i$), kids (Kid_i) and young goats ($Young_i$).

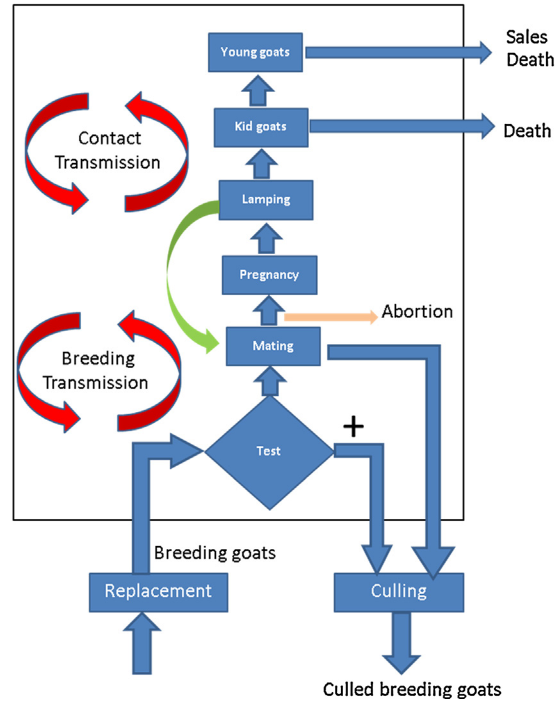

Fig. 1. Structural diagram of our model related to the dynamics of a goat population and infectious transmission in a flock.

A young goat was defined as a goat with an age greater than 3 months and less than 12–18 months, the age at which it was ready to be sold (Table 1).

$$Pop_i = Female_i + Male_i + Kid_i + Young_i \quad (1)$$

The adult population was defined as the goats that were already mated. The age distribution of the adult population was given in the first time step and was assumed to be equal for each time step. Serial serology testing was performed on adult and young goats. When the test-and-slaughter programme was implemented, seropositive ($_{P}$) and false seropositive ($_{FP}$) females ($Female_{P(i)}$, $Female_{FP(i)}$), males ($Male_{P(i)}$, $Male_{FP(i)}$) and young goats ($Young_{P(i)}$, $Young_{FP(i)}$)) were replaced (see in formulas 12–22). For the remaining adult population, if they were not culled due to positive brucellosis results in the subsequent time steps, females ($Female_{L(i)}$) and males ($Male_{L(i)}$) remained in a flock until the end of their productive lives (*Prod age*; years) (Table 1) and then became culled females ($Female_{C(i)}$) and males ($Male_{C(i)}$). After culling, adult goats were replaced with breeding adults for both females ($Female_{R(i)}$) and males ($Male_{R(i)}$). According to the assumption of the equal number of adult goats in each time step, the number of culled goats in each time step depends on the total number of adult goats in a flock and the probability of their time spending in that time step comparison with their productive lives as shown in formula (4) and (7).

$$Female_i = Female_{L(i-1)} + Female_{R(i-1)} \quad (2)$$

$$Female_{R(i)} = Female_{C(i)} + Female_{P(i)} + Female_{FP(i)} \quad (3)$$

$$Female_{C(i)} = Binomial\left(Female_i, \frac{T}{\text{Prod age}}\right) \quad (4)$$

$$Male_i = Male_{L(i-1)} + Male_{R(i-1)} \quad (5)$$

$$Male_{R(i)} = Male_{C(i)} + Male_{P(i)} + Male_{FP(i)} \quad (6)$$

$$Male_{C(i)} = Binomial\left(Male_i, \frac{T}{\text{Prod age}}\right) \quad (7)$$

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