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Risk evaluation of nonvaccinated, weaned calves transported through areas under systematic foot and mouth disease (FMD) vaccination

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A B S T R A C T

The recurrence and persistence of foot and mouth disease (FMD) could be the consequence of cyclic and massive transportation of calves. For this reason, in South America, vaccination strategies related to livestock dynamic are being promoted. In order to aid the evaluation of such strategies, a method for predicting the risk of transportation of nonvaccinated weaned calves was developed; this method combines expert opinion and empirical evidence using Bayesian estimators. It was applied through Monte Carlo simulation to data of Argentina under four hypothetical vaccination schemes: E1, extended vaccination season of 1/6 of the population of calves each month from July to December without second round vaccination (SRV); E2, extended irregular vaccination from July to December with SRV applied to 70% of the calves resembling the scheme applied in Argentina in 2001; E3, vaccination in November and December without SRV; and E4, vaccination concentrated in November. E1 resulted in probability of transporting non vaccinated calves (*tnvc*) reaching its maximum in the following year in May with mean = 0.0250 and percentile 95% (P95) = 0.0404; for the same month *tnvc* estimates for the other schemes were E2: mean = 0.0071; P95 = 0.0162; E3: mean = 0.0017; P95 = 0.0042 and E4: mean = 0.0001; P95 = 0.0004. Bonferroni multiple comparison for simultaneous assertions for May showed that E4 resulted the best scheme, E1 the worst, and E2 and E3 are intermediate with nonsignificant difference observed between overall ($p < 0.05$). Results were consistent with historical records and quantification for future needs for re-vaccination was made possible. While the ratio "total vaccinated"/"total estimated existences" will give a biased vision of vaccination coverage under the situation of extended vaccination campaigns, a model as the one developed here could allow a more accurate assessment and the design of mitigation plans.
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1. Introduction

In 1989, the Pan American Health Organization (PAHO) launched the *Hemispheric Program for the Eradication of FMD* (PAHO/World Health Organization [WHO], 1988). In South America, eradication programs are based mainly on two strategies: (a) early detection of foot-and-mouth disease (FMD) infection followed by immobilization of affected animals and fomites, plus ring vaccinations and

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(b) systematic vaccination campaigns for at least 2 years (Saraiva and Darsie, 2004).

Persistence of FMD is explained by the transmission of the virus from infected to susceptible individuals that have contact with one another. These contacts are favored by production and marketing systems prevailing in South America where, once a year, weaned calves are massively transported to fattening farms (Cané et al., 2004). Therefore, to control FMD, vaccination schedules should take into account births and cattle transportation dynamics. To obtain an adequate immune coverage, in particular during critical time periods, a high vaccination ratio (animals vaccinated over total population) per se is not enough—massive vaccination should also be achieved in a short period of time. In many countries such as Argentina, births take place during vaccination campaigns; thus, the consolidated vaccination rate (total vaccinated animals in a campaign over an estimated population) produces a biased visualization of the real vaccination coverage.

In Argentina, FMD incidence had seasonal peaks during the weaning season in March and April until 1992. The *1993–1997 Stage of the Eradication Plan*, launched by the National Service for Agri-food Health (SENASA), was based on two yearly national vaccination campaigns applied in a short period of time by vaccination brigades, hired and coordinated by local entities; ring vaccination in premises near the outbreaks; and controls to avoid transportation of infected or nonvaccinated cattle (SENASA, 1993). Argentina achieved full vaccination coverage and reduction to cessation of incidence in 1994.

After 5 years without FMD outbreaks, vaccination was halted in 1999, and the disease re-emerged in July 2000 and rapidly disseminated in the naïve population. The *April 2001, FMD Eradication Plan* (SENASA, 2001) was launched with a similar strategy as the one adopted in 1993.

Due to the high number of outbreaks and vaccine shortage, in the second half of 2001 vaccination was applied during the whole semester, combining systematic and ring vaccinations. Typically, a farm received the vaccination brigade once in the semester for the principal vaccination operation, consisting of vaccinating the whole cattle herd on the premises, including calves of all ages with no exceptions. The second round vaccination visits aimed to cover calves born after the main vaccination campaign was implemented. A full 100% of the herds were covered by principal vaccination operations, while around 70% of the calves born after the main vaccination received second round vaccination. This scheme proved effective—the epidemic ceased in January 2002. and the 2002 weaning season (March–April) occurred with nonrecurrence of the disease.

Systematic vaccination plans based on risk analysis with the goal of high vaccination rates are recognized as necessary conditions in the processes of FMD control in South America (PAHO, 1988). Up to now, the use of stochastic modeling to integrate information from the population dynamic in ex post or ex ante evaluations of vaccination schemes has not been reported.

In Argentina, according to Executive Order 394/2001 (Anon., 2001), the President of SENASA has the authority to establish vaccination schemes, and the National Director of Animal Health, with the aid of the Director of Epidemiology, is responsible for recommending vaccination schemes based on expert opinion of their own staff and SENASA's advisory bodies, and on previously gathered data.

To aid in the ex ante and ex post evaluation of vaccination strategies against FMD in cattle, a quantitative stochastic risk assessment model was developed using information provided by experts and empirical evidence to evaluate the effect of a vaccination campaign on the vaccination rate of transported weaned calves.

The proposed model is meant to be useful for predicting, on a specific date after the vaccination season, the probability of transporting nonvaccinated weaned calves; to foresee the number of calves that would need to be vaccinated before transportation; and for comparing, ex ante, the effect of different vaccination schemes.

2. Materials and methods

2.1. The model

A multidimensional scenario tree for estimating the probability of transporting a nonvaccinated calf was developed. The information is obtained during a period named Observation/Estimation Window (OEW) and is projected to a later period defined as Prediction Window (PW). The OEW is the lapse of time, measured in K discrete dates (months), prior to the point of analysis; and PW is the time, divided in J months, after the point of analysis. The Dirichlet distribution with parameters obtained from expert opinion and data gathered by the veterinary services is used to model variability and uncertainty of multinomial processes through Monte Carlo simulation (Metropolis and Ulam, 1949).

In this study, the vaccination scheme consisted of Principal Vaccinations (PVs), in which all animals in a herd are vaccinated, and subsequent second round vaccinations (SRVs), in which calves born after the PV are vaccinated. Under this scheme, the transportation in month j of a nonvaccinated calf born in month i ($i = 1, 2, \ldots, K$; $j = 1, 2, \ldots, J$) can be disaggregated in three independent events: (a) a calf was not vaccinated during PV, because it was born after (or too close to) PV; (b) a calf born in month i was not vaccinated during SRV; and (c) the transportation occurred in month j. The multidimensional scenario tree of dimension $K \times J$ (Fig. 1) can be presented as exemplified in Miller et al. (1993).

Thus, for a calf born in month i, the probability of being transported in month j without being vaccinated is given by:

$$f1_i \times f2_i \times f3_{ij} \tag{1}$$

where:

$f1_i$: is the probability that a calf born in month i misses the principal vaccination;
$f2_i$: is the probability that a calf born in month i does not receive a vaccine in SRV;
$f3_{ij}$: is the probability of transporting, in month j, calves born in month i.

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