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Designing a risk-based surveillance program for *Mycobacterium avium* ssp. *paratuberculosis* in Norwegian dairy herds using multivariate statistical process control analysis

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ABSTRACT

Surveillance programs for animal diseases are critical to early disease detection and risk estimation and to documenting a population's disease status at a given time. The aim of this study was to describe a risk-based surveillance program for detecting *Mycobacterium avium* ssp. *paratuberculosis* (MAP) infection in Norwegian dairy cattle. The included risk factors for detecting MAP were purchase of cattle, combined cattle and goat farming, and location of the cattle farm in counties containing goats with MAP. The risk indicators included production data [culling of animals >3 yr of age, carcass conformation of animals >3 yr of age, milk production decrease in older lactating cows (lactations 3, 4, and 5)], and clinical data (diarrhea, enteritis, or both, in animals >3 yr of age). Except for combined cattle and goat farming and cattle farm location, all data were collected at the cow level and summarized at the herd level. Predefined risk factors and risk indicators were extracted from different national databases and combined in a multivariate statistical process control to obtain a risk assessment for each herd. The ordinary Hotelling's T^2 statistic was applied as a multivariate, standardized measure of difference between the current observed state and the average state of the risk factors for a given herd. To make the analysis more robust and adapt it to the slowly developing nature of MAP, monthly risk calculations were based on data accumulated during a 24-mo period. Monitoring of these variables was performed to identify outliers that may indicate deviance in one or more of the underlying processes. The highest-ranked herds were scattered all over Norway and clustered in high-density dairy cattle farm areas. The resulting rankings of herds are being used in the national surveillance program for MAP in 2014 to increase the sensitivity of the ongoing surveillance program in which 5 fecal samples for bacteriological examination are collected from 25 dairy herds. The use of multivariate statistical process control for selection of herds will be beneficial when a diagnostic test suitable for mass screening is available and validated on the Norwegian cattle population, thus making it possible to increase the number of sampled herds.

Key words: risk-based surveillance, *Mycobacterium avium* ssp. *paratuberculosis*, multivariate statistical process control, cattle

INTRODUCTION

Surveillance programs for animal infections are designed for early detection of emerging infections in a population, to document that a population is free from a variety of infections, or to estimate the prevalence of an infection in a population. The veterinary field faces challenges in developing surveillance programs for rare or low-prevalence infections because such diseases are rarely homogeneously distributed within a susceptible livestock population (Hadorn and Stärk, 2008). Random sampling implies choosing in a way that each unit has the same chance of being selected (Thrusfield, 2005). However, at the population level, in terms of detecting rare diseases, this type of data collection is limited in terms of financial and operational feasibility because a larger sample size is required with a lower prevalence in a specific population (Salman, 2003). Nonrandom sampling is therefore more efficient in detecting rare diseases. Cameron (2012) proposed that if an infection is present, the highest sensitivity of surveillance is obtained by focusing on units that are most likely to be infected. In a risk-based surveillance program, the population is divided into strata based on factors that

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can affect the outcome (risk indicators). Designing surveillance programs so that samples are collected from the strata having higher probabilities of being infected or acquiring the infection may increase the probability of disease detection or decrease the required sample size without reducing the probability of disease detection (Martin et al., 2007). The success of such a program depends partly on proper risk indicator selection, which should be based on scientific knowledge and on properties of the data sources, such as coverage, timeliness, availability, and quality of data.

In Norway, *Mycobacterium avium* ssp. *paratuberculosis* (**MAP**) infection in ruminants is a notifiable disease. In 1996, a national surveillance and control program for bovine MAP was implemented in Norway. During the first 2 yr of the program, samples from imported cattle and from cattle that had been in contact with imported cattle were examined by serology, histopathology, or bacteriological cultures from fecal samples or organs. In 1998 and 1999, the program was expanded to include Norwegian cattle that had no contact with imported animals. Initially, serological examinations were used to screen the herds, and on average, about 8% of the animals tested were identified as seropositive. However, a follow-up study of these seropositive cattle showed that the reactions were false positives, probably caused by environmental mycobacteria (Fredriksen et al., 2004). Paisley et al. (2000) simulated a surveillance program for bovine MAP in Norwegian dairy herds assuming a prevalence of 0.2%. They concluded that a randomized national survey using serological examinations would be advisable because of the low probability of detecting infected herds and the high number of false-positive reactions that would be expected. In Norway, herds that are suspected of or diagnosed with MAP are placed under strict restrictions regarding animal movement, sales, shared pasture, and manure deposit. False-positive reactions arising from low specificity of the serological examinations, eventually followed by a long period to confirm or reject the diagnosis, could cause extreme hardship to many dairy farmers. Given the cost of false-seropositive cattle, the current national surveillance program for MAP in cattle relies on bacteriological examination of fecal samples. Fecal samples are collected from the 5 oldest cows in 50 randomly selected herds from a total of approximately 15,000 dairy and beef herds.

A risk-based surveillance program has been developed for MAP to increase the sensitivity of the surveillance. Thus, the aim of this paper was to describe the risk-based selection of herds for the MAP surveillance program in dairy cattle herds in Norway by applying multivariate statistical process control (**MSPC**; Hotelling, 1947). In MSPC analyses, several variables are combined in a training data set to establish a normal range in which the process is assumed to be in control. Afterward, monitoring of these variables is performed to identify outliers that may indicate deviance in one or more of the underlying processes, suggesting that a unit (herd) should be flagged for further inspection, and to assess whether the herd should be incorporated in the national surveillance program for MAP.

MATERIALS AND METHODS

The target population for the surveillance program was the dairy cattle population in Norway. The study population included dairy herds in the Norwegian Dairy Herd Recording System (**NDHRS**; Tine SA, the Norwegian Dairies, Ås, Norway). The study period spanned January 1, 2002, to December 31, 2011, and included 95.3 to 98.3% of dairy herds in Norway (Tine Rådgiving, 2011). The analyzed data covered a 10-yr time period to evaluate how different risk indicators changed over time and to determine the time intervals over which these indicators should be aggregated.

Data Sources

The NDHRS comprises data on each cow, including age, origin, calving dates, number of calves, milk production, disease records, movements to or from the herd (purchase and culling), and slaughter information (Figure 1). Milk production and quality are monitored and recorded monthly or every second month. Data reporting is mandatory for members, and data are reported directly or indirectly to the NDHRS database by the farmer, veterinary practitioner, or abattoir or field personnel from the dairy or meat industry (Figure 1). Since 1975, disease cases have been recorded on individual cow health cards, which have been reported to the NDHRS (Solbu, 1983). The Carcasses Database (Animalia, the Norwegian Meat and Poultry Research Centre, Oslo) also transfers data from the slaughterhouses directly into the NDHRS.

The Register of Production Subsidies (Norwegian Agricultural Authority, Oslo) collects information on the number of animals distributed, including species and production type for all holdings that apply for production subsidies. All dairy cattle and dairy goat farmers in Norway are entitled to production subsidies, and the amount is based on the number of animals. The register includes more than 99.7% of the dairy cattle and goat herds in Norway; for the present study, all cattle and goat herds were extracted from this register.

The Norwegian Goat Health Service (Tine SA, the Norwegian Dairies) comprises data on each goat, including age, origin, milk production, and disease re-