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Review

# Capture–recapture approaches and the surveillance of livestock diseases: A review

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ABSTRACT

In disease surveillance, capture–recapture approaches have been used to estimate the frequency of endemic diseases monitored by imperfect surveillance systems. A standard output of these techniques is an estimate of the sensitivity of the surveillance. In addition, capture–recapture applications contribute to a better understanding of the disease detection processes and of the relationships between different surveillance data sources, and help identify variables associated with the under-detection of diseases. Although capture–recapture approaches have long been used in public health, their application to livestock disease surveillance is only recent. In this paper, we review the different capture–recapture approaches applied in livestock disease surveillance, and discuss their benefits and limitations in the light of the characteristics of the surveillance and control practices used in animal health.



## 1. Introduction

In animal health, surveillance systems are used to estimate the frequency (prevalence or incidence) of a disease or a syndrome, to find cases of an endemic disease, to detect as early as possible the occurrence of an exotic or emerging threat, and to demonstrate freedom from disease (Dufour and Hendrikx, 2011). Because the evidence generated by surveillance systems influences decisions regarding the implementation of prevention and control measures, their systematic evaluation is of importance (Salman et al., 2003; Drewe et al., 2012). To this end, several evaluation frameworks have been developed (German et al., 2001; Hendrikx et al., 2011; Drewe et al., 2013), and a number of indicators or evaluation attributes have been suggested to assess the performance of surveillance systems. The sensitivity of the surveillance system appears consistently in all evaluation frameworks (Drewe et al., 2012).

Depending on the epidemiological situation and the objectives of the surveillance system, surveillance sensitivity has slightly different definitions (Hoinville et al., 2013). Sensitivity may be defined as the probability of detecting a disease in a population, given that it is present in that population at a minimum expected prevalence. With this

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definition, sensitivity is a key parameter for the assessment of the effectiveness of surveillance systems aiming at detecting as early as possible the occurrence of an exotic disease in a population or at demonstrating that a population is free from a disease (Martin et al., 2007; Hood et al., 2009; Christensen et al., 2011). Alternatively, sensitivity may be defined as the proportion of true cases in a population that are correctly detected by the surveillance system. With that definition, sensitivity provides an evaluation of the effectiveness of surveillance systems aiming at finding cases of a disease or at monitoring the frequency of a disease (German, 2000). In this situation, capture–recapture approaches are of interest to estimate surveillance sensitivity (Hook and Regal, 1995).

Capture recapture (CR) approaches include sampling and statistical modelling methods that allow drawing inference on the size and composition of populations that can only be partially observed as well as on the parameters that drive the dynamics of such populations. CR approaches were initially used in the 17th and 18th century to estimate human population sizes in England and in France (Graunt, 1662; Laplace, 1786). They were then applied in ecology where they were used to estimate the size of wild animal populations (Petersen, 1896). CR approaches were then further developed for the estimation of the parameters that drive wild animal populations dynamic such as birth, mortality, immigration and emigration rates. A comprehensive review of these methodologies in the context of ecology can be found in Lebreton et al. (1992). Subsequently, the development of multi-state models allowed the incorporation of individual states that could change over time, so that it became possible to estimate the probabilities of transition between such states (for example the probability that an individual who bred on a given year would not breed on the following year) (Nichols et al., 1994; Lebreton and Pradel, 2002). The latest development of CR approaches are generalizations of multi-state models, referred to as multi-event models, that allow dealing with state uncertainty (Pradel, 2005). These latter models find great applications to study infectious disease transmission in wildlife populations where monitoring of individual epidemiological states is hampered by the difficulty of repeatedly catching wild animals and by imperfect diagnostic tests (Conn and Cooch, 2009; Santoro et al., 2014).

The first applications of CR methods in the fields of epidemiology were adaptations of early ecological models for the estimation of disease surveillance sensitivity in public health (Wittes and Sidel, 1968; Wittes, 1974). In the 1990s three major reviews were published (Hook and Regal, 1995; IWGDMF, 1995b,a), and since then CR methods became increasingly popular for sensitivity estimation in public health settings (van Hest, 2007, chap. 3). In public health, most applications focus on chronic conditions such as diabetes and cancers, but a substantial number also target infectious diseases (Hook and Regal, 1995; van Hest, 2007, chap. 3). In animal health CR applications for sensitivity estimation were first introduced in the early 2000s.

In what follows, we review the different CR approaches used in animal health to date, and discuss their benefits and limitations given the characteristics of standard livestock disease surveillance and control activities.

## 2. An overview of capture–recapture applications in animal health surveillance

At the time of writing, and to the best of our knowledge, thirteen published works had applied CR methods to animal health surveillance problems (Table 1). These applications focused on five different health conditions, three acute (foot-and-mouth disease, highly pathogenic avian influenza, and the occurrence of abortions) and two chronic (scrapie and east coast fever) in both high- and low-income countries. This range of applications shows that animal disease under-detection issues are not limited to particular diseases or settings.

As in public health, the primary objective of most CR applications in animal health was to quantify under-detection by estimating the total number of infected units (Table 1). For example, Cameron (1999) estimated the total number of villages with clinical cases of foot-and-mouth disease in Northern Thailand from the subset of infected villages that were detected by the surveillance system. Similarly, for scrapie in Great Britain, the interest was the estimation of the total number of scrapie-infected holdings (Del Rio Vilas et al., 2005; Del Rio Vilas and Böhning, 2008). CR approaches were also applied to identify those variables likely to influence the detection probabilities of the epidemiological units and to identify characteristics of units more likely to be under-reported to inform surveillance strategies (Bronner et al., 2013; Vergne et al., 2014).

Although Kivaria and Noordhuizen (2009) managed to cross individual lists of cases of East-coast fever in Tanzania to estimate the individual-level prevalence of the disease, the epidemiological units of interest in most of the published CR applications in animal health were clusters of animals, either in the form of animal holdings (Del Rio Vilas et al., 2005; Bronner et al., 2013), villages (Vergne et al., 2012b) or administrative areas (Vergne et al., 2014). This is because control measures for infectious animal diseases often leads to the culling of infected animals, and thus prevents the required re-capture event to support CR models at the individual level. This may not be the case for holdings which can be detected several times by surveillance systems: the detection of different infected animals from a holding represents different capture events of that holding. In public health, despite the fact that the seminal work conducted by McKendrick in 1926 targeted households (Dahiya and Gross, 1973), CR applications often consider the individual as the epidemiological unit of interest (see for example (Debrock et al., 2000; van Hest et al., 2002; Gill et al., 2003)), and very few define it at the group level (Gallay et al., 2000).

## 3. Capture–recapture methodologies

### 3.1. Overview

In disease surveillance, CR approaches model the multiple detections (either in time or by distinct surveillance components) of infected epidemiological units of interest, in order to infer the number of infected units that remain undetected. Therefore, CR approaches allow estimating the total number of infected units (detected and undetected),