



Manual 5

Surveillance and epidemiology



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Contents

Contents	iii
Background	1
Surveillance: an overview	1
Purpose of surveillance	2
Types of Surveillance	2
Origin of data	2
Disease focus	2
Population coverage	3
Frequency	4
Selecting the right kind of surveillance activity	4
Early detection	4
Demonstrating freedom	4
Measuring the level of disease	5
Surveillance needs	5
Surveillance tools	6
Passive disease reporting systems	7
Sentinel herds	7
Abattoir surveillance	8
Negative reporting	8
Syndromic surveillance	8
Indirect surveillance	8
Participatory disease surveillance	9
Surveys	9
Participatory epidemiology	9
Advantages and disadvantages of participatory approaches	10
Participatory rural appraisal 'toolkit'	11
The semi-structured interview	11
Mapping	12
Timelines and seasonal calendars	12
Ranking, scoring and proportional piling	13

Contents

Participatory surveillance: to complement and strengthen existing surveillance systems	13
Participatory epidemiology in South-East Asia	14
Epidemiological analysis	14
Epidemiological analysis for SEACFMD Member Countries	15
Descriptive Epidemiology	15
Measures of disease frequency	15
Cumulative incidence	16
Incidence density	16
Prevalence	16
Attack rate	17
The relationship between prevalence and incidence	17
Spatial and temporal trends	18
Spatial patterns of disease	19
Analytical epidemiology	19
Calculation of measures to demonstrate association	20
Relative risk (RR)	21
Odds ratio (OR)	21
Attributable risk (AR)	21
Attributable fraction	21
Vaccine efficacy (VE)	21
From association to inference	21
Bias and Confounding	22
Epidemiology Networks	22
References	23

Background

In order to understand the epidemiology of a disease, detect incursions of disease, monitor the occurrence of disease and the impact of control measures, it is essential to gather information about the disease itself, the livestock it affects and the environment in which the disease occurs. This collection of information related to animal health is known as surveillance and the range of different activities that produce data about the status of a disease in the population is known as a surveillance system. The purpose of this manual is to provide general information on types of surveillance, strengths and weaknesses of different surveillance tools and how the information generated by surveillance activities may be analysed in order to generate useful information on which to base decisions. Many of the surveillance systems described in this manual have been and are used to good effect in the SEACFMD campaign.

As the information contained within this manual will demonstrate, there are strengths and weaknesses for all types of surveillance, including participatory epidemiology/surveillance methods, which are described in detail later in the manual. In reality, a variety of methods may be used within an overall surveillance system, in order to generate information from a variety of sources which can be compared and combined to provide greater confidence in the information generated from the system as a whole. A process of triangulation is used, which involves cross-verification of information gathered from several sources.

This manual provides some detail on methods for epidemiological analysis of data, focusing on the methods which are most applicable to the needs of SEACFMD Member Countries. There is particular reference to temporal and spatial analysis of disease and measures of association between disease occurrence and specific risk factors. As this manual is only intended as a general guide to these topics, references are provided to documents and software which may be used to access further information on specific topics and to perform some of the analyses described, respectively.

Within this manual there are several distinct, but related, sections including: surveillance, epidemiological analysis, participatory epidemiology and epidemiological networks. For each of these sections, an overview will be provided in the relevant sections of the manual and so further detail is not provided here.

Surveillance: an overview

Surveillance is the systematic, ongoing collection, collation and analysis of information related to animal health, and

the timely dissemination of information to those who need to know, so that action can be taken (OIE *Terrestrial Animal Health Code*). This definition outlines the fact that the purpose of surveillance is to provide information such that Veterinary Authorities can make decisions about livestock diseases and take action, based on the information collected. There are many different options for surveillance and the approach taken by countries will depend upon their surveillance needs and capabilities (Cameron, 2012). A surveillance system, for a particular disease, refers to the range of different activities that are able to produce data about the status of that disease in the population (FAO, 2014). In this manual, different surveillance systems will be described, together with strengths and weaknesses of different surveillance methods.

In order for a surveillance system to be effective it must be sensitive, specific and timely. In regard to sensitivity, the system must be capable of detecting the majority of field events that are clinically compatible with the disease targeted for control - as they occur. At the same time, the system must be capable of accurately confirming the identity of causal agents within a useful time frame (FAO, 1999). In terms of specificity, surveillance systems should not generate too many false positives or false alarms which suggest the disease is present when it is not, or that identifies animals as having the disease when, in fact, they do not.

The publication of the Global Foot and Mouth Disease Control Strategy and the 3rd edition of the SEACFMD Roadmap (2016-2020) has provided the basis for countries (both those free from FMD and those where it is endemic) to implement, and/or strengthen surveillance systems in order to meet the needs of the various programs/stages of the Progressive Control Pathway for FMD (PCP-FMD) tool elaborated upon within the Global Strategy. Additionally, countries which are seeking to achieve (or maintain) OIE recognition of FMD free-status or to have their official FMD control program endorsed by OIE, will have to meet specific requirements for surveillance. These requirements will be described further within this manual and in the various references provided at the end of the manual.

The content of this section of the manual is based largely on the following references: Cameron, 1999; Cameron, 2012; FAO, 2014; FAO, OIE and EuFMD, 2011 and The OIE *Terrestrial Animal Health Code* (Chapter 1.4 and articles 8.8.40, 8.8.41 and 8.8.42). These documents provide comprehensive detail about surveillance, with much of the information relevant to developing countries. Contained within these texts are some useful guides to designing and evaluating surveillance systems. The reader who wishes to gain a more in-depth understanding of surveillance and its

application is urged to read these documents in addition to the information presented in this manual.

This manual is intended to cover broad aspects of surveillance rather than to provide copious detail on underlying epidemiological principles, epidemiological survey design, sample selection, interpretation of diagnostic tests, etc. Therefore, readers are assumed to have a basic knowledge of epidemiology and should refer to a general textbook on veterinary epidemiology (Thrusfield, 2007) and other references provided within this manual for additional background information on the material covered.

Purpose of surveillance

There are many different reasons why Veterinary Authorities undertake surveillance, but most of these can be summarized into four general purposes, thus (Cameron, 2012):

1. When disease is absent (from a country/zone)
 - a. Demonstrating freedom from disease
 - b. Early detection of disease
2. When disease is present (in a country/zone)
 - a. Measuring the level of disease
 - b. Finding cases of disease

Almost all types of surveillance conducted will fit into one of these four categories, and these will form the basis of information presented throughout this manual on surveillance.

Types of Surveillance

Surveillance may be classified in a number of different ways, including: the origin of the data used/collected during a surveillance activity; the disease focus of surveillance; whether surveillance is based on a sample of the population, or on the whole population; and how often a particular surveillance activity is conducted (i.e. whether it is continuous or occurs only periodically). These different approaches to classifying surveillance activities are outlined in more detail below. By considering the different characteristics of various surveillance systems, it is possible to see why some systems are better suited to certain situations than others. The information presented here is largely based on material from FAO (2014).

Origin of data

Different surveillance systems will often be referred to as 'passive surveillance' or 'active surveillance' (illustrated in

Figure 1). The terms passive and active refer to whether or not the Veterinary Authority has purposefully collected the data for the purposes of disease surveillance or not. Passive surveillance refers to systems where information on disease events is brought to the attention of Veterinary Authorities without them actively seeking it (FAO, 2014). A common example of a passive surveillance system is a farmer disease reporting system in which farmers report disease (usually because they are seeking advice/treatment) in their livestock, but the information in that report can also be used by the Veterinary Authority for the purposes of surveillance. Generally, passive surveillance systems are inexpensive due to the fact that the data is already being collected for other purposes.

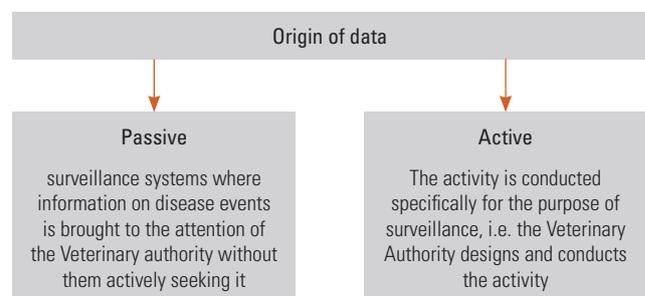


Figure 1. Diagram showing classification of surveillance based on origin of data

Active surveillance can be described as when an activity is conducted specifically for the purpose of collecting information for surveillance. Active surveillance activities are generally designed and implemented by the Veterinary Authorities and therefore have the advantage that they can collect data which will suit their needs and best support necessary decisions. However, active surveillance activities tend to be more expensive, and time-consuming, to conduct. Examples of active surveillance include: serological surveys to determine the vaccination coverage in large ruminants in a village following an FMD vaccination campaign or farmer questionnaires to estimate the level of lameness in sheep flocks. Participatory surveillance is a form of active surveillance but will generally be less expensive to conduct than other types of active surveillance (see section on participatory epidemiology).

Disease focus

Another way in which surveillance systems may be classified is whether they provide information on a single disease (targeted) or whether they can be used to detect multiple diseases. An example of targeted surveillance, in the sense of disease focus, would be a serological survey conducted with

the purpose of estimating prevalence of FMD in a country. An example of general surveillance systems would include farmer disease reporting systems, whereby any disease may be reported by a farmer, or abattoir surveillance which is based on observation of carcasses and therefore may detect the presence of several different diseases.

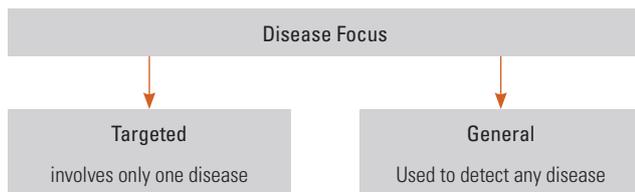


Figure 2. Diagram showing the classification of surveillance based on disease focus

Population coverage

Population coverage describes whether a particular surveillance activity covers the whole population of interest or whether it covers only a sample of the population. Where samples of a population are discussed in this manual, it should be noted that the term ‘sample’ refers to a selected sub-set of the population. This is distinct to a clinical sample (such as blood, tissue, etc.) which is taken from an individual animal for diagnostic or monitoring purposes and the two meanings should not be confused.

Most surveys (serological surveys or questionnaire surveys, for example) will be performed on a sample of the population of interest rather than on the whole population. The results from the sample are then used to make inferences about the whole population. How well the results from that sample reflect the true population depends upon how representative the sample is of the target population which, in turn, is based on how the sample is selected (see Cameron, 1999 for information on sample selection). Comprehensive surveillance systems, on the other hand, cover the whole population and therefore there is no need for identifying a sample. An example of a comprehensive surveillance system (when dealing with livestock diseases) would be a farmer disease reporting system given that, in general, all livestock will be owned by a farmer and that almost all of those animals would be seen on a regular basis. An example of a surveillance system which only covers a sample of the population would be a farmer questionnaire study in which a selection of farmers are interviewed in order to find out which livestock diseases occur most commonly in a particular country.

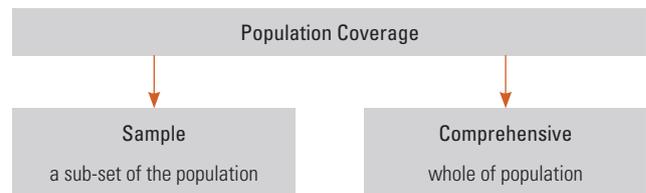


Figure 3. Diagram showing the classification of surveillance based on population coverage

When selecting from a target population, how that sample is selected will depend upon the objective of the surveillance. If the purpose of the surveillance activity is to estimate the level of disease in a population, then it is important that the sample selected (i.e. the animals selected to test) have the same features as the target population. This type of sampling is referred to as representative sampling as the sample population is representative of the target population. If, however, the purpose of the surveillance activity is to demonstrate freedom from a particular disease, risk-based sampling (in which the sampling targets individuals more likely to have the disease) may be more applicable, as this can provide a similar level of confidence that a disease is not present, but involves a lower sample size and is, therefore, a more efficient approach to surveillance than representative sampling to demonstrate freedom from disease. This concept is described further below, but for comprehensive detail on demonstration of freedom, refer to FAO (2014).

Representative (random) sampling

Representative sampling is generally used where surveillance aims to measure the level of disease in a population or describe the distribution of disease. This involves testing a sample of animals and using the results from that sample to make inferences about the whole population. The method used to select the sample is very important to ensure that the sample is representative of the whole population. For example, if we want to estimate the number of farmers who have seen FMD in their animals in the last 4 years in a particular country, we would need to ensure that the farmers were selected at random (with each farmer having the same chance of being selected) and that a sufficiently high number of farmers were interviewed to ensure that the resulting estimate was both representative of the whole population and a sufficiently precise estimate of the true value in the whole population (refer to Cameron (1999) and Cameron (2012) for more information on random sampling and calculation of sample size).

Risk-based sampling

Risk-based sampling is only appropriate where sub-populations can be identified which have a different risk

of having a particular disease compared to other sub-populations, due to the existence of certain risk factors (for identification of risk factors see the section on epidemiological analysis). The use of risk-based surveillance for demonstrating freedom from disease is now considered appropriate by the OIE provided that it is based on a sound understanding of the disease (and its risk factors) in a particular area. Risk-based surveillance basically means looking for something where it is most likely to be found (FAO, 2014). By focusing surveillance in areas (or sub-populations) where the disease is most likely to occur, an appropriate degree of confidence that a disease is not present in the country (above a pre-determined level) can be achieved more efficiently than with other sampling strategies (FAO, 2014; Stark *et al.*, 2006). Such surveillance, with the rationale, strategy and results appropriately described and documented, would be an important part of a country's dossier for submission to OIE to support endorsement of a zone as free from FMD.

Frequency

Finally, surveillance may be classified according to whether it is carried out, or occurs, on a continuous basis (all the time) or whether it only occurs periodically. A farmer disease reporting system is an example of continuous surveillance as farmers will generally see their livestock at least once a day and, therefore, livestock are under continuous surveillance. A serological survey, or disease reporting by veterinarians, on the other hand, are both examples of periodic surveillance activities which tend to be conducted only at specific times.

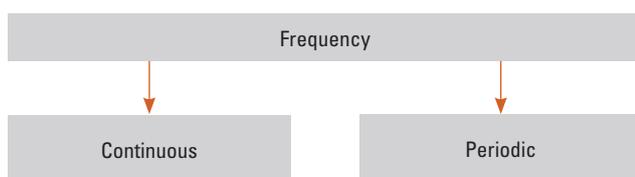


Figure 4. Diagram showing the classification of surveillance systems based on frequency of activity

Selecting the right kind of surveillance activity

This section focuses on what features of a surveillance activity are required in order to achieve specific objectives. This addresses surveillance systems with the purpose of early detection of disease, demonstrating freedom from disease and measuring the level of disease. The information presented here is largely based on a document by Cameron (2012).

Early detection

Features of surveillance required for early detection

- Continuous
- Comprehensive population coverage
- Sensitive with a very low design prevalence (see FAO, 2014)

Demonstrating that a country has an effective early detection system in place is necessary in order to demonstrate to the OIE and to trading partners that the Veterinary Authority of a country is able to rapidly detect incursions of disease into a country (or zone), should they occur. Failure to detect occurrence of a new or exotic disease in a country (particularly one which exports livestock and livestock products to other countries) could result in extensive spread of disease, including spread to other countries, before detection.

An effective early detection system will generally need to detect disease in a very small number of animals compared to the total population, given that when a disease is first introduced to a country or zone it will generally only affect a small number of individuals and the aim of early detection systems is to detect the incursion of disease before it has spread widely in the population. In order to achieve this, the surveillance system will need to cover the whole population (comprehensive), occur on a continual basis, and be sensitive at a very low design prevalence. The sensitivity of a surveillance system is the probability that the system would find disease in the population if it is infected at (or above) a specified level (design prevalence). Estimating the sensitivity of a surveillance system and the principles of sensitivity and design prevalence are quite complex. However, this is described comprehensively in an FAO manual for veterinarians on the design and analysis of surveillance for demonstration of freedom from disease (FAO, 2014) and readers are directed to this manual for more information on these terms.

In most cases, for FMD, an early detection system would be in the form of a farmer disease reporting system and so countries should aim to ensure that disease reporting by farmers is optimized such that it functions as effectively as possible. A later section will discuss the specifics of disease reporting systems.

Demonstrating freedom

Features of surveillance for demonstrating freedom

- Continuous or periodic/ad hoc
- Can be based on a sample rather than whole population (risk-based sampling may be used)
- Higher design prevalence than early detection

Demonstrating freedom from FMD is an essential requirement for countries seeking OIE recognition of freedom. The requirements for demonstration of freedom by the OIE have become less prescriptive in recent years, recognizing the fact that the impact and epidemiology of FMD vary widely in different regions and therefore, the OIE recognises that surveillance strategies employed for demonstrating freedom from FMD in the country, zone or compartment at an acceptable level of confidence, should be adapted to the local situation (see OIE *Terrestrial Animal Health Code* for more information).

Evidence from multiple data sources may, according to the OIE *Terrestrial Animal Health Code*, be combined to produce an overall level of confidence that a country (or zone) is free from FMD. The way in which evidence is combined and the value provided from each source (i.e. the methodology used to combine evidence from multiple data sources) should be scientifically valid. Detailed explanation of this methodology is beyond the scope of this manual, but a comprehensive guide is provided by FAO (2014).

Despite the considerable latitude afforded Member Countries in designing and implementing surveillance to demonstrate freedom from FMD, it is essential that surveillance systems are carefully designed and implemented to avoid producing results that are insufficient to be accepted by the OIE or trading partners, or being excessively costly or logistically complicated (OIE *Terrestrial Animal Health Code*). For further information on the OIE requirements for demonstration of freedom from FMD, and the methods by which these standards might be achieved, refer to OIE *Terrestrial Animal Health Code* (Chapter 1.4 and article 8.8.40).

Given that evidence from multiple types of surveillance can be combined to demonstrate freedom from disease, the types of surveillance applied will vary. However, surveillance to demonstrate freedom will generally include some form of serological surveillance, which will take place on a periodic, or ad-hoc, basis. However, further evidence may be provided by continuous types of surveillance such as farmer disease reporting systems. There is likely to be a combination of active and passive surveillance approaches used to demonstrate freedom. The approaches used, and the level of confidence afforded by the system as a whole, will determine the adequacy of surveillance to demonstrate freedom (see FAO, 2014). Caporale, *et al.* (2012) provides an excellent reference on surveillance strategies for FMD to prove absence of disease and absence of viral circulation.

Measuring the level of disease

Features of surveillance for measuring the level of disease

- Usually periodic/Ad hoc
- Based on a representative sample of the population

When designing surveillance for measuring the level of disease in a population the sample selected for testing should be selected such that it is representative of the target population and is large enough to achieve an acceptable level of precision. For further information on sample selection and calculation of sample size for surveys to estimate the level of disease in a population (or measure the level of immunity in a population to estimate vaccination coverage, for example) see Cameron (1999).

Surveillance needs

The FMD surveillance needs for different countries or zones differ depending on factors such as: the status of FMD (endemic/sporadic/free (with or without vaccination)), potential for trade (import/export of livestock and livestock products), involvement (and stage) in the PCP for FMD, whether a country is seeking to achieve or maintain OIE recognition of FMD freedom or seeking OIE endorsement of an official FMD control program. However, there is a certain minimum surveillance capability that every country should have and this recognizes the responsibility that the Veterinary Authorities from all countries have to help protect their own community, as well as the global community, against the threat of new and emerging diseases. These minimum surveillance capabilities (as described by Cameron, 2012) are, the ability to: describe what important diseases are present in their country, and detect the occurrence of new, emerging or exotic diseases. Failure to fulfil these minimum requirements indicate that a country has a non-functioning Veterinary Authority (Cameron, 2012).

Table 1 (based on information from Cameron, 2012) describes surveillance needs for different countries at different stages in FMD control and/or involvement in trade in animals and animal products (focusing on those relevant to FMD).

For countries following the PCP for FMD (which is also identified by the SEACFMD Roadmap as an important tool), specific surveillance activities are required throughout the process of control and eradication of FMD, according to the requirements in each stage of the PCP. For full details of the surveillance activities and needs under the PCP FMD, readers

Table 1. Surveillance needs for different countries at different stages in FMD control and/or involvement in trade in animals and animal products (Cameron, 2012)

Country type	Surveillance needs
Endemic disease control program	<ul style="list-style-type: none"> – Priority setting: surveillance to establish the level of disease – Monitoring program effectiveness: surveillance to measure level of disease at intervals before and after a control program, also surveillance to measure the level of immunity in a vaccinated population (see manual on vaccination and post-vaccination monitoring) – Identifying areas/sub-populations where different levels of disease are present and identifying risk-factors (helps to identify areas of high prevalence which may represent critical points for targeting control measures, or areas of low prevalence/absence of disease which may be suitable for establishing zones) – Case finding: usually less applicable to FMD, except in vaccinated populations where surveillance may involve searching for FMD infected animals/detecting isolated disease foci (testing for NSP-antibodies in a vaccinated population)
Exporting countries	<ul style="list-style-type: none"> – Demonstration of freedom from disease (in the whole country or a zone) – Estimating disease prevalence for risk analysis (if unable to demonstrate freedom from disease) – Describe distribution of disease to support zoning – Early detection of disease incursions
Importing countries	<ul style="list-style-type: none"> – If the importing country wishes to prohibit imports from countries where FMD is present, it will need to conduct surveillance, either to demonstrate freedom from disease or as part of an effective control program

should refer to FAO, OIE and EuFMD (2011). In summary, the surveillance needs depend upon the objectives of each stage. Throughout the PCP there should be a surveillance system in place to enable Veterinary Authorities to measure the level of disease, detect new outbreaks of disease and, in the latter stages, demonstrate freedom from disease.

In the early stages of the PCP-FMD, emphasis is on understanding the epidemiology of FMD in a particular country and, therefore, there is a specific requirement to conduct surveillance (usually in the form of a serological survey) to identify differences in risk between animal populations/production systems. This type of survey (which would provide an estimate of the level of disease) would also provide a baseline for future monitoring and help to identify risk-factors for FMD. Participatory surveillance may also provide valuable information on FMD epidemiology in certain areas (see section on participatory epidemiology) and, if used alongside a serological survey, may be used as part of the planning of a serological survey, or to help interpret the results of such a survey.

As a country progresses along the PCP-FMD, their surveillance needs will evolve to suit the progressive control of FMD. With implementation of control measures, such as vaccination, comes the need to conduct surveillance to measure vaccination coverage and population immunity and to monitor the level of disease and, by comparing this with the results of baseline surveys, determine the impact of the control measures on FMD incidence/prevalence. As the disease is progressively controlled and the country moves towards eradication, early detection of outbreaks becomes key to ensuring that any incursions/outbreaks are rapidly detected and appropriate action can be taken. The early detection of outbreaks of FMD will generally be

achieved through farmer disease reporting, given that this provides wide coverage of the livestock population and occurs constantly. However, countries need to consider the limitations of this system in their particular country and address factors which could lead to under-reporting (see section on farmer disease reporting below).

Finally, as countries move to a stage where FMD has been eradicated, and no further outbreaks are detected, surveillance will focus on demonstrating freedom from disease/infection (for which more information is provided below) and on maintaining an adequate surveillance system to ensure that any FMD outbreaks would be rapidly detected.

Surveillance needs for countries seeking OIE recognition of freedom (with or without vaccination) are clearly outlined in the OIE *Terrestrial Animal Health Code* (Chapter 1.4 and articles 8.8.40., 8.8.41. and 8.8.42.). These will not be described in more detail here as they follow the same basic principles as those explained in other parts of this manual.

Surveillance tools

Thus far, this manual has focused on the features of different types of surveillance systems in terms of which features are required to meet specific surveillance needs. This section focuses, more specifically, on the actual methods of surveillance that might be employed to fulfil the requirements outlined above. Some of these have been mentioned as examples already, but this section will focus on presenting the key features of various forms of surveillance system, with reference to documents where

further information is required. The information presented here is based, largely, on Cameron (2012) and FAO (2014) where further detail on these surveillance approaches may be accessed. Greater emphasis will be placed on those more relevant to FMD.

Passive disease reporting systems

Farmer reporting systems are the most common and probably the most important form of surveillance in any country (Cameron, 2012). Other key stakeholders may also be utilized in such systems, based on large or regular throughput of animals, including livestock markets, slaughterhouses, transport companies and exporters/importers. These systems have the advantage that they are relatively inexpensive as disease reports are being made independent of the need for surveillance. However, although the system may be inexpensive to maintain, there may be need for investment in order to strengthen the system such that it becomes more effective (e.g. there may be a need to conduct farmer/stakeholder training/awareness programs, improve reporting systems/methods of communication, etc.). When functioning effectively, these systems provide excellent coverage of the whole livestock population and occur on a continuous basis. Therefore, this system is ideally suited to early detection of disease and can also be used to provide additional evidence of disease freedom.

A passive disease reporting system is particularly suited to surveillance of diseases which cause obvious clinical signs in affected animals given that farmers are more likely to notice (and report) cases of disease, or for diseases which have significant (and immediate) impact on farmer livelihoods. For FMD, where there are higher levels of immunity (in endemic areas) or where vaccination is used, and in certain species (small ruminants) clinical signs in infected animals may be less obvious and, therefore, the reporting system will be less sensitive in these situations. In addition, research in some South-East Asian countries suggest that farmers may not report FMD as the disease is generally non-fatal and, therefore, they do not see any advantage to reporting disease (Bellet, *et al.*, 2012). Other reasons for not reporting may be

that farmers or stakeholders perceive a negative outcome when making a report.

The key to success in this type of system is to ensure that there is adequate incentive for stakeholders to report suspected cases of disease, and certainly no disincentives to reporting. Historically, some countries have implemented harsh measures in response to reported outbreaks of FMD, with little or no compensation provided to farmers who may have suffered financial consequences from these control measures. Such responses to disease reporting function only to dissuade farmers from reporting disease and potentially result in farmers or others hiding suspicious cases and under-reporting of disease. In order to encourage reporting, relevant operators should be aware of the response to a report and the likely positive consequences of making a report (such as control of the spread of disease to other livestock), and financial losses incurred due to the control measures should be adequately compensated. The response of the Veterinary Authorities should be consistent, based on sound principles of disease control suitable for the stage of FMD control/eradication, and according to the status of FMD in the affected area.

Mariner, *et al.*, (2014) outlines some incentives and disincentives which may function to encourage or discourage, respectively, farmers (or other stakeholders) to contribute to surveillance activities (table 2). While these factors relate to any surveillance activity they are particularly pertinent to passive disease reporting systems where there is a need to incentivize stakeholders to report disease.

A comprehensive guide to passive disease reporting systems, including guidelines on developing/strengthening these systems, is provided in FAO (2014).

Sentinel herds

Sentinel herds are generally small numbers of animals grouped together and tested on a regular basis to determine whether they have been exposed to a specific disease. The

Table 2. Incentives and disincentives to contributing to surveillance (Mariner *et al.*, 2014)

Incentives to contributing to surveillance	Disincentives to contributing to surveillance
Easy access to the surveillance system that recognizes the value of people's time	Time and money invested in providing surveillance information rarely result in action
Surveillance personnel show genuine respect for knowledge and information provided	Providing surveillance information that results in actions that negatively affect household or community well-being
Surveillance personnel seek to build trust	Disease reporting result in social isolation of the participant or community retribution
Surveillance information leads to action that has a positive impact at the household level or at the level of the reporter	Transmission of disease reports is perceived to endanger the careers of surveillance actors or place informants in stress situations

sentinel animals will usually be located in areas identified as a high risk for exposure to the pathogen of interest. This approach is often used for vector-borne diseases and would generally be less applicable to FMD. However, a form of this approach may be used to detect, or provide evidence for absence of, FMD circulating in vaccinated populations. By placing young, unvaccinated animals within vaccinated populations and periodically testing these animals for evidence of sero-conversion (and/or clinical disease), this may provide evidence that FMD is not circulating in the vaccinated population.

Abattoir surveillance

Abattoir surveillance can be useful and cost effective, given the large numbers of animals that are processed through abattoirs and that some information will be collected for other purposes. It can represent a form of passive surveillance. Using abattoirs to conduct active surveillance, targeting a specific disease, may also be convenient and cost-effective, but the sample would not be representative of the whole population given that, in general, only a specific sub-population of animals are sent to abattoirs. For more information on abattoir surveillance see FAO (2014).

Negative reporting

This form of surveillance is specifically used for the purpose of providing evidence of freedom from disease. It consists of reports made by veterinarians (but could also be veterinary para-professionals, farmers, etc.) after they have visited a particular herd/farm/village that they have not seen evidence of the target disease (i.e. FMD). The report made can (and should) be brief, providing details on location, date and confirmation that the target disease was not seen. The value of this form of surveillance depends upon the probability that the veterinarian visiting the area would have detected the disease if it was present at the time of the visit. This type of surveillance can be sensitive for detecting disease in species (and populations) which show obvious clinical signs. For FMD, it would be sensitive for detecting disease in naïve, unvaccinated populations of cattle and pigs. However, it would be very insensitive for detecting sub-clinical disease, e.g. during the incubation period; in vaccinated populations; in sheep/goats (which often show subtle clinical signs of FMD); or in animals with partial immunity due to previous exposure).

If these limitations are taken into account, this form of surveillance can provide useful additional evidence for freedom from FMD when applied to suitable populations of livestock.

Syndromic surveillance

Syndromic surveillance involves the identification of specific signs, or groups of signs, and analysis of these signs in space and time (Cameron, 2012). The purpose of this type of surveillance is not to diagnose a specific disease, but to detect abnormal patterns of signs that may be due to one of a large number of diseases. When an abnormal pattern is detected, a disease investigation is then implemented (Cameron, 2012).

Syndromic surveillance may be particularly useful for detecting new diseases, or detecting incursions of exotic diseases, given that specific diseases are not being identified but, rather clinical signs or groups of signs. In animal health systems, the main sources of information for syndromic surveillance are clinical data from practitioners and laboratory data (Dórea *et al.*, 2011). Therefore, this is classed as a passive surveillance activity as the information is already being collected but can then be used by Veterinary Authorities for the purposes of surveillance. In order to detect changes in the patterns of clinical signs, large amounts of data are required. By collecting and analyzing these data on a continual basis, it is possible to identify the normal level of the signs/syndromes of interest including any normal seasonal/cyclical fluctuations. Once the normal patterns are understood, any deviation from these patterns may be identified and investigated.

Dórea *et al* (2015) describes a veterinary syndromic surveillance system developed in Sweden based on laboratory test requests, which may serve as a useful example of this type of system.

Indirect surveillance

This method involves monitoring indicators other than direct disease, which may indicate occurrence of an unusual disease event. In some situations, this involves monitoring laboratory submissions, or information from private veterinary practices but could also include monitoring other indicators such as drug sales. Figuié *et al.*, (2013) describes how collecting surveillance data from within a value chain of a commodity may identify unusual events suggestive of disease outbreaks. For example, some farmers will sell large numbers of birds during a suspected outbreak of HPAI but they may not directly report the disease to the Veterinary Authority. Therefore, changes in sale volumes may indicate an outbreak, and thus could be a valuable part of a surveillance strategy.

Participatory disease surveillance

What is Participatory Epidemiology?

Participatory epidemiology is an emerging branch of veterinary epidemiology which is based on the principles and methods of Participatory Rural Appraisal (PRA). In some contexts, PE is used in a very similar way to PRA but focuses on animal health issues rather than taking a broad view of problems in a given community (as is the case with PRA). At other times, PE is used to work with communities to study specific disease problems and identify best-bet solutions (Catley, 2005).

Participatory disease surveillance (PDS) is the application of participatory epidemiology (PE) methods to disease surveillance. It represents a form of active surveillance whereby the Veterinary Authority conducts planned activities to gather disease information from farmers. This approach, in common with traditional PE approaches, is based on engagement with farmers and is conducted by trained teams conducting semi-structured or non-structured interviews to gather information on animal diseases. Participatory methods will be described in more detail in the section of this manual on PE.

Surveys

Surveys are a form of active surveillance and, therefore, the Veterinary Authority has full control over the survey design and the data collected. They are generally performed on a sample of the population and the sample may be representative or risk-based, depending upon the objective of the survey (see earlier section). Surveys may involve collecting information through taking specimens from animals and testing them in a laboratory, asking farmers questionnaires, making clinical examinations of animals in the sample, etc. These are useful for various purposes, including estimating the level of disease and demonstrating freedom from disease. For information on how to plan a survey (including sample size and sample selection), refer to veterinary epidemiology text books and/or Cameron (1999).

Participatory epidemiology

Participatory Epidemiology can be described as the application of participatory rural appraisal techniques (described below) to the collection of epidemiologic information (Mariner *et al.*, 2001a). Participatory Epidemiology uses a combination of practitioner communication skills and participatory methods to improve the involvement of animal keepers in the analysis of animal disease problems, and the design, implementation and evaluation of disease control programs and policies (Catley

et al., 2012). Key features of PE are outlined below. The value of PE is that it draws upon the extensive knowledge of livestock keepers in order to improve our understanding of the social and cultural contexts that affect the distribution and dynamics of diseases as well as the suitability of control alternatives (Mariner *et al.*, 2014; Jost *et al.*, 2007).

This manual focuses predominantly on Participatory disease surveillance (PDS) in describing participatory methods for epidemiology. Participatory disease surveillance can be viewed as a branch of PE, which involves application of PE methods to gathering epidemiological intelligence with the objective of informing decision-making and action (Mariner *et al.*, 2014). Participatory disease surveillance differs from PE, however, in that it is principally an information gathering exercise rather than a consultative process. The same tools are used in PE and PDS and, when applied effectively, PDS should still involve mutual learning, respect and trust between practitioners and stakeholders. Participatory disease surveillance has also been shown to complement and strengthen existing surveillance systems in countries where it has been applied (Mariner *et al.*, 2014).

Key features of participatory epidemiology (Catley and Admassu, 2003)

Attitudes and behaviour: Practitioners are required to assess their own professional and cultural biases. Essentially, they need to be genuinely willing to learn from local people, not lecture to them but actively and patiently listen. This requires respect for local knowledge and culture.

Combined methods and triangulation: Participatory epidemiology uses interviewing, scoring and ranking, and visualisation methods. Of these, interviews are the most important group of methods because they are used alone but also complement and form the basis for other methods. The visualisation methods include mapping (natural resource maps, social maps, service maps), seasonal calendars, time-lines, transects, Venn diagrams, flow diagrams. Scoring methods include matrix scoring and proportional piling. These methods are combined with conventional veterinary investigation and epidemiological tools.

The use of key informants: Although pastoral communities generally are recognised as knowledgeable about animal health matters, certain people are known to possess special livestock knowledge and skills. These local experts are important key informants for participatory epidemiologists.

Action-orientated: Participatory epidemiology aims to generate information that can be verified with communities and leads to agreement on appropriate action. Initially, the aims of a particular study or investigation should be clearly explained to avoid raising expectations. In some situations, further laboratory results will be required and the mechanism for transferring these results back to the community should be defined.

Methodological flexibility, adaptation and development: Participatory epidemiology is a relatively new branch of epidemiology that is still developing. The approach is based on qualitative inquiry and complements the qualitative nature of standard veterinary investigation procedures. According to the needs of a given community or organisation, participatory epidemiology can also combine the benefits of participatory approaches and methods with quantitative inquiry. Methodological adaptation is encouraged.

The website 'Participatory Epidemiology' provides information on the origins and current uses of

participatory epidemiology, and a collection of reports, workshop proceedings and training materials (<http://www.participatoryepidemiology.info/index.html>). This is a useful reference, together with the website for the Participatory Epidemiology Network for Animal and Public Health (<http://penaph.net>) which also hosts a link to the Participatory Research on Emerging and Infectious Disease in South-East Asia (SEA-PREID) network. These, together with other references provided in this manual, should be used to provide further detail on the concepts and applications of PE. In particular, the PRA tools described in this manual are only described in summary. Readers planning to apply these techniques should seek further information from references provided and should receive training on participatory techniques.

Advantages and disadvantages of participatory approaches

The PE approach was developed to overcome the constraints in applying conventional epidemiology and formal research in developing countries. Conventional epidemiology can be expensive and logistically complex, producing large quantities of information from formal surveys that are often biased (Jost *et al.*, 2007).

Participatory epidemiology provides a useful tool for gathering information, planning projects, engaging stakeholders, and improving relationships between the Veterinary Services and livestock keepers. Given that it is purposive in its sampling method, it can be targeted in the places where information is most needed, such as in remote, marginalized areas which have poor access to veterinary services and, therefore, may be under-represented in more conventional approaches to surveillance, and/or may represent 'pockets' of disease remaining after completion of control programs.

In the section of this manual which deals with epidemiological analysis, measuring association between disease occurrence and certain risk factors is described. It is important to note here that quantitative data, such as those generated from more conventional forms of active surveillance, and the statistical methods used to analyse quantitative data, cannot establish causal relations. They can merely establish the probability of association between factors. It is, in fact qualitative information that is used to determine causal relationships (Mariner *et al.*, 2001a). Participatory epidemiology is particularly well-suited to gathering qualitative data on risk factors for disease.

FAO (2000) described the following list of PE features which make it suitable for application to animal health problems compared to more conventional types of surveys:

- Often the only way of gathering data from certain areas (particularly remote or strife-torn areas)
- Usually cheaper and more feasible than full-scale randomised surveys; thus often an attractive option for poorly-resourced veterinary services
- Results are usually available very rapidly
- More flexible and adaptable to new issues uncovered during the appraisal
- Effective method for the design of more conventional studies through better identification of the breadth, depth and priority of issues that may merit quantitative study
- Participatory methods build on what local people already know; enables them to use their own knowledge and skills in disease surveillance and control
- Participation is a tool for empowerment, particularly of the poor and of rural women

Despite the obvious advantages of PE, this method still has limitations and it is important to acknowledge these limitations and thus apply PE only where it will provide useful information and where the situation suits this approach. Participatory epidemiology should be carefully planned and conducted in order to minimise bias and maximise the value of information collected. This requires that those individuals conducting the PE are adequately trained and experienced in these methods. Such training will require an investment of time and money. In reality, most surveillance systems will consist of a combination of approaches to surveillance, the results of which can be combined and are often complementary.

The application of participatory epidemiology to surveillance systems where the priorities of the livestock keepers differ from the national/international policy makers (Catley *et al.*, 2012) can present challenges in that livestock keepers may have limited knowledge of, or interest in, diseases of low priority and may therefore be unable (or unwilling) to provide information on such diseases. It is important that the priorities of livestock keepers are understood when applying PE methods for the purposes of disease surveillance.

Target areas/individuals for participatory epidemiological studies are generally selected purposively rather than randomly. Therefore, the resulting information may not be representative of the wider population and may introduce bias which limits the value of the resulting information. According to Chambers (1983) (in FAO (2000)) there are six sources of bias which may affect rapid appraisals (but

these can also be applied to PE as a surveillance method) and which should be addressed when planning rural appraisals (or PE activities):

1. **Spatial bias:** investigators often travel on better roads and the farmers they are able to reach are determined by proximity to roads/villages leaving the farmers in more remote areas (who are often the poorest) out of the picture.
2. **Project bias:** visitors and researchers are often channelled to areas where projects have been active and most of the work will then concentrate on these places.
3. **Person bias:** influential people interviewed (particularly as key informants) are often biased against poor people, or ignorant of their needs. It is essential to include the rural poor as key informants and ensure they are interviewed in settings where they feel comfortable enough to express their views.
4. **Seasonal bias:** Malnutrition, morbidity and mortality all tend to be highest at the end of the dry season; surveys carried out at other times may miss these phenomena.
5. **Diplomatic bias:** For many communities, poverty is the subject of shame, and the needs of the poorest are sometimes glossed over or even concealed, either by the poor themselves or by officials working with them. “Politeness” and “diplomacy” will try to hide the problem. PRA offers specific tools, such as wealth ranking, to help define the social strata within a community as well as each group needs, views and interactions.
6. **Professional biases:** Professional training may in itself be an obstacle, making it difficult for the researcher to understand the linkages in the system they are trying to observe, or leading them only to “see” the richer segment of rural society. This is one reason why it is important to seek training or assistance experienced in the application of PRA methods at the outset of any new program.

Participatory rural appraisal ‘toolkit’

Participatory epidemiology utilizes methods applied by PRA, a qualitative intelligence gathering approach designed to rapidly achieve a best-bet understanding of a situation as a basis for an action plan (Mariner *et al.*, 2001a). When used for PE, these methods are applied specifically to animal health issues rather than to a broader range of issues facing communities.

Catley (2005) describes three main categories of participatory methods:

- Informal/semi-structured interviewing methods
- Visualization methods
- Ranking or scoring

These participatory methods should also be supported by knowledge of secondary literature including, for example, existing literature, reports, maps and databases on the communities and issues under study (Mariner *et al.*, 2001a), and direct observation including clinical examination of livestock and transect walks (the process of walking a straight line through the community in order to directly observe production systems and community life away from the main road (FAO, 2000)). The different participatory methods will generally be used in combination, with results generated by the different methods being compared. This process of comparison and cross-checking, which serves as a validation tool, is called triangulation (Catley, 2005) and is one of the key components of participatory approaches.

Within the general categories outlined above, there are several specific methods which may be applied, depending upon the information required. Table 3 provides examples of which methods may be used for gathering which types of information for participatory epidemiology.

As demonstrated in Table 3, there are numerous tools used for participatory epidemiology. The application of these, together with guidelines on how to conduct these methods, can be found in the literature. A brief summary of some of the main methods applied in participatory epidemiology, and the type of information generated by each method is provided below. However, for further detail on these methods, readers should refer to the following documents (FAO, 2000; Catley, 1997; Catley, 2005) together with other literature outlined in the reference section of this manual.

The semi-structured interview

The semi-structured interview is one of the key tools in PE. A checklist of subjects to be covered is used as a point of reference during the interview. The purpose of this is to guide the general direction of the interview and to prevent key points from being forgotten. However, the interview team should remain flexible in their approach to the interview, allowing time and opportunity for participants to introduce topics and issues (Mariner *et al.*, 2001a). For example, after introductions, an opening question might be ‘What are the problems with your livestock?’ As the participants introduce topics, probing questions are asked to obtain more detail and check information for internal consistency (Mariner *et al.*, 2001a). This approach allows

Table 3: Table showing methods used for gathering different types of information for participatory epidemiology (Catley, 2005)

Information required	PE methods
Any information	Informal interviews
System boundary	Natural resource maps social maps
Social organisation	Social mapping, Venn diagram
Wealth groups	Wealth ranking
Relative livestock ownership	Proportional piling
Role of livestock in household economy	Livelihood analysis
Preferred types of livestock reared	Livestock species scoring
Income from livestock	Proportional piling
Marketing structure	Flow diagrams, service maps
Veterinary services	Service map, Venn diagrams, ranking and scoring
Animal husbandry	Seasonal calendars, mobility maps, transects
Resources available to rear livestock	Natural resource maps, transects
History of livestock diseases	Timelines
Priority livestock diseases	Livestock disease scoring
Seasonal variations in livestock disease	Seasonal calendars
Relative mortality rates	Proportional piling
Livestock productivity	Progeny history

the interview to be flexible and permits the respondents to express their thoughts in their own words within their own conceptual frameworks (FAO, 2000).

Mapping

Mapping is a highly useful tool in PE and can provide a wealth of epidemiological information. The participants (the respondents together with the appraisal team) sketch a map of useful resources, grazing movements, trade movements, livestock density, community boundaries, vector prone areas and disease prone areas (FAO, 2000). Respondents should be asked to illustrate locations on the map, and the interview team should also probe for more information to provide underlying reasons for movements and resource use (FAO, 2000).

Mapping can generate information on the spatial relationship between communities, their social relations and movement patterns (Mariner *et al.*, 2001a). This can go a long way to determining livestock contact patterns which are key to understanding the epidemiology of infectious diseases (Mariner *et al.*, 2001a). Mapping can also provide spatial information on livestock distribution, movements, interactions, diseases and disease vectors, all of which are extremely useful in epidemiology (Catley, 2005).

Mapping has been used to map disease outbreaks, both spatially and temporally, within rural and urban communities. Respondents indicate the locations and

dates of clinical disease events and describe the sequence of events, which reflects how diseases spread through communities and populations. This can highlight key risk factors and important epidemiological information, as well as contributing data to aid in estimating transmission parameters for disease models (Jost *et al.*, 2007).

Timelines and seasonal calendars

Many animal health issues are seasonal. Timelines and seasonal calendars are tools which gather data, primarily on temporal patterns of disease (FAO, 2000; Mariner *et al.*, 2001a). During construction of a seasonal calendar, participants will often mention key risk factors such as humidity, vector populations, grazing conditions, water scarcity, etc. Thus, not only do calendars provide information on seasonality; they are also useful tools for identifying predisposing factors (FAO, 2000).

Instructions on how to generate timelines and seasonal calendars is outlined in most text books on participatory methods and can be found in: Mariner *et al.*, 2001a and FAO, 2000).

Ranking, scoring and proportional piling

Ranking and scoring refers to a group of techniques used to prioritise information or provide semi-quantitative estimates of the relative size or impact of categories as perceived by the participants (Mariner *et al.*, 2001a).

Proportional piling is a flexible technique in which respondents are asked to divide 100 objects such as seeds or stones into piles of sizes representing the relative size or importance of different categories. The number of objects in each pile is then counted to give a score (Mariner *et al.*, 2001a). These techniques are more quantitative than simple ranking because it allows great graduation of emphasis. In some cases, a very significant problem may receive almost all the beans. The second most important may receive only two or three. This type of drastic difference in importance would not be evident in a simple ranking exercise (FAO, 2000). Participatory epidemiology studies have included estimation of disease incidence and mortality using methods such as proportional piling (Catley and Admassu, 2003).

According to Jost, *et al.*, (2007), proportional piling techniques can be adapted to study issues such as:

- disease prevalence and incidence
- mortality rates
- clinical presentation
- epidemiological risk factors
- disease impact
- the efficacy of disease interventions

Instructions on how to perform these techniques are provided in FAO (2000); Mariner *et al.*, (2001a); and Jost *et al.*, (2007).

Participatory surveillance: to complement and strengthen existing surveillance systems

What is Participatory Surveillance?

Participatory surveillance involves application of PE to gathering epidemiological intelligence with the objective of informing decision-making and action (Mariner *et al.*, 2014).

Participatory Surveillance (PS) is an active surveillance method that is usually used for purposive surveillance in high-risk areas for a specific disease of interest, and combines livestock keeper disease descriptions, observations of livestock, and diagnostic sample collection from animals that fit the case definition of the disease of interest (Mariner *et al.*, 2014). Applying PS will generally lead to an increase in the number of cases detected, if the disease is present, and an improved description of the local epidemiological

situation. This can provide valuable information on potential risk factors for a specific disease, and improves overall understanding of disease epidemiology in the target areas. Where a disease is believed to be absent, PS can also be used to provide evidence on absence of a disease in a population (Naing Oo, 2010).

Participatory surveillance methods are not intended to be used in isolation, and should not replace conventional surveillance and analytical capacities (Mariner *et al.*, 2014) but, rather they are intended to complement existing surveillance activities to increase the sensitivity of the overall surveillance system and ensure that high risk and marginalized populations are well represented in the overall system (Mariner *et al.*, 2002). As well as extending the capabilities of national surveillance systems by generating additional information, participatory surveillance methods also enhance the community ownership of data collection activities (Mariner *et al.*, 2014).

For traditional passive reporting systems, in which livestock keepers make a report of a disease event to Veterinary Services, the data generated may not be representative of the disease situation due to under-reporting, especially from remote, under-served, marginal areas (Mariner *et al.*, 2014). Amongst SEACFMD Member Countries, there is likely to be under-reporting of FMD for reasons, including: that the disease does not cause mortality and therefore, farmers see no benefit in reporting the disease (Bellet *et al.*, 2012) or where negative outcomes to reporting may be perceived. Participatory surveillance has been shown, in some situations, to provide additional disease intelligence to complement that collected through traditional passive reporting systems as well as strengthening passive disease reporting through encouraging more reports following improved communication, trust, etc. established between Veterinary Services and stakeholders engaged in participatory surveillance (Mariner *et al.*, 2014).

For more information on application of participatory methods of surveillance and examples of PS programs and lessons learnt from previous programs, refer to Jost *et al.*, (2007).

Participatory epidemiology in South-East Asia

There are several examples where PE has been successfully applied in South-East Asia, including but not restricted

to, those outlined in the following references: Naing Oo, (2010); Bellet *et al.*, (2012); Mariner *et al.*, (2014). The value of participatory epidemiology and its role in strengthening and complementing existing surveillance systems is recognised by international organisations, such as OIE (Figuie *et al.*, 2013) and efforts have been made to expand the use of this approach in recent years. Amongst the SEACFMD Member Countries, where resources are often limited, where there is known to be under-reporting of FMD through passive reporting systems and where active surveillance is often lacking, participatory epidemiology and participatory surveillance could provide a useful addition to current surveillance systems.

A participatory research network (The Participatory Research on Emerging and Infectious Disease in South-East Asia (SEA-PREID)) was established in 2012. The SEA-PREID is hosted by the GREASE Network (www.grease-network.com) and received initial support from the Rockefeller Foundation through PENAPH. The objectives of this network are to: promote inter-disciplinarity; promote appropriate use of PE in South-East Asia; build capacity in PE and to develop group projects with participatory components. For more information on this network, including details of participatory epidemiology training in South-East Asia, visit: <http://penaph.net/seapreid/>

Epidemiological analysis

Once data has been collected through surveillance activities, some form of analysis is needed in order to generate information which is meaningful and useful on which to base decisions on such things as: prioritizing diseases for control; targeting disease control measures; monitoring the impact of control measures; policy, etc.

This manual focuses on descriptive epidemiology, which involves counting the frequency of cases and describing distribution patterns of disease among different groups in the population for further analysis (Stevenson, 2008) and some basic applications of analytical epidemiology, which is aimed at determining the strength, importance and statistical significance of epidemiological associations (Pfeiffer, 2002).

The type of epidemiological analysis applied depends upon the questions that need to be answered, and/or the purpose of the data collection/analysis in the first place. The analytical tools presented here focus on those which are likely to be most useful for analysing data produced from surveillance activities conducted in SEACFMD Member Countries, consistent with the activities outlined under

the PCP-FMD. For this reason, the following objectives of epidemiological analysis covered in this manual include:

- Describing the occurrence of disease (i.e. calculating measures of prevalence and incidence)
- Describing the pattern of FMD in terms of temporal patterns and spatial patterns
- Identifying potential risk factors for FMD
- Determining the strength, importance and statistical significance of risk factors for FMD

The information presented in this manual will provide a summary of some of the key analytical tools and calculations which can be used to conduct basic analyses. Detailed description of complex analytical methods is beyond the scope of this manual. Therefore, readers wishing to conduct more complex analysis should consult veterinary epidemiological text books and other references for further information. The information in this manual assumes a basic understanding of statistics. For basic concepts of epidemiological analysis readers should refer to general epidemiology textbooks and/or other references, including: Pfeiffer (2002); Stevenson (2008) and Thrusfield (2007).

Any calculations or statistical tests described in this manual may be performed using free open-source programs (such as EpiTools or Apache Open Office Calc) or widely available software (such as Microsoft Excel). Further details on these applications are provided below.

Available programs for performing epidemiological analyses

- **EpiTools (free/open-access):** An excellent resource available at (<http://epitools.ausvet.com.au>) which can be used to perform different calculations for surveillance utilities, epidemiological studies and diagnostic tests). This provides clear instructions for conducting calculations and presents results in a simple and clear way.
- **Microsoft excel (paid)** – A data analysis add in is available which will enable you to perform some of the tests described in this chapter. These can be found by clicking on tools, add-ins and then selecting 'analysis tool pack'. Once added, this can be found under the data tab, and then clicking on data analysis.
- **Apache Open Office Calc (free/open-access):** Similar to Microsoft Excel, suitable for carrying out simple data handling and analysis

Epidemiological analysis for SEACFMD Member Countries

SEACFMD Member Countries are at different stages of control and eradication of FMD, with some countries and zones having achieved OIE recognition of FMD free

status (either with or without vaccination) while others have achieved OIE endorsement of an official FMD control program. In the majority of SEACFMD member countries, however, FMD remains endemic. For endemic countries seeking to control FMD, the PCP-FMD approach will be used as a tool. The FMD control strategy that underpins the SEACFMD strategic plan for FMD eradication is consistent with the approach of the PCP-FMD.

In order to achieve the objectives of different stages of the PCP-FMD and progress to the next stage, certain information and knowledge must be gathered about FMD in a country such that decisions can be made about how and where to target control measures and then to monitor the impact of those control measures. Once countries have successfully eradicated FMD, or for those countries which have already achieved FMD freedom, information will be needed to demonstrate freedom from FMD. The necessary information for the purposes outlined above is gathered from the field through surveillance activities (outlined in the previous section). However, raw data from the field can provide limited information without some level of analysis. The following component of the manual will consider the main analytic needs for countries following the PCP and provide a summary of the basic concepts and tools needed in order to understand and carry out these analyses. These include:

- **Describing spatial and temporal trends of FMD** (particularly related to presentation of data in a useful form). This will use basic tools and will not include complex analytical techniques.
- **Calculating measures of disease frequency.** These measures are vital to understanding the level of disease in a particular geographical area/husbandry system and to compare levels of disease in different populations in order to identify potential risk factors. Measures of disease frequency are useful for providing baseline estimates of the level of FMD and then for monitoring the impact of any control programmes. Measures of disease frequency (especially prevalence) are also important contributors to risk analyses.
- **Measures of association.** Determining the strength, importance and statistical significance of epidemiological associations which can help to identify suitable targets for disease control measures and predict areas/populations/husbandry systems where there is a higher risk of disease.

This section will not include descriptions of analysis of risk-based surveillance to demonstrate freedom, as there is a detailed guide available on this, to which readers should refer for more information (FAO, 2014).

For all surveillance conducted and analysis undertaken for FMD, the existence of different serotypes and immunological sub-types should be taken into account. Previous infection or vaccination against one subtype may offer incomplete protection against other subtypes, thereby complicating the choice of vaccines for control programs. In addition, the epidemiology of different strains can vary among animal species and husbandry systems. In order to understand the behaviour and occurrence of individual FMD subtypes, efforts should be made to improve the level of sample submission for diagnosis and for further characterisation to the level of VP1 or whole genome analysis. Phylogenetic analysis of FMD viruses allows us to understand better the spatial and temporal distribution of virus in the region and provides better information by which to design and monitor control measures.

Descriptive Epidemiology

Measures of disease frequency

The following example is provided to illustrate calculation of different measures of disease frequency. Note that in this example, the unit of interest is the herd (with a herd counted as being infected when a farmer makes a report of one or more animals showing clinical signs of disease, followed by a positive diagnosis based on laboratory testing). The unit of interest could also be individual animals, individual pens within a barn, herds/flocks, villages, etc.

Example A: Farmers from a certain Province are asked to report when their herds become infected with FMD (based on suspicion of FMD due to clinical signs and then followed up by a positive diagnosis from laboratory testing). There are a total of 50 herds in the Province (none of which were infected prior to week 1). For the purposes of this example, it is assumed that all farmers would notice and report clinical signs of FMD if they were present in their herd. It is also assumed that, once FMD has been reported, the herd remains infected for the duration of the study period. The results are presented below:

Cumulative incidence

This is the proportion of disease-free units (individuals, pens, herds, etc.) developing a given disease over a specified time, conditional on that unit not succumbing to any other disease during the period. Units have to be disease free at the beginning of the observation period to be included in the numerator or denominator of this calculation (Pfeiffer, 2002).

Week number (taken as the number of reports at the end of the week)	1	2	3	4	5	6	7	8	9
Number of new FMD infected herds reported each week	1	3	9	12	7	5	2	2	0

From example A, the unit is a herd, and the cumulative incidence could be calculated for various periods within the total study period. For example, the cumulative incidence at the end of week 1 is:

$1/50 = 0.02$ which means that a herd had a 2% chance of becoming infected during week 1.

If we want to calculate the cumulative incidence for becoming infected during week 4, this is calculated as:

$12/(50-13)$ given that 13 herds had already been infected by week 4 and therefore should not be included in the denominator. Therefore, during week 4, a herd had a 32% chance of becoming infected.

Finally, if we use the same example to calculate a cumulative incidence for the first 4 weeks:

$(1 + 3 + 9 + 12)/50 = 0.5$. Therefore, a herd had a 50% chance of becoming infected in the first 4 weeks of this outbreak.

Incidence density

Incidence density (also called true incidence rate, hazard rate, force of morbidity or mortality) is defined as the instantaneous potential for change in disease status per unit of time at time t, relative to the size of the disease-free population at time t. The numerator contains the number of new cases over the time period observed and the denominator is the accumulated sum of all individual's time at risk (=population time at risk) (Pfeiffer, 2002).

Using the example above to calculate the true incidence rate for herds during the study period (9 weeks), this can be calculated as follows:

1 herd reported in week one, so this means that $1*1 =$
1 herd week at risk

3 herds reported in week 2, so this means that $3*2 =$
6 herd weeks at risk

9 herds reported in week 3, so this means that $9*3 =$
27 herd weeks at risk

12 herds reported in week 4, so this means that $12*4 =$
48 herd weeks at risk

7 herds reported in week 5, so this means that $7*5 =$

35 herd weeks at risk

5 herds reported in week 6, so this means that $5*6 =$

30 herd weeks at risk

2 herds reported in week 7, so this means that $2*7 =$

14 herd weeks at risk

2 herds reported in week 8, so this means that $2*8 =$

16 herd weeks at risk

At the end of the 9-week period, 50 (total no. of herds) – 41 (no. of herds reporting FMD within 9-week period) = 9 herds had not reported FMD and so they contributed $9*9 =$
81 herd weeks at risk.

True incidence rate in this example is calculated =

number of herds reported by the end of the study period/total herd weeks at risk

$$41/(1+6+27+48+35+30+14+16+81) = 41/258 = 0.16$$

Therefore, the incidence rate for FMD breakdowns in this province (during this period) is 0.16 FMD breakdowns per herd week at risk.

Prevalence

This is the proportion of a population affected by a disease at a given point in time. It can be interpreted as the probability of a unit (individual, pen, herd, etc.) from the same population having the disease at this point in time (Pfeiffer, 2002). Prevalence does not take into account whether cases are new or old, but rather the total number of 'cases' at any one time. Prevalence is affected by the number of new cases of disease and the duration of the disease.

Example B: The following example describes FMD status of specific villages in a province occurring over a one-year period. The start date (start of the red line) is when FMD is confirmed in a particular village and the end date (end of the red line) is when there have been no further cases of FMD seen in that village for 14 days. Therefore, the shaded line is taken to represent the period during which a particular village is classed as 'FMD infected.' There are a total of 20 villages in the province.

From the example above, we can calculate prevalence of FMD in the Province (with village being the unit of interest) for any point in time (point prevalence) or for any given period (period prevalence). In this example, a 'case' is any

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Village 1												
Village 2												
Village 3												
Village 4												
Village 5												
Village 6												
Village 7												
Village 8												
Village 9												
Village 10												
Village 11												
Village 12												
Village 13												
Village 14												
Village 15												
Village 16												
Village 17												
Village 18												
Village 19												
Village 20												

village where FMD is present (i.e. has been reported and confirmed by laboratory testing).

Point prevalence: Prevalence of FMD infected villages in the Province in June is calculated as the number of villages which are classed as infected during the month of June divided by the total number of villages in the Province:

$$3/20 = 0.15 \text{ or } 15\%$$

Period prevalence: A period prevalence refers to the number of cases that are known to have occurred during a specified period of time; for example, a year (annual prevalence). It is the sum of the point prevalence at the beginning of the period, and the number of new cases that occur during the period (Thrusfield, 2007).

Therefore, the period prevalence for the first 6 months (January to June) is calculated as the point prevalence at the beginning of the period (i.e., the prevalence of FMD in January) plus the number of new villages which become infected during this period (February to June), divided by the total number of villages in the Province:

$$(2 + 5)/20 = 0.35 \text{ or } 35\%$$

This means that 35% of villages in the Province were infected with FMD during a six-month period (January to June)

Note that this example refers to villages as the unit of interest, but the same calculations are used and the same process to calculate measures of disease frequency at the individual animal level.

Attack rate

Attack rate is defined as the number of new cases divided by the population at risk. While this is based on the same calculation as cumulative incidence, it is generally applied when the risk period is short, such as feeding contaminated feedstuff to a herd of cattle.

The relationship between prevalence and incidence

A disease with a long duration is more likely to be detected during a cross-sectional survey than is a disease of short duration. Prevalence (P) therefore depends upon the duration of a disease (D) and the incidence rate (I) of a disease. This means that a change in prevalence can be due to:

- A change in incidence rate
- A change in the average duration of the disease
- A change in both incidence and duration

Other measures such as morbidity rate, mortality rate, death rate, case fatality rate, etc. are also useful measures which may be used to describe a disease. These measures

may be used by SEACFMD Member Countries but they are not included in this manual given that they are described extensively in the literature. Further details and definitions of these measures can be found in any veterinary epidemiology text book.

Spatial and temporal trends

These approaches to epidemiological analysis will often be applied to data generated by disease reporting systems given that these provide data related to the timing and geographical location of an outbreak of disease. Serological surveys may provide useful spatial information but will provide little information on temporal disease patterns, given that antibodies persist in infected individuals for considerable periods and thus cannot differentiate between recent exposures and those which occurred some time ago. However, age stratification of sample collection may overcome this limitation of serological analysis to some degree, and may provide some useful information about the temporal distribution of disease. The impact of vaccination should also be considered in analysing serological data. Despite the suitability of data from passive reporting systems for temporal and spatial analysis of disease, the value of data from disease reporting systems is often limited by such things as under-reporting of disease, insufficient or inconsistent data provided about the outbreak, bias due to variable reporting rates from geographical areas or industry sectors. Alternatively, participatory epidemiology/surveillance can provide useful information on spatial and temporal patterns of disease, but there are also limitations to the information generated through PE, which were described in the section in this manual dedicated to PE.

Epidemic curves: Epidemic curves are used for presenting information about new cases of disease during an outbreak. The data for these will be generated through farmer reporting and/or outbreak investigations. These curves can provide useful information on the cause of an outbreak and on features of the disease and the affected population (such as incubation period, infectivity of the agent, proportion of susceptible animals in the population, animal density (Thrusfield, 2007)) and can also help to monitor impact of control measures. These will not be covered further here as epidemic curves are well documented in general literature and also described in the manual on outbreak investigation. For guidance on how to construct an epidemic curve using Microsoft Excel refer to CDC (date unknown).

Other temporal patterns of disease: Identifying and presenting trends in temporal distribution of disease can be useful for identifying 'high risk' periods when there is a higher probability of disease, predicting when there may

be increases in disease occurrence and identifying the risk factors which result in these seasonal fluctuations. Short term (epidemics), cyclical (including seasonal fluctuations) and long term (secular) trends may all be detected by simply plotting the information in a bar chart or line-graph showing the number of cases of disease/number of outbreaks reported (plotted on the vertical axis) and the time period (plotted on the horizontal axis). Many animal health information systems will have the capacity to perform these simple functions. Alternatively, such charts can be plotted using basic spreadsheet programs such as Microsoft Excel or Apache OpenOffice Calc.

For instance, the chart in figure 5 shows the number of outbreak reports made per month for a country where FMD is endemic. It can be seen that there is an apparent seasonal pattern of FMD. This is clearly visible when the data is presented in this way, but would have been difficult to appreciate as a table of data.

By presenting data in this way, possible risk factors may be identified which increase the risk of FMD outbreaks at specific times of the year. Based on this information, further studies (such as participatory surveillance or serological/questionnaire surveys) can be used to gather more information on the level of disease in certain areas and the existence of potential risk factors at different times.

In addition to seasonal trends in temporal distribution of disease, there may also be cyclical trends, associated with regular, periodic changes in the level of disease occurrence. They are associated with periodic changes in the size of the susceptible host population and/or effective contact and may produce recurrent epidemics or endemic pulsations (regular, predictable cyclical fluctuations) (Thrusfield, 2007). An example of this is the 3-4 year cycle of FMD seen in many endemic countries in South-East Asia. Understanding these temporal patterns of disease in an endemic situation, as a background level of disease, is important when interpreting data following interventions such as disease control measures, i.e. understanding whether a reduction in reports of disease is due to success of a control program or due to normal cyclical patterns in disease occurrence.

Conducting further statistical analysis on populations where control measures have been implemented (such as vaccination) compared to populations where they have not been implemented can help to determine whether controls have been successful and to what extent they have affected the level of disease (see manual on vaccination).

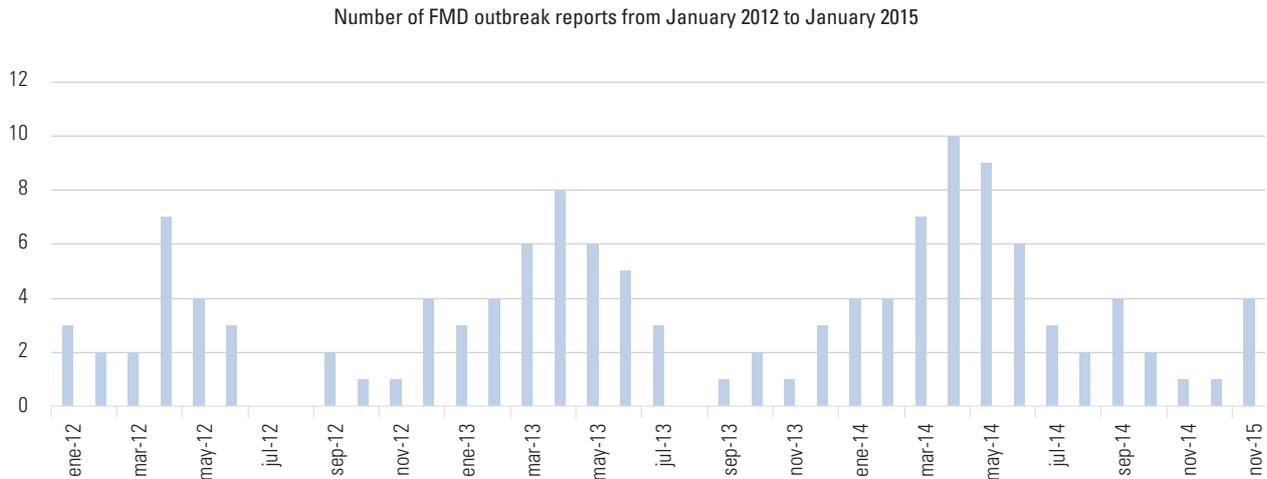


Figure 1. Chart showing outbreak reports made per month in a country

Spatial patterns of disease

Spatial analysis can provide insights into the epidemiology of FMD, assist in the identification of regionally important risk factors, quantify costs and benefits in economic analyses, and permit the effectiveness of control activities to be monitored closely throughout the infected area(s) (Durr and Gatrell, 2004). Spatial patterns of disease can be best appreciated when presented in the form of maps. Mapping functions are available in many animal health information systems where, for example, outbreak reports are plotted on a map.

It is also possible to present different features on a map (such as a livestock population/density, location of livestock markets, location of main-roads, etc.) in order to demonstrate potential associations between spatial distribution of disease and distribution of other factors. Whether this approach can be used is determined by access to up to date and accurate data-sets at a sufficient level of detail to be useful for analysis. In South-East Asia, the unit of interest is generally the village (Sanson and Morris, date unknown) and, therefore, having data available at the village level on information such as: livestock population (according to species), location of livestock holdings/processing areas (markets, abattoirs, etc.) can be useful. Through displaying this information, together with disease occurrence, on a map, it can be possible to identify and present potential risk factors (i.e. proximity to livestock markets, proximity to main roads, etc.). More detailed active surveillance may then be designed to measure association between potential risk factors and disease occurrence (see next section). It is also possible to estimate disease frequency if sufficiently accurate population data is available at the village level. For example, if a disease report from a village provides

information that 30 animals were affected by FMD, but no denominator is provided, the population figures saved in the database may be used to provide the denominator, thus allowing approximate measures of disease frequency to be mapped.

Although many national animal health information systems will have a mapping function, for individuals interested in spatial analysis of FMD, there is a free geographic information system (GIS) software that can be downloaded and used for this purpose. Any GIS software used will require a shape-file of the area of interest to be provided by the user. QGIS (previously known as Quantum GIS) is a cross-platform free and open-source desktop geographic information system (GIS) application that provides data viewing, editing, and analysis (refer to the following link for further information: <http://www.qgis.org/en/site/about/features.html>). This can be downloaded at: <https://www.qgis.org/en/site/forusers/download.html>. User guides and training manuals are available at: <http://www.qgis.org/en/docs/index.html>.

Analytical epidemiology

Analytical epidemiology is aimed at determining the strength, importance and statistical significance of epidemiological associations. This process typically begins with data collection and eventually leads to data analysis and interpretation. The data collection component can be based on a survey or a study (Pfeiffer, 2002).

Risk is the probability that an event will happen. A characteristic or factor that influences whether or not an

event occurs, is called a risk factor (Stevenson, 2008). The following section focuses on measuring association between FMD occurrence and certain risk factors. This is the cornerstone of identifying high-risk populations/husbandry systems for targeted FMD control measures, and is a key component of the SEACFMD control strategy.

Identifying potential risk factors to be tested may be done through developing questionnaires which include many different factors which may, or may not, be associated with the level of FMD and then comparing the occurrence of certain risk factors with occurrence of disease. Naing Oo, (2010) conducted a survey in Myanmar to identify potential risk factors for FMD using questionnaires and a serological survey. Alternatively, PE may be used to identify potential risk factors, the information from which may be used as a basis for designing and targeting suitable control measures or for designing another survey to quantify associations between potential risk factors and the level of disease (see section on PE).

This section is intended as a basic introduction to terms and calculations which can be used in analysis of data to determine associations between risk factors and disease occurrence. These are based on comparing the incidence or prevalence of disease between groups exposed to a risk factor and those not exposed to a risk factor. Different types of observational studies can be used to generate this information, including: case studies, cohort studies, cross-sectional studies and case-control studies. The different features and applications of these studies are described widely in the literature and so are not included here. For further information on these, refer to epidemiology text books; Pfeiffer (2002) and/or Stevenson (2008).

When making calculations to measure association between risk factors and disease, a common approach is the use of a 2x2 table (table 1) which provides a rapid method of calculating different values (and is used here to aid explanation of the different values to be calculated). Alternatively, the tests outlined below can be calculated using statistical software, the output of which will include confidence intervals and a p value for any calculations made.

Calculation of measures to demonstrate association

What is a p-value and how is it interpreted?

(Pfeiffer, 2002)

The p - value is the probability that the observed difference could have happened by chance alone, assuming that there is no difference.

So, if we are comparing the level of disease in one breed (A) with the level of disease in another breed (B) and we get a chi square value of 8.33 with 1 degree of freedom and a p value of 0.004, this means that there is a 0.4% (or 4 in 1000) probability that the observed difference in the level of disease between the breeds occurred by chance.

Therefore, with a p-value as low as this, one can be quite confident that there truly is a difference in the level of disease between breed A and breed B.

Alternatively, we could be testing the difference between the level of disease in a group of animals exposed to a risk factor, and the level of disease in a group of animals not exposed to the risk factor. In this situation, the p-value would indicate the probability that the difference observed occurred due to chance variation or whether there truly is a difference between the two groups.

Outcomes with p-values below 0.05 means that there is 95% chance that there is a real difference (or that the association is real). This is often used as a cut-off value for identifying risk factors. In other cases, a p-value of less than 0.01 may be used if more confidence is required.

The following descriptions provide a summary of the purpose of different calculations (i.e. what is the question they seek to answer) and how to perform the calculation manually. As described above, these calculations can also be done using statistical software. This is intended as a basic introduction to the terms and calculations and for more information on use of these, and interpretation refer to (Thrusfield, 2007; Pfeiffer, 2002; Stevenson, 2008) or any general epidemiology text book.

Relative risk (RR)

Question to be answered: how much more (or less) likely are exposed individuals to get the disease relative to non-exposed individuals?

Table 4. A 2x2 table for calculating associations between risk factors and disease

	Disease +	Disease -	Total
Exposed to risk factor	a	b	a + b
Not exposed to risk factor	c	d	c + d
Total	a + c	b + d	

How is it calculated? The ratio of cumulative incidence or prevalence between exposed and non-exposed individuals.

$$RR = [a/(a+b)] / [c/(c+d)]$$

Example: if there is a relative risk of 5, the disease is 5 times more likely to occur amongst those individuals exposed to the suspected risk factor than among those with no such exposure.

If RR is close to 1, the exposure is probably not associated with the risk of disease. The greater the departure from 1, the stronger the association. If using statistical software, p-values and confidence intervals will help to demonstrate the probability that the difference between the two groups is a true difference.

RR cannot be applied to case-control studies but is useful for cross-sectional studies.

Odds ratio (OR)

Question to be answered: What are the odds of having the disease among those exposed to the suspected risk factor compared to the odds of disease among those with no such exposure?

How is it calculated? The ratio between the odds of disease in exposed individuals and the odds of disease in non-exposed individuals.

$$OR = (a/b) / (c/d)$$

Example: If there is an odds ratio of 2, the odds of having the disease in the group exposed to the risk factor is two times the odds of having the disease if in the group not exposed to the risk factor.

If OR is close to 1, the exposure is unlikely to be associated with the risk of disease, the greater the departure from 1, the stronger the association.

Odds ratio can be used for any study type.

Attributable risk (AR)

Question to be answered: what is the additional risk of disease following exposure to a risk factor over and above that experienced by individuals who are not exposed?

How is it calculated? Subtracting the cumulative incidence (or prevalence) of disease in non-exposed group from the corresponding values for the exposed group.

This assumes that the risk of disease in the unexposed group represents the background level of disease.

$$AR = [a/(a+b)] - [c/(c+d)]$$

The larger the attributable risk, the greater effect of the risk factor on the exposed group.

Attributable risk cannot be estimated from most case control studies.

Attributable fraction

Question to be answered: what proportion of disease in the exposed individuals is due to exposure to this risk factor?

How is it calculated? By calculating the proportion that the attributable risk represents within the total disease risk in exposed individuals.

$$AF = AR / [a/(a+b)]$$

This also allows us to estimate how a disease may be influenced by controlling a particular risk factor, so this is useful for decision making purposes.

AF cannot be used for case-control studies

Vaccine efficacy (VE)

While not related directly with calculating associations with disease and risk factors, calculating VE would be useful for SEACFMD Member Countries who are conducting PVM. There is more information on PVM design and analysis in FAO and OIE (2016).

Question to be answered: what proportion of disease is prevented by the vaccine in vaccinated animals?

How is it calculated? VE is estimated by subtracting the cumulative incidence in vaccinated animals from the cumulative incidence in unvaccinated animals and dividing by the cumulative incidence in unvaccinated animals

From association to inference

Investigating the relationships between potential risk factors (such as age of an animal) and the outcome variable of interest (such as infection status of an animal) requires an evaluation of an observed difference (to see whether the two variables are related). Take as an example a herd of cattle during an outbreak of FMD. The herd is observed and an

infected animal is counted as any animal showing clinical signs of disease.

	No. with clinical signs of FMD	No. without clinical signs of FMD
< 2 years old	10	15
> 2 years old	15	150

A test known as Chi-square test can be used to test the relationship between the two variables (age group and showing clinical signs) for statistical significance. That is, to determine whether the difference observed in the level of disease between the different age groups is unlikely to have occurred by chance.

The data from the example above were entered into a 2x2 table and the resulting Chi-square result was 18.15 with a p-value of <0.0001, this means that there is a less than 0.01 chance that the difference seen in the prevalence of disease in these two age groups would have occurred by chance. In other words, it is highly likely that there is a real difference in disease prevalence in animals under 2 years compared to animals over 2 years.

The basic epidemiological analysis tools described in this part of the manual are intended as an introduction to some of the tests available and what these tests can tell us. For readers planning to conduct epidemiological studies, further reading from the references provided in this chapter, and/or a text book on veterinary epidemiology should be consulted to provide more detail.

Bias and Confounding

Any study can potentially be affected by bias (also known as systematic error). This type of error can be caused by any systematic (non-random) error in design, conduct or analysis of a study resulting in a mistaken estimate of an exposure's effect on the risk of disease (Pfeiffer, 2002). Selection error can occur during design of a study in which the study population is not representative of the target population. Measurement error can occur through misclassification of disease status. Bias should be minimized and any existing bias should be taken into account when interpreting results.

One should also be aware of the potential for confounding. Confounding refers to a situation where an independent risk factor is associated with the disease as well as another risk factor, and thereby may wholly or partially account for an apparent association between exposure and disease (Pfeiffer, 2002). An example may be that a positive

statistical association is found between cats that wear collars and cats involved in road traffic accidents (RTA) (figure 6). This would appear to suggest that wearing collars somehow increases the risk that a cat will be involved in a RTA. In fact, cats which are allowed to roam outside are more likely to wear collars and are also more likely to be involved in a RTA. Therefore, the apparent association between wearing a collar and being involved in an RTA was actually a confounding effect.

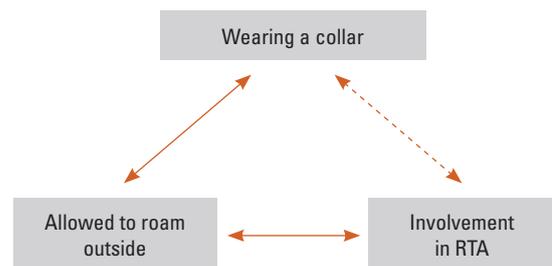


Figure 5: Example of a confounding relationship

For more information on bias, confounding and also on interaction of multiple risk-factors, refer to Pfeiffer (2002) or epidemiology text books.

Epidemiology Networks

Epidemiology networks have been established in a number of the regional programmes for FMD control, including the SEACFMD campaign (Metwally *et al.*, date unknown). These networks generally consist of a focal point from each Member Country, who will usually be an epidemiologist from the National Veterinary Services. The purpose of epidemiology networks, at the regional level, is to share information on epidemiology of FMD, epidemiological methods, and potentially to implement joint activities such as training, research and surveillance. This network can help to establish better communications between countries and thus may also function as an early warning system whereby an epidemiologist may be more likely to contact other members in the network if an unusual or significant epidemiological event occurs. For FMD control in South-East Asia and China, a regional epidemiology network is essential given the fact that FMD is readily spread across borders and that there is extensive movement of livestock between countries in the region. Therefore, a regional approach to control of FMD is essential in South-East Asia and China.

The SEACFMD EpiNet meets annually to discuss issues relevant to epidemiology of FMD, particularly presentation and analysis of outbreak reports from each country, other

surveillance activities and control measures. EpiNet occasionally meets jointly with LabNet to discuss issues of relevance to both networks and to explore solutions which can be implemented jointly.



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