Title

Factors influencing the performance of voluntary farmer disease reporting in passive surveillance systems: a scoping review

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Abstract

The impacts of exotic disease incursions on livestock industries can be mitigated by having robust surveillance systems in place that decrease the time between disease introduction and detection. An important component of this is having farmers routinely observe their animals for indications of clinical disease, recognise the existence of problems, and then decide to notify their veterinarian or animal health authorities. However, as highlighted by this literature review, farmers are believed to be underreporting clinical events due to factors such as (1) uncertainty around the clinical signs and situations that warrant reporting, (2) fear over the social and economic consequences from both positive and false positive reports, (3) negative beliefs regarding the efficacy and outcomes of response measures, (4) mistrust and dissatisfaction with animal health authorities, (5) absence of sufficiently attractive financial and non-financial incentives for submitting reports, and (6) poor awareness of the procedures involved with the submission, processing, and response to reports. There have been few formal studies evaluating the efficacy of different approaches to increasing farmer engagement with disease reporting. However, there is a recognised need for any proposed solutions to account for farmer knowledge and experience with assessing their own farm situation as well as the different identities, motivations, and beliefs that farmers have about their role in animal health surveillance systems. Empowering farmers to take a more active role in developing these solutions is likely to become even

more important as animal health authorities increasingly look to establish public-private partnerships for biosecurity governance.

Keywords

Biosecurity; Disease Reporting; Farmer Behaviour; Veterinary Behaviour; Infectious Disease

1. Introduction

Exotic disease incursions can have significant economic and social impacts on food and fibre animal industries, particularly when there are delays between the time of disease introduction and the time of disease detection that allow the pathogen to become widely disseminated before appropriate control measures can be implemented (East et al., 2016). Consequently, there has been considerable interest worldwide in finding new and innovative solutions for improving the performance of animal health surveillance systems while simultaneously encouraging farmers to adopt routine on-farm biosecurity measures that have the potential to reduce the total number of opportunities for pathogen transmission (Hadorn & Stärk, 2008; Hafi, Addai, Zhang, & Gray, 2015).

While the decisions around implementing on-farm biosecurity measures are still primarily left to the voluntary discretion of individual farmers, most developed countries have structured animal disease surveillance programmes that integrate data from several different complementary surveillance streams to increase the likelihood of detecting disease incursions (Hoinville et al., 2013). These include:

- **Active Surveillance** – Active surveillance programmes are typically designed and administered by national animal health authorities to purposefully sample livestock populations at appropriate intensities to achieve a desired confidence level for detecting a disease outbreak within their resource constraints or to meet other regulatory requirements for demonstrating freedom from disease. Since these programmes most often rely on diagnostic tests that look directly for a specific pathogen or evidence of an immune response against a specific pathogen, separate surveillance streams must be implemented for each disease of interest. Although these programmes can be fairly resource-intensive to maintain, animal health authorities have direct control over the quality and completeness of surveillance data.

- **Passive Surveillance** – Passive surveillance programmes typically make use of existing electronically captured animal health data streams such as animal production records, diagnostic laboratory submission data, veterinary medical records, and slaughterhouse inspection data to monitor the population for changes in baseline trends that may indicate a disease outbreak. However, passive surveillance also includes the routine investigation of observed clinical disease events with mechanisms like telephone hotlines that allow farmers and veterinarians to notify animal health authorities of suspected disease incursions. The primary advantage of passive surveillance programmes is that they do not require much additional effort from data providers eliminating many of the issues with getting farmers and veterinarians to engage with disease reporting. However, since the data is primarily being collected to support other routine animal health activities, there can be significant issues with the quality, representativeness, completeness, and appropriateness of the data for use in disease surveillance.
- **Enhanced Passive Surveillance** – Enhanced-passive surveillance programmes are a hybrid between active and passive surveillance programmes where animal health authorities take a more active role in encouraging farmers and veterinarians to report and investigate certain types of disease presentations. These programmes often use more standardised reporting templates to capture higher quality data on the potential outbreak that can assist animal health authorities in deciding whether to conduct further investigations. The primary disadvantage of enhanced passive surveillance programmes is that they most often rely on getting farmers and veterinarians to voluntarily contribute data into the system and can therefore be difficult to sustain long-term engagement with disease reporting even when incentives are provided.

There have been many previous research studies exploring different opportunities to improve the cost-effectiveness and overall performance of animal disease surveillance systems through strategies like conducting risk-based (Schwermer, Reding, & Hadorn, 2009) or targeted sampling (Blickenstorfer et al., 2011) for active surveillance programmes to reduce sampling intensity or developing more efficient algorithms for processing and integrating electronic data from passive surveillance streams to reduce false classification rates (Dórea, McEwan, McNab, Sanchez, & Revie, 2013). However, there are still significant challenges and knowledge gaps around the components of passive and enhanced passive surveillance systems that rely on farmers identifying an emerging disease problem with their animals and following a course of action that will result in the appropriate animal health authorities being notified (Gates, Holmstrom, Biggers, & Beckham, 2015). There is growing evidence that engaging farmers can significantly improve the performance of both active and passive surveillance systems. For example, during the 2006 bluetongue epidemic in the Netherlands, the use of clinical signs as a diagnostic test for outbreaks in cattle herds and sheep flocks was associated with sensitivities and specificities of around 70% when compared against result from more expensive laboratory diagnostic tests conducted as part of active surveillance for the disease (A. R. W. Elbers, Backx, Ekker, van der Spek, & van Rijn, 2008). A simulation study evaluating strategies for mitigating the risk of a fast-moving foot-and-mouth (FMD) incursion in Australia found that educating farmers to increase the likelihood of early reporting could reduce the time to official detection of the outbreak by 5 days when compared against the performance of the existing passive surveillance system (Garner et al., 2016). This highlights the importance of understanding the factors influencing farmer disease identification and reporting behaviour to further strengthen this component of national animal health surveillance systems (Brugere, Onuigbo, & Morgan, 2017).

The objective of this non-systematic narrative review was to summarise the current literature on farmer disease reporting behaviour to identify key challenges preventing timely disease reporting as well as potential opportunities for improving farmer engagement with passive surveillance systems. The review was structured according to the chain of events that occurs from the time disease is initially introduced to a farm through lapses in boundary biosecurity that must occur in order for the animal health authority to be notified of the potential outbreak (Figure 1). These were based on frameworks reported in previously published manuscripts (Gates et al., 2015; P. Martin et al., 2015) and include (1) farmers being aware that diseased animals are present in the herd, (2) farmers deciding that the disease problem is significant enough to warrant action, (3) farmers choosing which course of action to take including doing nothing, treating the disease problem themselves, contacting a veterinarian or farm consultant, and/or directly notifying the animal health authority. The further subsections within the review were identified through an informal thematic analysis of the key findings from the literature and were used to highlight how the decisions that farmers make at each point in this process can significantly influence the time it takes for animal health authorities to become aware of an exotic disease incursion. Lastly, the discussion reviews other potential considerations and approaches for increasing farmer engagement with passive surveillance systems that can be used to inform future research.

2. Farmer recognises a disease problem

Before farmers can even consider whether or not to report an exotic disease incursion to animal health authorities, they must first recognise that they have diseased animals on their farm. This depends on a number of factors including:

Disease pathogenesis

Exotic diseases can present with varied clinical signs ranging from asymptomatic carrier states to severe illnesses accompanied by sudden death depending on agent, host, and environmental factors. It is inherently much easier for farmers to recognise acute fast-moving diseases like FMD or African swine fever that produce severe clinical signs in a large percentage of animals in the herd compared with chronic slow-moving diseases like bovine tuberculosis or scrapie where animals can remain in subclinical states for months to years and only a small number of animals are expected to develop observable clinical signs. Furthermore, many common endemic diseases can produce similar clinical signs to exotic pathogens and are more likely to be considered as the primary differential diagnosis. In New Zealand, these factors likely contributed to the delay between when *Mycoplasma bovis* was first thought to be introduced in 2015 and when it eventually detected in 2017 in a dairy herd with significant ongoing mastitis problems that did not respond to conventional treatments (Jordan et al., 2020; Rawdon, 2018). The two main approaches that animal health authorities have used to combat poor specificity is either asking individuals to report diseases that have been grouped into syndromes like abortion, sudden death, or diarrhoea on the basis of observed clinical signs rather than a definitive diagnosis (syndromic surveillance) or asking individuals to report atypical cases with unusual clinical signs, severe clinical signs, or appearance in unusual species, locations and time periods (Vourc'h et al., 2006).

Production type and system

The frequency at which animals are routinely observed varies significantly between production systems and species. Lactating dairy animals are typically handled one to three times daily for milking which gives farmers and staff ample opportunities to observe individual animals for signs of disease. In contrast, extensively managed beef cattle or sheep may be located in remote grazing areas where it is difficult to get close enough to individual animals in the herd or flock to perform detailed observations. These animals may also only be handled for routine husbandry procedures a few times per year. It is also likely, however, that the incidence of exotic disease incursions will be lower in these herds given their lower contact rates and less frequent import pathways such as imported animals, germplasm, and overseas staff.

Another potential mechanism for identifying changes in the disease situation on farm is through the routine monitoring of animal health and production records, which may include key performance indicators for growth, reproduction, and culling as well as more syndromic data on disease conditions like mastitis, lameness, and abortions. Some countries like Sweden, for example, collate these records into a national animal health database to assist with passive disease surveillance (M. Mörk, Lindberg, Alenius, Vågsholm, & Egenvall, 2009; M. J. Mörk, Wolff, Lindberg, Vågsholm, & Egenvall, 2010). This system likely to have more value for dairy herds where the data collected is generally of high enough quality and on a sufficiently small timescale to produce reasonable trends. Some other examples of data streams that are used to generate on-farm alerts for dairy herds include daily sensor data from automated milking systems to identify cows with clinical mastitis (Kamphuis, Mollenhorst, Heesterbeek, & Hogeveen, 2010) or wearable biological monitors to measures changes in activity levels and other biological parameters that may indicate an animal is sick (Eckelkamp & Bewley, 2020). However, the uptake of more advanced technology is low even amongst dairy herds (Jago, Eastwood, Kerrisk, & Yule, 2013; Kaler & Ruston, 2019). Anecdotally, record-keeping in beef herds and sheep flocks is comparatively poor and even when farmers do track key performance indicators, these tend to be measured or calculated at isolated time points during the year which limits their use for detecting acute disease problems.

Staff experience and role

With the general global shift away from smaller family owned and operated farms towards larger commercial farms, there have been growing issues in the livestock sector with staff retention and turnover particularly for more labour intensive systems like dairy farms (Tipples, Hill, & Wilson, 2012; Tipples, Trafford, & Callister, 2010). As a result, it is possible that many of the staff now employed to provide day-to-day care for animals may not come from farming backgrounds and may have less experience than other trained employees with recognising abnormal behaviours and clinical signs of disease in animals. The relationship between farm workers and their managers may also influence the likelihood of information about animal health being communicated to key decision-makers on farm, but further research is needed to investigate these factors. Age and experience are often positively correlated with the adoption of biosecurity measures and farmer disease reporting behaviour (Mahon, Sheehan, Kelleher, Johnson, & Doyle, 2017). However, even trained individuals may struggle to recognise abnormal patterns in a herd or flock if they are unaware of the normal baseline patterns.

National situational context

In the public health field, the "worried-well" syndrome has been reported following publicised disease events like avian influenza outbreaks or bioterrorism attacks and describes the phenomenon whereby individuals become much more vigilant in monitoring themselves for compatible symptoms (Kavanagh, Robertson, Murdoch, Crooks, & McMenamin, 2012; Stone, 2007). Previous research in the animal health space has shown that pig farmers (Maria Nöremark, Lindberg, Vågsholm, & Lewerin, 2009), cattle and sheep farmers, (Donaldson, 2008), duck farmers (Delpont et al., 2020), and horse owners (Schemann, Taylor, Toribio, & Dhand, 2011) often change their biosecurity practices in response to disease outbreaks in their countries. It is possible that awareness of a potential catastrophic disease threat may encourage farmers to become more vigilant in monitoring their stock for clinical signs of disease. For example, it would be interesting to know whether the recent disease incursions of *Mycoplasma bovis* and *Theileria orientalis Ikeda* into New Zealand have heightened farmers' vigilance for new diseases (Jordan et al., 2020; Watts, Playford, & Hickey, 2016). Raising farmer awareness of diseases was considered by a panel of experts one of the most important biosecurity measures that could be implemented in the Swiss cattle industry (Kuster, Cousin, Jemmi, Schüpbach-Regula, & Magouras, 2015).

3. Farmer decides to take action

While lack of farmers' awareness and understanding of infectious disease is often blamed for their failure to adopt biosecurity measures as recommended by animal health authorities (M. Nöremark, Frössling, & Lewerin, 2010), numerous research studies have shown that there are many complex economic, social, and psychological factors underlying farmer decisions regarding herd health including the decisions to report suspected exotic disease incursions either to their vet or animal health authorities (Garforth, 2015; Kristensen & Jakobsen, 2011; Mankad, 2016). Knowing whether farmers decide to treat animals first before contacting anyone would also be useful information since data streams like drug sales records could be monitored as part of the passive surveillance system (Gates et al., 2015).

Perceived impacts of disease

A major determinant of whether farmers decide to take any action against an identified disease problem is how much impact it is perceived to be having on the health, welfare, and production of their livestock. A few dead lambs in a flock of several thousand animals is unlikely to cause significant concern whereas an abortion storm affecting a large percentage of lactating dairy herd is likely to trigger immediate action. When English pig farmers were interviewed about intentions to control disease in their herds, the three main drivers were reported as pig mortality, entering an economically critical situation, and animal welfare (Alarcon, Wieland, Mateus, & Dewberry, 2013). Some individuals also consider the potential impacts of the disease problem on neighbouring properties. Bolivian cattle farmers, for example, indicated that they may not report a disease situation if they saw only a few cases on their farm, but would be more likely to if they knew others in the community were also currently experiencing similar problems (Limon et al., 2014). Similarly, veterinarians have also indicated that they are more likely to report if disease is fast moving or perceived to have threat for other neighbouring properties (A. Elbers, Gorgievski-Duijvesteijn, Zarafshani, & Koch, 2010).

Local situational context

One of the challenges for farmers in identifying exotic disease incursions is that many outbreaks present with non-specific clinical signs that mimic common endemic diseases or could potentially be explained by other local phenomenon such as weather events or acute changes in farm management practices. For example, pig farmers in England were more likely to attribute clinical signs of fever, lethargy, anorexia, and coughing to the endemic disease porcine reproductive and respiratory syndrome virus (PRRS) rather than African swine fever despite being aware of the potential for disease incursions (Guinat, Wall, Dixon, & Pfeiffer, 2016). Similarly, farmers in both the poultry industry (A. Elbers, Gorgievski-Duijvesteijn, Zarafshani, et al., 2010) and swine industry (Vergne et al., 2016) indicated that they did not see the value in reporting situations that are believed to be linked to other common conditions or situations that they believe they can manage themselves. Over a third of Australian beef farmers who observed cattle with unusual signs of disease reported that they would do nothing and expect that the animals will get better with time (Hernandez-Jover, Higgins, Bryant, Rast, & McShane, 2016). Interestingly, another Australian study exploring factors influencing participation in a voluntary passive surveillance system found that farmers with a veterinary qualification were less likely to submit timely disease reports than farmers from other educational backgrounds (Pfeiffer, Stevenson, Firestone, Larsen, & Campbell, 2021). It is possible that these individuals felt comfortable enough in assessing the risks and causes for each clinical scenario themselves without feeling the need to contact animal health authorities.

In general, diseases that are not currently present in a country are considered to be low risk whereas in an outbreak situation, farmers are more likely to be aware of the disease and adopt more appropriate biosecurity measures (Ekboir, 1999). Having previous personal experience with the disease or having awareness of other farmers who are experiencing outbreaks increases the likelihood that farmers will correctly identify clinical signs associated with exotic diseases (Guinat et al., 2016; van Andel et al., 2020). Brennan and colleagues (2016) noted that farmers will often develop their own personalised risk assessment that takes into account their own farm situation, but cautioned that this may not always include advice from veterinarians or other farm advisors. Overall, this suggests the need for better communication between farmers, veterinarians, and animal health authorities around situations that should trigger disease notifications taking into account local and national disease contexts.

Beliefs in efficacy of response measures

There is strong evidence across many research studies that farmers are more willing to adopt biosecurity and disease control measures that they perceive to be effective (Casal, De Manuel, Mateu, & Martín, 2007; Toma, Stott, Heffernan, Ringrose, & Gunn, 2013). In a study of Australian grain farmers, the biggest factor influencing their decision to seek advice from a consultant or to report disease directly to the agricultural authority was the belief that something could be done to control disease (Hammond, Hardie, Hauser, & Reid, 2016). There are likely similar views amongst livestock farmers. For example, a study investigating reasons why cattle farmers in England failed to attend free workshops on bovine tuberculosis control found that many respondents identified the disease as costly, unmanageable, and out of their control so did not see the point in taking action (Hamilton, Evans, & Allcock, 2019). Similarly, Australian beekeepers reported high awareness of the risks of having *Varroa destructor* enter the country, but did not make any significant changes to their biosecurity behaviours because an incursion was seen as inevitable and unavoidable (Phillips, 2020). An interesting point noted by sheep farmers in Australia about reasons why they did not report mortality events to their veterinarian or to the government was because they saw no point in spending more money when the animal was already dead (Palmer, 2006).

Sense of personal responsibility

Many farmers still believe that biosecurity is the exclusive responsibility of animal health authorities and industry organizations (Hernandez-Jover et al., 2016) rather than a shared responsibility amongst all stakeholders involved in food animal production chains (Sinclair, Curtis, & Freeman, 2020). In a previous study of factors influencing biosecurity adoption, there was a strong positive correlation between farmer knowledge of biosecurity and their sense of personal responsibility for protecting wider animal, public, and environmental health interests (Renault et al., 2020). Wright and colleagues (2018) also showed that farmers who perceive disease control to be the responsibility of government had the lowest self-efficacy for recognising exotic disease and were less willing to report diseases to animal health authorities compared with farmers who acknowledged their own contributions to biosecurity. This suggests that finding ways to increase farmer awareness of their roles may help to improve disease reporting behaviour. When farmers have a vested interest in the disease, they also appear more likely to voluntarily engage with requests to provide surveillance data (Brook, 2010).

Farmer identity

It is interesting to note that the identity of being a "good farmer" has evolved over time to include the biosecurity measures that farmers take to protect animals against the negative impacts of infectious disease (Hidano, Gates, & Enticott, 2019; Naylor, Hamilton-Webb, Little, & Maye, 2018; Shortall, Sutherland, Ruston, & Kaler, 2018). Naylor and colleagues (2018) described three conflicting good farmer identities that influenced perceptions towards disease reporting. Farmers with a "good stockman" identity focused on the health and welfare of animals tended to view disease identification and reporting as an important part of farming. In contrast, farmers with a "good neighbour" identity focused on responsibility to the local community did not want to be judged poorly by their neighbours or engage in behaviours like disease reporting that could cause unnecessary problems. Farmers with a "good public facing identity" had a tendency to engage in behaviours that would make their own industry look good during an exotic disease outbreak, but had a tendency to place responsibility and blame on other sectors for spreading infectious diseases. Farmers have also been categorised into groups based on their levels of risk aversion (Bucini et al., 2019), personality traits (Döring et al., 2019), farming goals (Fairweather & Keating, 1994), and attitudes (Willock et al., 1999) which all likely influence how they choose to engage with disease reporting systems. This suggests that animal health authorities need to develop multi-modal approaches for communicating with farmers and developing interventions to improve disease reporting (Ritter et al., 2017).

4. Farmer decides what action to take

When farmers have recognised a disease problem, they are generally faced with four options: (1) doing nothing, (2) attempting to treat the problem themselves, (3) contacting their veterinarian or other herd health consultant for advice, and/or (4) directly notifying animal health authorities. Options 3 and 4 are the most desirable because they minimise the time until trained professionals are able to assess the situation for risks. However, both channels are often significantly underutilised with consistent barriers reported across the literature.

Relationship with veterinarian

After farmers have identified a disease problem that requires action, their most likely next step is contacting their herd health veterinarian or local government veterinarian with relatively few farmers electing to use exotic disease hotlines (Hernandez-Jover et al., 2016). Similar trends have been observed in the Australian grain industry with over 80% of farmers indicated that they reported the last disease episode with most choosing to contact a farm consultant or local governmental agricultural department office (Hammond et al., 2016). For livestock farmers, the value of the animal again has a strong influence of their decision to contact a veterinarian. A previous study found that dairy farmers were more likely than beef farmers to contact a veterinarian and that both farmer types were much more likely to contact a veterinarian when there was a higher prevalence of disease in the herd (Gilbert, Häsler, & Rushton, 2014). Other factors such as ability to access veterinary services, relationships with veterinarians, concerns over costs, and desire to achieve quicker resolution of the clinical problem can also influence the likelihood that farmers will notify a veterinarian (Adam, Henry, Baillie, & Rushton, 2014; Beam et al., 2013; M. Espetvedt et al., 2013; M. N. Espetvedt et al., 2013; Jensen, English, Menard, & Holland, 2009; Palmer, Sully, & Fozdar, 2009). In the reverse direction, there is evidence from the French brucellosis surveillance system that there are veterinary-specific factors such as the number of veterinarians per practice and veterinary membership in a technical association that can significantly influence the proportion of farmers that submit disease notifications to animal health authorities (Bronner, Morignat, & Calavas, 2015). Further work is needed to explore opportunities for better leveraging the veterinary profession in motivating farmers to engage with disease reporting systems.

Criteria for reporting to animal health authority

An interesting point raised by Palmer (2006) is that many farmers do not recognise the concept of "under-reporting" in disease surveillance because they perceive that they are making rational decisions about the types of disease situations that warrant notifying animal health authorities. The French oyster industry used a participatory approach that directly engaged farmers in developing a set of objective criteria for defining the meaning of "increased mortality" (Lupo, Osta Amigo, Marce, & Prou, 2014). The exercise highlighted that farmers were using various different methods for counting oysters to determine mortality rates, using other subjective criteria such as "nauseating odour" or "specific noise when manipulating the oyster bag" to determine whether the mortalities were unusual, and taking into account other factors such as the production type and age class of the animals when setting their own on-farm thresholds for abnormal mortality rates. In the French scheme for reporting abortions in cattle as part of brucellosis surveillance, it was also noted that farmers defined an abortion as the expulsion of the fetus and/or placenta whereas the official definition also included cows that returned to heat more than 42 days after an insemination (Bronner, Henaux, Fortane, Hendrikx, & Calavas, 2014). This highlights the importance of animal health authorities working closely with farmers and veterinarians to develop shared definitions of clinical situations to report and making the threshold values for reporting tailored to individual farm circumstances.

Trust in animal health authority

Just as trust was an important factor in determining whether farmers will contact their veterinarian in the event of an outbreak, trust also plays a significant role in decision around whether to notify animal health authorities (Palmer, Fozdar, & Sully, 2009). Common concerns amongst Australian beef and sheep farmers included that the outbreaks would not be dealt with quickly and effectively by the government, the government would not treat farmers in a fair and equitable manner, and the government did not value the farmers' own knowledge about the disease situation (Palmer, Sully, et al., 2009). Trust was further eroded when animal health authorities failed to respond to disease reports, were perceived to have managed other endemic diseases ineffectively, and demonstrated poor coordination with other departments involved in animal health responses (Gunn, Heffernan, Hall, McLeod, & Hovi, 2008; Palmer, Fozdar, et al., 2009). Some farmers also perceive that the biosecurity guidelines and recommendations released by animal health authorities for routine disease situations are not relevant or effective, which undermines farmer confidence in the guidelines and recommendations for exotic disease incursions (Brennan et al., 2016).

Similarly in Bolivia, most respondents indicated that they would not report disease outbreaks to animal health authorities because they believed that the government would not respond or provide support (Limon et al., 2014). Respondents also expressed concerns that government priorities often differed from those of farmers with the example given around vaccine campaigns for FMD that was not present in the region when farmers were already experiencing significant losses from other diseases like parasites and blackleg. In the context of avian influenza, government veterinarians are perceived by farmers to be inexperienced and arrogant with little appreciation for the unique situation on farm (A. Elbers, Gorgievski-Duijvesteijn, Zarafshani, et al., 2010). The latter is important as it has previously been shown farmers who are provided with tailored advice are more likely to adopt biosecurity recommendations (Cardwell et al., 2016). This highlights the need for government to demonstrate relevance to farmers' current animal health issues in order to improve trust and perceived value in engaging with disease surveillance systems.

Mandatory reporting

One of the potential solutions that countries have tried to increase farmer reporting rates is to make it a mandatory activity. Many countries maintain a list of specific notifiable diseases or conditions that farmers and veterinarians are required by law to report to animal health authorities if suspected on farm. France, for example, has implemented a clinical surveillance system for *Brucella abortus* that requires farmers and veterinarians to report every observed abortion and submit samples from the fetus and/or cow for diagnostic testing (Bronner et al., 2013). Although failure to report cases is punishable by fines, it is difficult for the animal health authorities to identify individuals who are not complying with the regulations and only an estimated 34% of all abortions are believed to be captured by the system (Bronner, Gay, et al., 2015). The most common reasons for failure to comply were (1) beliefs that the risk of a brucellosis outbreak were negligible, (2) farmers defining abortion as the expulsion of the fetus and/or placenta whereas the official definition also included cows that returned to heat more than 42 days after an insemination, (3) the additional costs in diagnosing the cause of abortion if aborted materials were not available for analysis, and (4) veterinarians giving in to farmers who were reluctant to report abortions for fear of damaging the veterinary-client relationship (Bronner et al., 2014). This highlights the limitations of mandatory reporting in increasing reporting rates and the importance of better understanding how to motivate farmers and veterinarians to engage with disease reporting systems.

Consequences of reporting

Many farmers fail to report suspected exotic disease incursions to animal health authorities because of concerns about what will happen with the response. Pig farmers in Vietnam indicated that they would be less willing to report swine diseases where the primary control measure was whole herd depopulation compared with diseases that involved culling only those pigs that had not yet recovered (Pham et al., 2017). In a qualitative interview study of beef producers' intentions to report FMD in the United States, participants expressed concerns about the costs and welfare implications of holding cattle on farm until authorities were able to send someone to inspect their cattle, especially since detection events were likely to occur when animals were being yarded for shipment to other locations (Delgado, Norby, Dean, McIntosh, & Scott, 2012). There is also often considerable stigma associated with being the first reported case in an outbreak situation as other subsequently affected individuals look for someone to blame (Mariner et al., 2014). This can have an impact on the farmer's reputation in the community and ability to continue trading cattle in the future. Lack on information on what happens after reporting a suspicion or if the investigation reveals a false positive result were also noted as particular concern of pig farmers in the context of reporting potential African Swine fever cases (Guinat et al., 2016). Providing farmers with more detailed information on post-reporting procedures may help to alleviate this concern (Delgado et al., 2014). It has also been suggested that veterinarians should be provided with additional training on how to manage farmer emotions and insecurities following reporting (A. Elbers, Gorgievski-Duijvesteijn, Van der Velden, Loeffen, & Zarafshani, 2010).

Incentives for reporting

One of the primary means of encouraging farmers to report diseases to animal health authorities despite the perceived risks to their business and reputation is to provide them with some form of financial compensation. This includes incentives that are directly related to report submission as well as the compensation schemes in place if the farm has a confirmed exotic disease incursion. For example, pig farmers in Vietnam reported being less willing to notify authorities about classical swine fever if there was no compensation for culling affected animals or if they thought the compensation payments for culled animals would be delayed (Pham et al., 2017). From an extensive systematic review on the effects of animal health compensation on encouraging farmer reporting behaviour (Barnes, Moxey, Ahmadi, & Borthwick, 2015), the key take-home message was that financial incentives were an important motivation for many farmers, but providing full compensation often led to farmers taking less responsibility to protect their animals from disease incursions.

A number of different incentives have been used to improve disease reporting including providing free examination of suspect animals by government veterinarians (Hopp, Vatn, & Jarp, 2007), subsidising the costs of laboratory diagnostic testing for disease conditions of interest (Thompson et al., 2016), and other non-monetary incentives such as providing farmers with aggregated summaries of national reporting data, instant feedback acknowledging report submission, and providing diagnostic test results along with advice on disease management (Halliday et al., 2012). There is unlikely to be a one-size-fits-all policy for incentivisation given the significant budget and resources constraints that animal health authorities often have for supporting surveillance activities as well as the diverse range of economic and social motivations that farmers have for engaging with reporting (Fraser, 2018; Gramig, Horan, & Wolf, 2005). This is especially true for countries that are balancing the costs of endemic disease control against investment in surveillance programmes to minimise the risks of exotic disease incursions (Enticott & Lee, 2015; Hennessy & Wolf, 2018). It is interesting to note that following the introduction of mandatory mortality reporting in the French oyster industry and subsequent decrease in the available subsidies, farmers who had received compensation before the law was passed were more likely to report mortalities than those who had not (Lupo, Amigo, Mandard, Peroz, & Renault, 2014).

Systems based on imposing financial penalties and fines on farmers and veterinarians that fail to report suspected disease outbreaks are typically unsuccessful because it is virtually impossible for animal health authorities to identify non-compliance (Bronner et al., 2014; Hamilton-Webb, Naylor, Little, & Maye, 2016). Other schemes such as providing higher levels of compensation during disease outbreaks to farmers who participate in approved biosecurity programmes may provide an acceptable alternative (Frössling & Nöremark, 2016)

Channels for reporting incursions

Many countries have multiple channels through which suspected disease incursions can be reported to animal health authorities, but there is often poor awareness amongst farmers and veterinarians about how to correctly access and use them (A. Elbers, Gorgievski-Duijvesteijn, Zarafshani, et al., 2010). In particular, there appears to be significant underutilisation of national disease reporting hotlines for reasons such as poor awareness that they exist, worry about whether their situations meets the criteria for a notification, concerns that staff answering the phones are not qualified to triage cases for further investigation, and uncertainty about how the process works for making phone reports (A. Elbers, Gorgievski-Duijvesteijn, Zarafshani, et al., 2010). Similar research in Australian grain industry revealed that more than 70% of survey respondents indicating they were not familiar with the national disease reporting hotline (Hammond et al., 2016).

Advances in technology had made it easier than ever for disease reporting to occur in real-time through online interfaces and mobile applications (Chunara, Freifeld, & Brownstein, 2012; Holmstrom & Beckham, 2017). These have the advantages of being convenient for farmers to use, standardising the types of information that are collected to support decisions around whether the cases need further investigation, and making the interactions lower stakes than speaking directly with an investigator on the national disease hotline. Numerous trials using smartphone-based apps have been conducted in developed countries including Australia (Langstaff, 2013) as well as low resource settings including Ethiopia (T. Beyene et al., 2017; T. J. Beyene et al., 2018), Kenya (Njenga et al., 2020), Zambia (Daum, Buchwald, Gerlicher, & Birner, 2018), Tanzania (Kijazi, Kisangiri, Kaijage, & Shirima, 2021), and Indonesia (Fadillah, Suroso, & Indrawan, 2019). Although these generally had good uptake and usage during the studies, most of these initiatives have failed to survive beyond the pilot stage often due to a lack of long-term funding as well as failure to provide participants with sufficient incentives to continue reporting (Andreassen, Kjekshus, & Tjora, 2015). From experiences in the Swiss programme where veterinarians were asked to submit equine surveillance reports through a web-based application, the individuals most likely to participate were those who were motivated by contributing to greater good (Struchen et al., 2016). However, it was recognised that other incentives were required to achieve long-term sustainability. As further highlighted by Hayes and colleagues (2020), any initiatives looking to utilise technology for disease reporting should engage users right from the initial planning stages to ensure that their concerns are adequately addressed and that the end product will be both functional and acceptable to their needs.

Another key issue for animal health authorities is having robust administrative processes in place to manage disease reports as farmers may get frustrated if their concerns are not addressed in a timely and productive fashion. An in-depth review of animal disease reporting structures in the Pacific Islands found that the overall efficiency was low due to having complex reporting chains that resulted in significant delays before information reached key decision makers and having high organisational turnover rates leading to significant staff shortages and positions that were often subsequently filled with inexperienced officials (Tukana, Hedlefs, & Gummow, 2018). Previous negative experiences with disease reporting systems can make it less likely for farmers to engage with them in the future (A. Elbers, Gorgievski-Duijvesteijn, Zarafshani, et al., 2010).

5. Discussion

As highlighted by this literature review, there are currently many factors that influence whether farmers will progress fully through the chain of events required for an exotic disease incursion to be reported to animal health authorities. The likelihood that farmers will notice an animal health issue depends on the severity of clinical signs, the frequency with which farm staff observe animals as well as their ability to recognise disease, and other local or national events that may raise disease awareness. Recognition of an animal health problem alone is not sufficient as farmers must also perceive that the economic impacts are enough to warrant action, that the potential interventions will be effective, and that they have a broader societal responsibility to safeguard animal health in order for them to take action against the disease. While some farmers may attempt to manage the issues themselves, veterinarians or other herd health consultants are often the first point of contact particularly if farmers have a good working relationship with their veterinarian. This is a positive outcome since veterinarians are trained to recognise exotic diseases and can conduct initial screening to rule out common endemic disease problems, which can help to reduce the investigative burdens on animal health authorities. Although farmers also have the ability to directly notify animal health authorities about animal health concerns themselves, this channel appears to remain the most underutilised worldwide.

Findings from the literature on barriers to farmer disease reporting can be grouped into several major themes that are important for animal health authorities to address in order to increase farmer engagement (A. Elbers, Gorgievski-Duijvesteijn, Zarafshani, et al., 2010). These include (1) farmer uncertainty around clinical signs and situations to report, (2) fear over the social stigma and economic consequences from both true positive and false positive reports, (3) negative beliefs regarding the efficacy and outcomes of disease control measures, (4) lack of trust and dissatisfaction with animal health authorities, (5) absence of sufficiently attractive financial and non-financial incentives to submit disease notifications, and (6) poor awareness of the different channels that can be used to submit reports to animal health authorities. The common underlying thread across multiple studies, species, and countries is the need for collaboration between animal health authorities, farmers, and veterinarians to develop clear guidelines on when and how to report disease concerns, what response they can expect from animal health authorities, and what measures are in place to minimise the economic and social impacts on their business (Fox, Christley, Lupo, Moore, & Campbell, 2020; Garza, Ågren, & Lindberg, 2020). These should all take in account the unique knowledge farmers have about their own farm situation as well as the different attitudes, personality traits, and motivations that drive their decisions around engaging with disease reporting systems.

While there have been many studies exploring the factors influencing farmer disease reporting, there is still a scarcity of randomised controlled trials looking at the efficacy of different interventions to improving farmer engagement with passive surveillance systems. This is a challenging topic to study prospectively because the measured outcome is reporting of rare events which typically means that either a large sample size and/or a long observation period is required to ensure that there are sufficient cases to compare against controls. Furthermore, it is inherently difficult to determine the overall performance of the system since there is no straightforward means of determining whether any disease outbreaks occurred that farmers may have missed. Using farmer intention to report disease outbreaks is unreliable since their actions during a real situation may differ from the responses they provide to researchers when presented with hypothetical incursion scenarios (Hopp et al., 2007). It should also be noted that there is significant underrepresentation of smallholders and backyard producers who are also at risk of experiencing exotic disease incursions but may have very different drivers to engage with disease reporting systems compared with commercial farmers (Burns, Ribble, McLaws, Kelton, & Stephen, 2013; Marta Hernández-Jover, Hayes, Woodgate, Rast, & Toribio, 2019; M Hernández-Jover, Schemann, East, & Toribio, 2015; Pramuwidyatama, Hogeveen, & Saatkamp, 2020).

One potential option for conducting prospective studies looking at interventions to improve farmer engagement would be designing a passive surveillance system that asks farmers to report "non-events" like routine veterinary visits or other times when animals are yarded for routine husbandry procedures where animals are observed and found not to be displaying any clinical signs of infectious. This information is still highly valuable to animal health authorities because it provides documented evidence that livestock populations are actually being monitored to detect clinical signs of disease. Other key advantages to reporting "non-events" are that (1) it carries much less risk to farmers than reporting disease events that may trigger an investigation by animal health authorities so they may be more likely to engage with the system, (2) it is easy to establish clear and unambiguous guidelines about when farmers should submit reports, (3) events like routine veterinary visits or routine husbandry procedures occur regularly but infrequently enough that reporting would not place significant time burdens on farmers, (4) it is possible to estimate farmer engagement by, for example, comparing veterinary practice records of farm visits against reports submitted by farmers, and (5) this may help to create a biosecurity culture around routine reporting to animal health authorities that may increase the likelihood of farmers being willing to report disease events.

It would also be interesting to explore the effects of COVID-19 on farmer perceptions towards national disease surveillance systems and their willingness to share data with animal health authorities. Many countries worldwide have deployed mobile applications that enable digital contact tracing either by having individuals voluntarily scan QR codes at public locations or enabling Bluetooth technology on their mobile phones that automatically logs proximity to other users (T. Martin, Karopoulos, Hernández-Ramos, Kambourakis, & Nai Fovino, 2020; Ming et al., 2020). The uptake of mobile apps has been variable across countries with factors such as trust in government, concerns around social stigma for being identified as a case, data privacy issues, perceived risks of acquiring COVID-19, degree of process automation, and individual demographic characteristics such as age, nationality, socioeconomic background, and health status highly correlated with app downloads and use (Altmann et al., 2020; Braithwaite, Callender, Bullock, & Aldridge, 2020; Guillon & Kergall, 2020; von Wyl et al., 2020). It is possible that increased public familiarity and experience with disease reporting for COVID-19 could increase the acceptability of similar programmes in the livestock sector and valuable lessons can also likely be learned from national public health campaigns to promote disease reporting for COVID-19 to improve uptake and use of disease reporting systems amongst farmers.

Another common theme across the literature was the importance of incorporating farmer experience and local practices of care when developing formal cases definitions for situations that authorities would like farmers to report, making inferences about whether the levels of farmer disease reporting are appropriate, and determining what measures should be implemented in response to potential outbreak situations. Not only is this likely to increase trust in animal health authorities, but it may also encourage farmers to take more personal responsibility for biosecurity which is becoming even more critical as governments move towards partnership approaches with farmers and industry bodies for biosecurity (Maye & Chan, 2020). One possible approach is to develop on-farm biosecurity programmes that help farmers identify ways in which they are already contributing to national biosecurity by, for example, observing their cattle during milking for signs of clinical disease and calling a veterinarian if they have concerns about animal health. This has the additional advantage of placing an increased emphasis on endemic diseases that are more directly relevant to normal farming operations rather than the government on important but extremely rare exotic disease incursion (Limon et al., 2014). Lishomwa (2016) describes the concept of "incidental biosecurity" which refers to the many practices that farmers already implement as part of their normal management routines that unintentionally align with biosecurity recommendations produced by animal health authorities. This concept was also described by Higgins and colleagues (2018) who highlighted that local practices of care may result in farmers contributing much more to national biosecurity than they are given credit for by government or researchers. In Australia, the government involved beekeepers in training around emergency response to *Varroa destructor* incursion and then had participants engage with a simulated outbreak scenario which helped individuals feel like they were part of a community contributing to the protection of their industry (Phillips, 2020). Although labour intensive, these types of initiatives may help build a community of practice around biosecurity that could translate into improved reporting behaviours.

While increased farmer engagement with disease reporting will likely improve the sensitivity of passive surveillance systems for detecting exotic disease incursions, this comes with the trade-off of reducing specificity with the system likely producing many false positive alerts. It is therefore important for animal health authorities to ensure that they have clear protocols and adequate resourcing in place to manage system alerts (Vial & Berezowski, 2015), especially given the evidence that farmers can lose trust if they perceive that the government is not responding to their concerns (Limon et al., 2014). Some potential solutions have included integrating data from other different surveillance streams looking for evidence of similar trends (Gates et al., 2015) and developing more sophisticated automated algorithms to more accurately detect abnormalities across time, space, and animal demographics (Buckeridge, Burkom, Campbell, Hogan, & Moore, 2005). This process is more challenging in countries that lack good quality data on animal demographics and health to better characterise baseline levels of disease in the population (Jewell, van Andel, Vink, & McFadden, 2016; van Andel et al., 2017), and countries where there is a high prevalence of endemic diseases that can produce acute outbreaks which look similar to exotic disease incursions.

Even with the best possible disease surveillance system operating in a country, there will inevitably be delays between the initial disease introduction and the eventual disease detection due to the latency periods of the pathogen as well as the potential for exotic diseases to present with non-specific or subtle clinical signs that make them more difficult to identify. Therefore, in addition to improving farmer reporting behaviours, there is still a strong need for the livestock industries to develop a more proactive biosecurity culture where disease-agnostic measures like reducing the volume and frequency of animal movements, installing double-fencing on shared field boundaries, and thoroughly cleaning any vehicles, equipment, or clothing that have been in contact with animals are routinely implemented by farmers to prevent pathogens from spreading through common transmission pathways.

In this review, we focused primarily on the role of farmers in voluntary disease reporting, but it should be acknowledged that veterinarians and other farm consultants also have key roles in strengthening this component of passive surveillance systems. While it is often assumed that animal health professionals would correctly identify a potential exotic disease incursions and recommend that the farmer implement a voluntary quarantine to prevent onward disease transmission until animal health authorities are notified, this may not always be the case in practice (Bronner et al., 2014). The barriers and challenges that prevent farmers from identifying and reporting disease events are also likely to affect veterinarians and other farm advisors. This emphasises the need for finding innovative ways of engaging all relevant stakeholders in developing solutions to the surveillance challenges particularly as animal health authorities increasingly look to establish public-private partnerships for biosecurity governance.

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Figure Legends

Figure 1: Chain of events for farmers following the incursion of an exotic disease into a livestock farm that result in notification of animal health authorities