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Comparative study in the control of bovine viral diarrhea

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Review

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Abstract

Bovine viral diarrhea virus (BVDV) is an important infectious agent affecting herd productivity and reproduction, and leading to massive economic losses. As such, BVD is the subject of a number of control and eradication schemes globally. The key elements of such schemes are: diagnosis and removal of persistently infected animals from herds; implementation of biosecurity practices aimed at preventing the introduction or re-introduction of BVDV in free herds; and ongoing surveillance to monitor the progress of the program and to detect new infections. The objective of this review is to examine the impact of BVD and the management of the disease in three countries: Scotland, Spain, and Argentina, where BVD control programs are in distinct phases: established, developing, and yet to be initiated. This work also sets out to highlight potential difficulties and formulate recommendations for successful BVD control. It concludes that a systematic, country-wide approach is needed to achieve a sustainable decrease in BVD prevalence. The role of vaccines in control programs is concluded to be a valuable additional biosecurity measure. This study also concludes that there are potential wider benefits to a systematic BVD control program, such as a reduction in antimicrobial use and increases in the competitiveness of the cattle industry.

Overview of bovine viral diarrhea

Definition and causal agent

Bovine viral diarrhea virus (BVDV) has a worldwide distribution and affects cattle of all breeds and ages (OIE, 2017). BVDV belongs to the *Pestivirus* genus of the *Flaviviridae* family (Simmonds *et al.*, 2011). Two main genotypes have been described: BVDV-1 and BVDV-2, which have been classified as separate species in the *Pestivirus* genus. Europe is mainly dominated by BVDV-1, while there is an equal prevalence of BVDV-1 and BVDV-2 in North America (Lindberg *et al.*, 2006*a*).

Both genotypes are classified into the two distinct biotypes: cytopathic and non-cytopathic (Ridpath and Bolin, 1998), according to the different type of proteins coded from their genomic RNA (Neill, 2013). A third genotype has also now been identified (OIE, 2017).

BVD is one of the most serious infectious diseases of cattle, leading to severe economic losses to the cattle industry and, as such, it is one of the most studied bovine diseases (Gunn *et al.*, 2004). BVDV results in a number of complex clinical manifestations in cattle. Clinical syndromes associated with the reproductive system are particularly damaging, resulting in significant economic losses due to abortions and perinatal mortality in affected animals. A serious aspect of the reproductive syndrome is the birth of persistently infected (PI) calves. PI animals are the main reservoir of the virus and are the leading source of BVDV transmission. In addition, they can go on to develop fatal mucosal disease (Bianchi *et al.*, 2017). BVDV also results in enteritis during acute or transient infection, which although generally not severe, can occasionally be fatal even in adult animals. Transient infection is believed to cause immunosuppression and is likely to contribute to bovine respiratory disease (BRD) (OIE, 2017). Given the wide variety of clinical manifestations resulting from BVDV infection, comprehensive knowledge of the signs and symptoms at each stage of the disease is essential for its management and control.

Transmission

BVDV transmission can be direct, with the main routes of infection being ingestion or inhalation of the virus (Grooms *et al.*, 2014). It is transmitted through contact with saliva, oculonasal discharge, uterine secretions, amniotic fluid or placenta, semen, urine and feces from PI animals or acutely infected animals (Newcomer *et al.*, 2017). As the virus is able to cross the placental barrier, vertical transmission can occur between pregnant females and their fetuses (Grooms *et al.*, 2014). BVDV transmission can also be indirect, through vectors such as hematophagous insects, needles and surgical equipment, etc. (Grooms *et al.*, 2014).

It has been found that BVDV can survive in slurry for up to 3 weeks at 5°C (Bøtner and Belsham, 2012). However, it is believed that the virus generally cannot survive more than 14 days in the environment and is likely susceptible to a range of common disinfectants such as hypochlorite, iodophors and chlorhexidine (Bøtner and Belsham, 2012).

Prevalence

Serological studies have found considerable variation in the number of antibody-positive animals, with prevalence varying from 20 up to 90% (Bolin *et al.*, 1985; Durham and Hassard, 1990; Houe *et al.*, 1995). Meanwhile, the prevalence of PI animals has been found to be between 1 and 2% of the general bovine population (Houe *et al.*, 1995). Variations in prevalence are believed to be due to cattle density, control measures and the use of vaccines (Grooms *et al.*, 2014), as well as the possible influence of climate and temperature (Bøtner and Belsham, 2012).

For example, studies have found that BVDV-antibody prevalence at herd level (before implementation of control or eradication programs) varied from 95% in England and Wales, to <1% in Finland (Greiser-Wilke *et al.*, 2003). In the countries of Scandinavia, southern regions with high cattle population density and large herds were found to have a higher prevalence of BVDV infection than northern regions with lower cattle population density and smaller herd sizes (Houe, 1999). There is generally a high correlation between cattle density and BVD prevalence in endemic zones (Lindberg *et al.*, 2006a). As such, an important factor that could increase the global prevalence of BVD is the increase in intensive farming systems seen in many countries (Castel *et al.*, 2011; Guevara and Grünwaldt, 2012; Scottish Government, 2016*a*), which increases animal density and the risk of BVD infection proliferation (Houe, 1999).

In Europe, BVD has been found to be endemic in all countries in which no systematic control has been implemented (Lindberg *et al.*, 2006*a*). In such countries lacking systematic control, up to half of all herds have PI animals and up to 90% of all cattle are exposed to BVDV during their lives (Lindberg *et al.*, 2006*a*).

National BVD control programs are leading to a wider variation in the prevalence of the disease among countries (European Commission, 2006). Table 1 shows various European BVD eradication programs. A number of countries, including Sweden, Norway, Denmark, and Finland, have eradicated BVD or are close to being free from the disease. Other countries in advanced stages of BVD eradication programs have seen a reduction in BVD infections (Wernike *et al.*, 2017). For example, in Germany, where an eradication program was commenced in 2011, the number of farms with PI animals decreased from 3.44 to 0.16% over 5 years (Wernike *et al.*, 2017).

Despite the many successful eradication programs happening in a number of countries, there remains a real danger that, without harmonized pan-European control efforts, BVD has the potential to spread across the continent, including BVDV-2 and any emerging genotypes (European Commission, 2006).

Global increases in the number of BVD eradication schemes have been seen in recent decades, indicating that BVD is becoming an international priority (European Commission, 2006). However, eradication is still in its early stages, given that a larger number of countries have not yet planned or implemented any control programs (Moennig and Becher, 2015).

Overview of BVD control and management

An important distinction in the strategies used to control BVD is whether the approach is systematic or non-systematic. Herd-to-herd control measures are considered to be non-systematic, while measures to reduce overall prevalence are considered to be systematic (Houe *et al.*, 2006).

A fundamental aspect of control and eradication programs is diagnostic testing. Diagnostic stages involve tests to classify the initial status of the herd; subsequent tests to identify and remove individual PIs from BVD-infected herds; and then regular monitoring to confirm ongoing negative BVD status (Houe *et al.*, 2006).

In addition to diagnostic testing, continuing biosecurity measures must be implemented to avoid the introduction of the infection into BVD-free herds, which is a fundamental part of any BVD control program. Risk factors for BVD include large herd sizes, close proximity to neighboring herds, over-the-fence contacts, high number of infected neighbors, having heifers on common pasture, and the purchase of animals without BVD documentation (Lindberg *et al.*, 2006*a*). The probability of such risk factors depends on the control measures that are implemented by individual holdings. Minimizing or eliminating these risks is the cornerstone of any BVD control program (Damman *et al.*, 2015). BVD biosecurity involves any measures that assist in the prevention of herd-to-herd BVD spread. While all farms benefit by implementing basic biosecurity practices, the implementation of large-scale or national measures brings significant cost-efficiency benefits, has a larger effect on decreasing the risk of herd-to-herd transmission, and significantly reduces the incidence of new infections (Lindberg *et al.*, 2006*a*).

Traceability and identification are key biosecurity practices which can help to control the spread of BVD and manage livestock movement restrictions. The movement of infected animals is well recognized as having a crucial role in the spread of disease (Mitchell *et al.*, 2005) and the transport of PIs is one of the leading ways in which BVDV is disseminated (Tinsley *et al.*, 2012).

While national and regional BVD control and eradication programs often do not involve the use of vaccines, in countries lacking such organized control programs, vaccination is much more likely to be used in BVD control (Houe *et al.*, 2006). A study by Damman *et al.* (2015) found that female vaccination before breeding could be a valuable tool in limiting losses caused by BVD-related reproductive failures, and reduces the spread of BVDV by decreasing the number of PI calves born. In the USA, vaccination has been used extensively, but much less so in European countries (apart from Germany) (Damman *et al.*, 2015).

Vaccination

There are several factors to be considered when incorporating the use of vaccines in BVD control. The first factor is whether to use modified live viral (MLV) vaccines or inactivated vaccines. Choosing a suitable biotype, BVDV-1 or BVDV-2, and genotype and subtype are also key considerations. In addition, it is important to evaluate if the formulation will be monovalent or multivalent (Newcomer *et al.*, 2017).

Inactivated BVDV vaccines, while safer than live vaccines, have variable effectiveness due to their low immunogenicity, which is directly correlated with antigenic concentration (Fernández *et al.*, 2009). Furthermore, because they are produced with less diversity of strains, they offer reduced cross-protection. BVDV vaccines are frequently combined with other reproductive and respiratory complex pathogens, meaning that they offer less BVDV viral antigen, and can lead to the development of low levels of antibodies by the host, providing inadequate immune protection against BVDV (Pecora *et al.*, 2015). In addition, the emergence of bovine neonatal pancytopenia, a fatal disease associated with the use of inactivated BVD vaccines, has been reported in a number of European countries, including Scotland (Bell *et al.*, 2010; Pecora *et al.*, 2015).

MLV vaccines have been approved in many countries and are frequently used in the European Union (EU) (Moennig and Brownlie, 2006). Compared with inactivated vaccines, MLV vaccines produced a better immune response in the host, conferring greater protection (Woolums *et al.*, 2013). However, they are less safe due to the possible risk of mutation, reactivation, and replication of the virus and the consequences that come with such events. As such, there are a number of countries where MLV vaccines have not yet been approved, including Argentina (Fernández *et al.*, 2009).

Key considerations that must be kept at the forefront of any vaccination program include:

- The safety of the vaccine and the levels of protection it confers.
- The antigen diversity and strain diversity, taking into account the strains of BVDV present in the region (Jones *et al.*, 2001).
- Continuing surveillance to identify and characterize emerging BVDV field strains to appropriately reformulate vaccines (Fernández *et al.*, 2009).
- The timing of vaccination to fit with the farm's management plan and type of production (Newcomer *et al.*, 2017).
- Design of programs that aim to reduce the birth of PI calves (Odeón, 2016).

Vaccination can make a significant contribution to the control of BVDV. Notwithstanding, it is significantly more effective when used alongside other biosecurity measures to prevent the introduction and circulation of the virus in herds (Newcomer *et al.*, 2017). It is important to highlight that vaccination is not compulsory in most countries (Jones *et al.*, 2001) and is considered a useful complimentary biosecurity measure in BVDV control. However, with the development of safer and more effective vaccines, vaccination may come to play an even more important role in the future of BVDV control.

Case study: BVD eradication in Scotland

Overview of Scottish farming

Almost 80% of Scotland's total land area is under agricultural production, and income from agriculture constituted of approximately 1% of the Scottish economy in 2016 (Scottish Government, 2016*a*). While only 1% of Scotland's land is capable of producing a wide range of crops, in contrast, up to 48% can be used for grazing or rough grazing (Scottish Executive, 2001). As such, livestock accounts for almost 40% of total farm output, an estimated £1.11 billion, with 65% of this coming from cattle (Scottish Government, 2016*a*). Cattle farming is therefore an important aspect of the Scottish agricultural industry, with Scotland being more dependent on this than either the UK as a whole or the EU (Scottish Executive, 2001). In 2016, there were 1.8 million cattle in Scotland (Scottish Government, 2016*a*). Unlike other parts of the UK, Scotland has a much larger beef sector than dairy sector (McCormick *et al.*, 2010).

Over the past few decades, significant changes have occurred in many farming systems in Scotland, leading in general to systems of specialized production (Scottish Executive, 2001). Technological advances in farming have seen in the growth of large farms. In 2016, 30% of beef cattle (131,000 cows) were in a herd size of 150 animals and over, while 69% of dairy cattle (121,000 cows) were in herds of 150 animals or more (Scottish Government, 2016*a*).

Scotland's climate can be particularly wet and windy in winter, this, coupled with reduced grazing quality, means that cattle are housed for longer periods of time. The majority of beef cattle and all dairy herds need to be housed for a 6-month or more winter feeding period, which has been a significant constraint on the competitiveness of Scottish farming (House of Commons, Scottish Affairs Committee, 1996). Furthermore, housed cattle are at higher risk of disease such as BRD and BVD. It has been found that in closely confined housing systems, a new born PI animal can infect over 90% of the herd before it has reached 4 months (Houe *et al.*, 1993).

BVD in Scotland

In Scotland and the UK as a whole, BVD is considered an endemic disease and the Department for Environment, Food and Rural Affairs (DEFRA) (2006) estimated that BVD costs the cattle sector between £25 and £61 million per year. Furthermore, the economic impact of the disease is most likely underestimated as herd infection is frequently undetected (Brülisauer *et al.*, 2010). Studies commissioned by the Scottish Government in 2007 found that, from a bulk milk sample survey of 400 dairy herds, only 22% of the farms studied displayed no evidence of recent BVD exposure, 42% of the farms displayed high antibody titer (indicating recent BVD exposure or vaccination), and 36% of the farms displayed intermediate levels of antibodies. Furthermore, a blood sample study of 300 suckler herds found that 17% of the farms had PI animals (Macrae and Esslemont, 2015).

Since 2009, farmers, vets, and the Scottish Government have been working together on creating and implementing a national BVD eradication program. The introduction of the program, currently entering into phase 5, has seen the level of BVD exposure drop significantly in breeding herds (Scottish Government, 2017). It is believed that BVD eradication will increase the profitability and sustainability of Scotland's cattle business and it has been estimated that BVD eradication from the herd could save the average dairy herd £15,800 per year and the average beef herd £4800 per year (Scottish Government, 2017).

BVD eradication in Scotland

Scotland began its BVD eradication scheme in 2010 with the aim of identifying and removing PI animals from the national herd. Farmers would be encouraged to eliminate BVD from their herds, thereby decreasing the number of PI calves born (Scottish Government, 2017). So far, four phases of the program have been implemented, with phase 5 currently being drafted. Over the past 7 years, the Scottish Government has initiated the legislative obligation for farmers of breeding herds to screen their cattle every year for BVDV and has implemented control measures based on the screening test results. There is also a ban on moving PI animals and suspected PI animals anywhere but directly to slaughter (Scottish Government, 2017).

Phase 1 focused on subsidized screening, with the Scottish Government providing money toward BVD testing for each herd and further funding for veterinary support if the herd tested positive (Scottish Government, 2016*b*). It was found that 23% of the beef herds tested and 52% of the dairy herds tested had been exposed to BVDV (Scottish Government, 2016*b*).

Phase 2 of the program, which began at the end of 2011, saw the introduction of mandatory annual BVD screening. There was a requirement for all farmers of breeding cattle herds to test their herds for BVD before a cutoff date, and then on a yearly basis thereafter (Scottish Government, 2016*b*). In this phase, there were eight testing procedures available; samples of blood, tissue, milk or semen were accepted and could be tested for antibody or for antigen (Scottish Government, 2016*b*). Bulk milk sampling to establish antibody status was the most common test in dairy herds and antigen blood testing was most often performed to detect PIs, while blood testing was the most common method in beef herds during phase 2 (Duncan *et al*., 2016).

The standard check test involves the sampling of five animals per management group (a management group is defined as animals that are housed or grazed together for at least 2 months). All samples must be sent to government-approved laboratories, who then report the results to the Scottish Government and give the herd a status of 'negative' or 'not negative' (Scottish Government, 2016*b*). Not-negative herds have evidence of exposure to BVDV, thus more comprehensive testing is needed to identify if there are PI animals in the herd. If a herd has a not-negative status, farmers should screen all new calves born or carry out a whole herd screen as their yearly test. Only cattle that have tested BVDV-negative or those believed to be negative can move from not-negative herds (Scottish Government, 2015).

The third phase came into force at the start of 2014 and was concerned with reducing the spread of infection through three main control measures. Knowingly selling or moving BVDV-infected cattle (both PI and transiently infected animals) was prohibited. Animals identified as BVDV-positive can solely be moved directly to slaughter. Such restrictions are facilitated through the Cattle Tracing System (CTS). A further control measure was the requirement that the BVD status of a herd be declared before selling, thus allowing potential buyers to verify the current BVD status of the herd or animal. The third measure involved a restriction on herds and animals that have not been tested, aimed at farmers who fail to comply with the mandatory testing requirement (Scottish Government, 2016*b*).

Scotland is currently in stage 4, which began in June 2015 and involves the introduction of enhanced testing and increased movement restrictions. Under stage 4, animals coming from a not negative herd are not permitted to move unless going directly to slaughter or if the individual animal tests negative for BVDV. Replacement animals from untested herds, including imported animals, must now be individually tested.

The number of permitted testing methods has been reduced, with bulk milk tests no longer available. The new measures also include assumed negative status for the mother of a BVDV-negative animal and assumed positive status for the calf of a PI dam (Scottish Government, 2015).

At the end of 2017, the Scottish Government opened public consultations to seek feedback on phase 5 of the eradication scheme (Scottish Government, 2018). The new measures were refined into the following eight proposals:

- Requirement for cattle keepers to investigate the cause of BVDV exposure in herds that have had a 'not negative' status for 13 months or more
- Restrictions on purchasing or bringing in animals to 'BVDV-positive' herds
- The use of primary or secondary identification tags for tissue tag sampling
- Requirement to test at least 10% of calves born in a herd in the last 12 months
- Faster reporting of laboratory results to the national database – from 40 to 5 days
- Requirement to track PI animals back to their herd of pregnancy risk period and birth (if different)
- New movement restrictions on animals before their test results have been uploaded to the national database
- Publishing of the location of 'BVDV-positive' herds

Phase 5 is currently being drafted based on these proposals and there is the potential for a sixth phase in the future. Scotland's BVD eradication scheme has been largely successful, with the level of exposure decreasing from 40 to 10% of herds over the past 7 years (Scottish Government, 2017). However, an area of the program that has been less successful has been in overcoming the issue of non-compliant farmers, with some being reluctant to quickly remove PI animals from their herd or not acting to deal with BVDV in their herd (Voas, 2017). Furthermore, the final stages of BVD eradication will most likely be the most challenging. As natural immunity diminishes alongside the number of herds exposed, national herds will become ever more susceptible to outbreaks of BVD.

Case study: BVD control in Spain

Overview of farming in Spain

In Spain, utilized agricultural area makes up 47% of the whole territory, and when compared with other Western European countries, the proportion of land used for agricultural purposes is low (European Commission, 2010). In total, agriculture constitutes approximately 3.5% of the GDP in Spain, with livestock production making up about 1.2% of the GDP (Castel *et al*., 2011). Within the Spanish livestock sector, meat production dominates, accounting for 73%, and milk production is in second place, accounting for 18% of production (Castel *et al*., 2011). The area with the highest concentration of cattle, both dairy and sucklers, is the north of Spain (Diéguez *et al*., 2017). Livestock production in Spain has transformed from a domestically oriented to an internationally focused industry, and has moved from an extensive to an intensive industrial model (Ríos-Núñez and Coq-Huelva, 2015). This can be seen in terms of the size of agricultural holdings, with a decline in the number of small holdings and an increase in the number of large holdings (European Commission, 2010).

BVD in Spain

The prevalence of BVD in Spain is not clear, due to the fact that few studies have been carried out at national level and the studies that do exist tend to be based on seroprevalence, which at least confirms the circulation of the virus. Such studies report a varied but generally high seroprevalence. For example, 85.7% in Asturias (Mainar-Jaime and Berzal-Herranz, 2001), 91.5% in León (Álvarez *et al*., 1994), 94.2% in Madrid (Vega *et al*., 2004), 70.9% in Andalucía (Gómez-Pacheco *et al*., 2009), and 70.2% in Galicia (Eiras *et al*., 2009). All of these studies identified BVDV-1 as the circulating strain.

In recent years, the existence of BVDV-2 has been confirmed in isolates in the north of Spain. In Asturias, two adult dairy cows, with no apparent symptoms, were found to be carrying BVDV-2 (strain 2406-2/12) (Aduriz *et al*., 2015). In Galicia in 2016, BVDV-2 was found in a 31-month-old animal, and it is believed that this strain was introduced through neighboring farms importing infected animals from other countries (France and Holland) (Factor *et al*., 2016). These neighboring farms were found to be lacking in biosecurity measures and did not test incorporations to the herd. Furthermore, over-the-fence contact with neighbor animals was possible.

In 2006, the European Commission funded a study (Lindberg *et al*., 2006*a*) into how BVD control efforts were performed within EU member states. It found that in Spain, the buying in of PI cattle, including pregnant cows carrying infected fetuses, was believed to be the most significant risk factor (accounting for around 80%) for the introduction of BVDV into previously uninfected herds. The transboundary movement of cattle within Europe is a key area in BVDV transmission, with almost 52,000 PI animals being moved across borders in a year. Countries highly affected in this context were Italy, the Netherlands, and Spain. The second most important risk factor in Spain was from contact with PI animals from other herds at markets, during transportation or at pasture, which was considered to account for approximately 20% of cases of introduction of BVDV into previously uninfected herds.

A number of countries in the EU, including Spain, do not monitor or report on BVD prevalence at the national level. Such countries are more likely to lack a systematic eradication program (Lindberg *et al*., 2006*a*), as is the case with Spain. BVD eradication in Spain is limited to mainly herd-to-herd control and occasional regional control efforts such as the eradication project being carried out in Galicia (Lindberg *et al*., 2006*b*).

BVD control in Galicia

The first region of Spain to implement a voluntary program of BVD control was Galicia, which started in 2004 (Diéguez *et al*., 2008). In the first stage, the initial BVD status of each herd is evaluated in order to differentiate herds with BVDV from those which are BVDV-free. The second stage is the identification and removal of PI animals from herds. Then continual monitoring of herds is performed to ensure the virus is not (re)introduced (Eiras and Arnaiz, 2010).

Initial sampling and analysis involves serological testing to determine exposure to BVDV in cattle over 1 year old. These samples are analyzed with a commercial enzyme-linked immunosorbent assay test, which detects antibodies against a virus protein. The same test is used in herd monitoring through biannual bulk milk testing and serum testing of heifers over 9 months old (Factor *et al*., 2016). In cases where herds show continued high antibody titers, indicating the presence of a PI animal, it is then necessary to test animals individually. It was found that, in 2014, the prevalence of PI animals from all those sampled in farms with suspected BVD was 1.5% (Calvo, 2016). A drawback of these diagnostic techniques is that inactivated vaccines can interfere with results, which should be taken into account when interpreting serological results (Makoschey *et al*., 2007).

The voluntary nature of the program puts it at a disadvantage, resulting in limited coverage; only 60% of cows and 40% of herds are participating (Factor *et al*., 2016). However, a noteworthy success of the Galician control program is its growth and expansion throughout the region in the past decade. Studies have shown the number of farms engaging with the program continue to increase (Calvo, 2016; Factor *et al*., 2016). A further success of this program has been in improved testing of animals being bought in to herds, improved detection of BVDV exposure in these animals, and in reducing the sale of PI animals (Calvo, 2016). Another positive outcome is that the average age at which PI animals are diagnosed has decreased, from 15.3 months in 2007 to 6.2 months in 2014 (Calvo, 2016). These successes demonstrate the impact of systematic control efforts and highlight the need for a national control program in Spain.

Recommendations for further BVD control in Spain

Proven successful BVD control practices can be extrapolated from existing programs, while keeping at the forefront the unique challenges that each country and region faces:

- The use of clear and distinct phases, beginning with voluntary participation and progressing to mandatory phases
- The implementation of a national, state subsidized control program, which covers all animals in the national herd
- Restrictions on the buying and selling of BVD-positive animals and animals not tested at origin, applying to animals from both the internal and the external markets
- The creation of a public register of the BVD status of holdings.
- Movement restrictions of cattle from or to farms with unknown BVD status
- The promotion of strict biosecurity measures
- The continuing education of producers in the sector

Case study: the importance of BVD control in Argentina

Overview of farming in Argentina

Agricultural land in Argentina is approximately 54% (World Bank, 2017). In 2016, agriculture accounted for 7.6% of the country's gross domestic product (GDP) (World Bank 2016). Argentina has traditionally been well known for its beef production and held a place as one of the world's largest beef exporters (Guevara and Grünwaldt, 2012). The EU has been a major buyer of Argentinean beef, especially of high-quality fresh beef (Souza-Monteiro and Caswell, 2004). Despite being ranked the third largest exporter of beef in the world in 2005, Argentina fell to 11th place in 2012, with high export taxes being a likely cause of this decrease (World Bank, 2014). In recent years, there has been a sharp decline in cattle stock, which between 2007 and 2010 had decreased by almost 10 million head (Guevara and Grünwaldt, 2012). While Argentina has gradually lost its place in the world export markets, it remains the country with the highest per capita meat consumption worldwide (56.3 kg per capita per year) and has a strong domestic beef market. The vast majority of beef produced in Argentina is sold in the domestic market; during the period 2001–2010, 84% of Argentina's beef production went to the internal market (Guevara and Grünwaldt, 2012).

Traditionally, beef cattle have been bred through natural service and raised on pasture, where bulls, cows, and calves coexist freely with little intervention (Campero *et al*., 2003). However, the sector is evolving and modernizing, incorporating technological advances such as pasture planting, diet management as well as reproductive technologies like artificial insemination (AI) and estrus synchronization. Feedlots have brought a change to the traditional pastoral cattle systems in Argentina and the number of animals from feedlot destined for slaughter has been increasing in the past decade (Guevara and Grünwaldt, 2012). Argentinian feedlot systems recently accounted for approximately 50% of animals slaughtered (Climate and Clean Air Coalition, 2015).

Argentina also has a large dairy sector. In 2012, the dairy sector had 10,453 farms, where 1,690,581 cows were milked, producing a total of 11,600 million liters of milk per year (Suero *et al.*, 2012).

BVD in Argentina

In Argentina, with its extensive livestock industry, BVD is one of the leading causes of infertility, abortion, and perinatal deaths (Muñoz *et al.*, 1996; Odeón *et al.*, 2003). In most herds, seropositive animals are extremely common, with studies demonstrating that up to 70% of cattle are seropositive to BVDV (Rweyemamu *et al.*, 1990; Pacheco and Lager, 2003). Even in closed herds, where infection from external sources is extremely unlikely, most calves are infected at a young age, many before they reach 6 months (Gogorza *et al.*, 2006). A number of BVDV strains have been found to circulate in Argentina, BVDV-1a, BVDV-1b, BVDV-1c and BVDV-2a are all present in the Argentine bovine population (Jones *et al.*, 2001; Jones and Weber, 2004; Pecora *et al.*, 2014). A study by Julià *et al.* (2009) found that BVDV-1, and most likely BVDV-2, circulate in sheep and the study found evidence that PI sheep were natural reservoirs, even without cattle participation.

Several outbreaks of fatal mucosal disease caused by BVDV have been reported over the past two decades in Argentina (Odeon *et al.*, 2003; Lunardi *et al.*, 2008). A severe outbreak occurred in 2009 in a herd in the southwestern part of Buenos Aires Province, during which 22% of yearling males from the herd died and 12% of the herd was subsequently found to be PI (González Altamiranda *et al.*, 2012). A study of this outbreak revealed that the most likely source of infection was AI, using semen contaminated with BVDV (González Altamiranda *et al.*, 2012). This demonstrates the risks associated with the semen of PI bulls, compounded by the fact that such bulls show normal growth and development and results of semen analysis can be normal. Furthermore, BVDV is able to survive processing and cryopreservation (Kirkland *et al.*, 1994; Givens and Waldrop, 2004). A further problem with using semen from PI bulls is that it produces notably lower fertilization rates (González Altamiranda *et al.*, 2012), which adds to the negative impact that BVDV has on the overall reproductive performance of animals.

Due to the complexity of the illness and the lack of studies into the economic impact of BVD in Argentina, it is difficult to quantify economic losses, but as with other countries where BVD is endemic, such losses are likely to be significant. One study estimated the economic losses of BVD-related abortions at approximately $1,496,880,000 (Argentine pesos) or $100,000,000 (US$) (Odeón, 2016).

Current BVD control in Argentina is based on vaccination using inactivated vaccines. Given the severe negative impact that BVDV has been demonstrated to have on the reproductive performance of cattle and the economic output of the sector, there is a strong argument supporting the need for a systematic control program.

Recommendations for BVD control in Argentina

Using the experience from existing BVD eradication programs, such a program in Argentina should be clearly defined and realistic and should include the following four basic strategies:

Table 1. BVD eradication programs in Europe

National and regional programs	Herd-to-herd programs
Austria	England (UK)
Brittany (FR)	France
Galicia (SP)	Italy
Germany	Portugal
The Netherlands	Spain
Ireland	
Nordic Countries (DK, FI, NO, SE)	
Northern Ireland (UK)	
Rome, Lecco, Como (IT)	
Scotland (UK)	
Switzerland	

Lindberg *et al.* (2006*a*; 2006*b*).

- Education and training
- Diagnostic testing
- Elimination of PI cattle
- Biosecurity and management

BVD is not considered a priority in Argentina, while other diseases such as TB and brucellosis continue to be endemic. Given the economic difficulties facing Argentina, a significant issue in implementing a control program may be in the reluctance of government to subsidize it. It is therefore essential that the scale of BVD and its economic impact are brought to the attention of all parties involved in cattle production and health, including government bodies.

To formulate an appropriate control program, it is essential to know the BVD status of herds in the region. This is initially achieved through the serological profiling of herds. It must be borne in mind that such tests may be adversely affected by the presence of colostral antibodies and vaccine antibodies.

The next step is to carry out further antigen tests on all animals in positive herds and after all births, in order to identify and remove PI animals as quickly as possible. While potentially challenging due to the type of extensive farming in Argentina, such tests should be carried out before weaning at the latest, so as not to lose the traceability between cow and calf.

The different routes through which BVDV could potentially infect or re-infect a herd should be evaluated. The types of biosecurity measures which would have the most impact in Argentina may differ from those given high priority in other regions such as Europe. For example, the low population density in Argentina decreases contact between animals in a herd and makes over-the-fence contact with neighboring herds unlikely, therefore decreasing BVDV transmission. Notwithstanding, the following biosecurity measures have an important role to play in BVD control in the region:

- Antigen and antibody testing of animals prior to selling and the use of quarantine on farms after purchase, with a new test after 4 weeks to prevent the entry of animals with active infection, PI, or cows carrying PI fetuses
- Particularly important for Argentina, strict protocols for the detection of the virus in the biological material used in AI and the elimination of contaminated materials.

Given the potential difficulties in implementing such a systematic control program in Argentina, the incorporation of a vaccination program may be a practical and cost-effective measure. This would base long-term control on the protection of breeding herds and the prevention of new PI births. A useful strategy would be to also vaccinate calves at weaning, after their negative diagnosis, to minimize the possibility of respiratory symptomatology. Currently in Argentina, only inactivated BVDV vaccines are licensed and most are formulated with strains of BVDV-1a, with only a few containing strains of BVDV-2, which limits their effectiveness (Pecora *et al*., 2014). Therefore, the research, development, and approval of new vaccines are fundamental, as well as government accountability in making decisions for the implementation of animal health policies.

Conclusions

Professionals in animal health and food safety have a duty to advocate for greater awareness and to urge governments, states, and other public and private bodies to contribute to the development of appropriate strategies to control and eradicate BVDV. This will lead to more efficient livestock production, contribute to more responsible use of antimicrobials, and, in turn, help in the fight against antimicrobial resistance. The ultimate impact will be in the production of safe, accessible, and abundant foods to meet the future nutritional requirements of a growing world population, which is predicted to reach 9.8 million in 2050 (UN 2017).

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References

Aduriz G, Atxaerandio R and Cortabarria N (2015) First detection of bovine viral diarrhoea virus type 2 in cattle in Spain. *Veterinary Record Open* **2**, e000110. Available at http://vetrecordopen.bmj.com/content/2/1/e000110?utm_source=TrendMD&utm_medium=cpc&utm_campaign=Vet_Rec_Open_TrendMD-1 (Accessed 20 December 2017).

Álvarez M, González M, Álvarez F, López JM and Llamazares J (1994) Prevalencia de la infección por el virus de la diarrea vírica bovina en rebaños bovinos lecheros y su posible participación en problemas reproductivos. In: Proc. 7as Jornadas Internacionales de Reproducción Animal de la Asociación Española de Reproducción Animal, Ponencias y Comunicaciones: Murcia, Spain.

Bell CR, Scott PR, Sargison ND, Wilson DJ, Morrison L, Howie F, Willoughby K and Penny CD (2010) Idiopathic bovine neonatal pancytopenia in a Scottish beef herd. *Veterinary Record* **167**, 938–940.

Bianchi MV, Konradt G, de Souza SO, Bassuino DM, Silveira S, Mosena AC, Canal CW, Pavarini SP and Driemeier D (2017) Natural outbreak of BVDV-1d induced mucosal disease lacking intestinal lesions. *Veterinary Pathology* **54**, 242–248.

Bolin SR, McClurkin AW and Coria MF (1985) Frequency of persistent bovine viral diarrhea virus infection in selected cattle herds. *American Journal of Veterinary Research* **46**, 2385–2387.

Bøtner A and Belsham GJ (2012) Virus survival in slurry: analysis of the stability of foot and- mouth disease, classical swine fever, bovine viral diarrhoea and swine influenza viruses. *Veterinary Microbiology* **157**, 41–49.

Brülisauer F, Lewis FI, Ganser AG, McKendrick IJ and Gunn GJ (2010) The prevalence of bovine viral diarrhoea virus infection in beef suckler herds in Scotland. *The Veterinary Journal* **186**, 226–231.

Calvo C (2016) Plan de vigilancia y control del BVD en Galicia. *Campo Galego*. Available at http://www.campogalego.com/es/leche/plan-de-vigilancia-y-control-del-bvd-en-galicia/ (Accessed 19 November 2017).

Campero CM, Moore DP, Odeon AC, Cipolla AL and Odriozola E (2003) Aetiology of bovine abortion in Argentina. *Veterinary Research Communications* **27**, 359–369.

Castel JM, Mena Y, Ruiz FA and Morales E (2011) *Ruminant Production Systems in Spain: Sustainability Analysis* de Theoretical and empirical studies on farming systems in Spain and Poland. Wiesław Mądry, Jose Maria Castel, Marcin Ollik, Barbara Roszkowska-Mądra. Warsaw and Sevilla, Wydawnictwo SGGW, Warsaw, Poland.

Climate and Clean Air Coalition (2015) Opportunities for integrated of manure management in Argentinian feedlots. *Fact Sheet*. Available at http://www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/kiosk/factsheet/20151029_OPC_Factsheet_Argentina_v3.pdf (Accessed 2 December 2017).

Damman A, Viet AF, Arnoux S, Guerrier-Chatellet MC, Petit E and Ezanno P (2015) Modelling the spread of bovine viral diarrhea virus (BVDV) in a beef cattle herd and its impact on herd productivity. *Veterinary Research* **46**, 12.

DEFRA (2006) England Implementation Group (EIG) Building a better future for England's kept animals. Second report on progress delivering the Animal Health and Welfare Strategy for Great Britain in England., London: Department for Environment, Food and Rural Affairs. p 2–3. Available at http://webarchive.nationalarchives.gov.uk/20090905080649/http://www.defra.gov.uk/animalh/ahws/eig/pdf/second_prog_report2008.pdf (Accessed 03 January 2018).

Diéguez FJ, Yus E, Sanjuán ML, Vilar MK and Arnaiz I (2008) Monitoring bovine viral diarrhea virus (BVDV) infection status in dairy herds. *Pesquisas Veterinaria Brasileira* **28**, 588–592.

Diéguez FJ, Cerviño M and Yus E (2017) Bovine viral diarrhea virus (BVDV) genetic diversity in Spain: a review. *Spanish Journal of Agricultural Research* **7**, 2. URL http://revistas.inia.es/index.php/sjar/article/view/10619/3407.

Duncan AJ, Gunn GJ and Humphry RW (2016) Difficulties arising from the variety of testing schemes used for bovine viral diarrhoea virus (BVDV). *Veterinary Record*. Available at http://veterinaryrecord.bmj.com/content/early/2016/02/11/vr.103329.full (Accessed 10 November 2017).

Durham PJ and Hassard LE (1990) Prevalence of antibodies to infectious bovine rhinotracheitis, parainfluenza 3, bovine respiratory syncytial, and bovine viral diarrhea viruses in cattle in Saskatchewan and Alberta. *The Canadian Veterinary Journal* **31**, 815–820.

Eiras C and Arnaiz I (2010) Programa sanitario en las ADSG de vacuno en Galicia. *Cría y Salud* **32**, 40–47.

Eiras C, Diéguez FJ, Sanjuán ML, Yus E and Arnaiz I (2009) Prevalence of serum antibodies to bovine herpesvirus-1 in cattle in Galicia (NW Spain). *The Spanish Journal of Agricultural Research* **7**, 800–806.

European Commission (2006) EU thematic network on control of bovine viral diarrhoea virus (BVDV). Available at https://www.afbini.gov.uk/publications/eu-thematic-network-control-bovine-viral-diarrhoea-virus-bvdv (Accessed 30 December 2017).

European Commission (2010) Agricultural census in Spain. Available at http://ec.europa.eu/eurostat/statisticsexplained/index.php/Agricultural_census_in_Spain (Accessed 3 January 2018).

Factor C, Yus E, Eiras C, Sanjuan ML, Cerviño M, Arnaiz I and Diéguez FJ (2016) Genetic diversity of bovine viral diarrhea viruses from the Galicia region of Spain. *Veterinary Record Open* **3**, e000196. Published online. Recuperado de Available at http://vetrecordopen.bmj.com/content/3/1/e000196.

Fernández F, Costantini V, Barrandeguy M, Parreño V, Schiappacassi G, Maliandi F, Leunda M and Odeón A (2009) Evaluation of experimental vaccines for bovine viral diarrhea in bovines, ovines and Guinea pigs. *Revista Argentina de Microbiología* **41**, 86–91.

Givens MD and Waldrop JG (2004) Bovine viral diarrhea virus in embryo and semen production system. *Veterinary Clinics: Food Animal Practice* **20**, 21–38.

Gogorza LM, Morán PE, Larghi JL, Braun M and Esteban EN (2006) Detection of bovine viral diarrhea virus by amplification on polycation-treated cells followed by enzyme immunoassay. *Revista Argentina de Microbiología* **38**, 209–215.

Gómez-Pacheco JM, Tarradas-Iglesias C, Luque-Moreno I, Arenas-Casas AJ, Maldonado-Borrego JL, González MA and Perea-Remujo JA (2009)

Seroprevalencia de las infecciones por el virus Diarrea Vírica Bovina en ganado bovino en Andalucía. *REDVET. Revista electrónica de Veterinaria* **10**, 2. Available at http://www.veterinaria.org/revistas/redvet/n020209/020904.pdf (Accessed 20 January 2018).

González Altamiranda EA, Kaiser GG, Weber N, Leunda MR, Pecora A, Malacari DA, Morán O, Campero CM and Odeón AC (2012) Clinical and reproductive consequences of using BVDV-contaminated semen in artificial insemination in a beef herd in Argentina. *Animal Reproduction Science* **133**, 146–152.

Greiser-Wilke I, Grummer B and Moennig V (2003) Bovine viral diarrhoea eradication and control programmes in Europe. *Biologicals* **31**, 113–118.

Grooms DL, Baker JC and Ames TR (2014) Diseases caused by bovine virus diarrhea. In Smith B (2014) *Large Animal Internal Medicine*, 5th edn. St. Louis: Mosby, pp. 791–797.

Guevara JC and Grünwaldt EG (2012) *Status of Beef Cattle Production in Argentina over the Last Decade and Its Prospects*, Livestock Production, Dr Khalid Javed (ed.), InTech, London. Available at https://www.intechopen.com/books/livestock-production/status-of-beef-cattle-production-in-argentina-over-the-last-decade-and-its-prospects (Accessed 15 January 2018).

Gunn GJ, Stott AW and Humphry RW (2004) Modelling and costing BVD outbreaks in beef herds. *The Veterinary Journal* **167**, 143–149.

Houe H (1993) Survivorship of animals persistently infected with bovine virus diarrhoea virus (BVDV). *Preventive Veterinary Medicine* **15**, 275–283.

Houe H (1999) Epidemiological features and economical importance of bovine virus diarrhoea virus (BVDV) infections. *Veterinary Microbiology* **64**, 89–107.

Houe H, Baker JC, Maes RK, Wuryastuti H, Wasito R, Ruegg PL and Lloyd JW (1995) Prevalence of cattle persistently infected with bovine viral diarrhea virus in 20 dairy herds in two counties in central Michigan and comparison of prevalence of antibody-positive cattle among herds with different infection and vaccination status. *Journal of Veterinary Diagnostic Investigation* **7**, 321–326.

Houe H, Lindberg A and Moennig V (2006) Test strategies in bovine viral diarrhea virus control and eradication campaigns in Europe. *Journal of Veterinary Diagnostic Investigation* **18**, 427–436.

House of Commons, Scottish Affairs Committee (1996) House of commons select committee on Scottish affairs. *The Future of Scottish Agriculture*, London: HMSO.

Jones LR and Weber EL (2004) Homologous recombination in bovine pestiviruses. Phylogenetic and statistic evidence. *Infection, Genetics and Evolution* **4**, 335–343.

Jones LR, Zandomeni R and Weber EL (2001) Genetic typing of bovine viral diarrhea virus isolates from Argentina. *Veterinary Microbiology* **81**, 367–375.

Julià S, Craig MI, Jiménez LS, Pinto GB and Weber EL (2009) First report of BVDV circulation in sheep in Argentina. *Preventive Veterinary Medicine* **90**, 274–277.

Kirkland PD, Mackintosh SG and Moyle A (1994) The outcome of widespread use of semen from a bull persistently infected with pestivirus. *The Veterinary Record* **135**, 527–529.

Lindberg A, Berriatua E, Fourichon C, Mintiens K and Houe H (2006*a*) Position paper: epidemiology and risks. EU Thematic Network on BVDV control. Available at https://www.afbini.gov.uk/articles/final-report-bvdv-control-europe (Accessed 30 December 2017).

Lindberg A, Brownlie J, Gunn GJ, Houe H, Moennig V, Saatkamp HW, Sandvik T and Valle PS (2006*b*) The control of bovine viral diarrhoea virus in Europe: today and in the future. *Scientific and Technical Review of the Office International des Epizooties* **25**, 961–979.

Lunardi M, Headley SA, Lisbôa JA, Amude AM and Alfieri AA (2008) Outbreak of acute bovine viral diarrhea in Brazilian beef cattle: clinicopathological findings and molecular characterization of a wild-type BVDV strain subtype 1b. *Research in Veterinary Science*, **85**, 599–604.

Macrae A and Esslemont R (2015) *The Prevalence and Cost of Important Endemic Diseases and Fertility in Dairy Herds in the UK*. Bovine Medicine, 3rd edn. New Jersey: Wiley-Blackwell.

Mainar-Jaime RC and Berzal-Herranz B (2001) Epidemiological pattern and risk factors associated with bovine viral-diarrhoea virus (BVDV) infection in a non-vaccinated dairy cattle population from the Asturias region of Spain. *Preventive Veterinary Medicine* **52**, 63–73.

Makoschey B, Sonnemans D, Bielsa JM, Franken P, Mars M, Santos L and Álvarez M (2007) Evaluation of the induction of NS3 specific BVDV antibodies using a commercial inactivated BVDV vaccine in immunization and challenge trials. *Vaccine* **25**, 6140–6145.

McCormick BJJ, Stott AW, Brülisaue F, Vosough Ahmadi B and Gunn GJ (2010) An integrated approach to assessing the viability of eradicating BVD in Scottish beef suckler herds. *Veterinary Microbiology* **142**, 129–136.

Mitchell A, Bourn D, Mawdsley J, Wint W, Clifton-Hadley R and Gilbert M (2005) Characteristics of cattle movements in Britain – an analysis of records from the Cattle Tracing System. *Animal Science* **80**, 265–273.

Moennig V and Becher P (2015) Pestivirus control programs: how far have we 497 come and where are we going? *Animal Health Research Reviews* **16**, 83–87.

Moennig V and Brownlie J (2006) Vaccines and vaccination strategies. In EU Thematic network on control of bovine viral diarrhoea virus: position paper (QLRT – 2001-01573). Available at http://www.afbini.gov.uk/chs-thematic-network-position-paper-on-bvd-control.pdf, p. 73–98 (Accessed 3 December 2017).

Muñoz DP, Lager IA, Mersich S, Zabal O, Ulloa E, Schudel AA and Weber EL (1996) Foetal infections with bovine viral diarrhoea virus in Argentina. *The British Veterinary Journal* **152**, 52–175

Neill JD (2013) Molecular biology of bovine viral diarrhea virus. *Biologicals* **41**, 2–7.

Newcomer BW, Chamorro MF and Walz PH (2017) Vaccination of cattle against bovine viral diarrhea virus. *Veterinary Microbiology* **206**, 78–83.

Odeón AC (2016) Control del virus de la Diarrea Viral Bovina. Grupo de Sanidad Animal de la EEA Balcarce. INTA.

Odeón AC, Risatti G, Kaiser GG, Leunda MR, Odriozola E, Campero CM and Donis RO (2003) Bovine viral diarrhea virus genomic associations in mucosal disease, enteritis and generalized dermatitis outbreaks in Argentina. *Veterinary Microbiology* **96**, 133–144.

OIE – World Organisation for Animal Health (2017) *Bovine Viral Diarrhoea*. Manual of diagnostic tests and vaccines for terrestrial animals 2017. Available at http://www.oie.int/en/international-standard-setting/terrestrial-manual/access-online/ (Accessed 1 November 2017).

Pacheco LM and Lager I (2003) Indirect method ELISA for the detection of antibodies against bovine diarrhea virus in bovine serum. *Revista Argentina de Microbiologia* **35**, 19–23.

Pecora A, Malacari DA, Ridpath JF, Perez Aguirreburualde MS, Combessies G, Odeón AC, Romera SA, Golemba MD and Wigdorovitz A (2014) First finding of genetic and antigenic diversity in 1b-BVDV isolates from Argentina. *Research in Veterinary Science* **96**, 204–212.

Pecora A, Malacari DA, Pérez Aguirreburualde MS, Bellido D, Escribano JM, Dus Santos MJ and Wigdorovitz A (2015) Desarrollo de una vacuna de subunidad BVDV mejorada basada en la glucoproteína E2 fusionada a un anticuerpo de cadena simple que se dirige a células presentadoras de antígeno. *Revista Argentina de Microbiología* **47**, 4–8.

Ridpath JF and Bolin SR (1998) Differentiation of types 1a, 1b and 2 bovine viral diarrhoea virus (BVDV) by PCR. *Molecular and Cellular Probes* **12**, 101–106.

Ríos-Núñez SM and Coq-Huelva D (2015) The transformation of the Spanish Livestock System in the second and third food regimes. *Journal of Agrarian Change* **15**, 519–540.

Rweyemamu MM, Fernandez AA, Espinosa AM, Schudel AA, Lager IA and Mueller SB (1990) Incidence, epidemiology and control of bovine virus diarrhoea virus in South America. *Science and Technology Review* **9**, 207–221.

Scottish Executive (2001) Agriculture's contribution to Scottish society, economy and environment. A literature review for the Scottish executive rural affairs department and CRU University. Available at www.gov.scot/resource/doc/158216/0042826.pdf (Accessed 21 November 2017).

Scottish Government (2015) The BVD Eradication scheme – Phase 4 – Vets guidance. Available at http://www.gov.scot/Publications/2015/06/9489/3 (Accessed 28 November 2017).

Scottish Government (2016a). Economic report on Scottish agriculture. Available at http://www.gov.scot/Resource/0050/00501417.pdf (Accessed 27 November 2017).

Scottish Government (2016b). The Scottish BVD Eradication Scheme. Available at http://www.gov.scot/Topics/farmingrural/Agriculture/animal-welfare/Diseases/disease/DVB/eradication (Accessed 29 November 2017).

Scottish Government (2017) Bovine Viral Diarrhoea (BVD). Consultation on Phase 5 of the Eradication Scheme. Animal Health and Welfare Division. Available at http://www.gov.scot/Resource/0052/00523628.pdf (Accessed 28 November 2017).

Scottish Government (2018) Bovine Viral Diarrhoea (BVD). Consultation on Phase 5 of the Eradication Scheme. Analysis of responses to the public consultation exercise. Available at http://www.gov.scot/Resource/0053/00530498.pdf (Accessed 01 May 2018).

Simmonds P, Becher P, Collet MS, Gould EA, Heinz FX, Meyers G, Monath T, Pletnev A, Rice CM, Stiansny K, Thiel HJ, Weiner A and Bukhet J (2011) Flaviviridae. In King AMQ, Adams MJ, Carstens EB and Lefkowitz EJ (eds.), *Virus Taxonomy: Ninth Report of the International Committee on Taxonomy of Viruses*. San Diego: Academic Press, pp. 1003–1020.

Souza-Monteiro DM and Caswell JA (2004) The economics of implementing traceability in beef supply chains: trends in major producing and trading countries. Department of Resource Economics, University of Massachusetts, Amherst. Available at http://www.umass.edu/resec/workingpapers.htm (Accessed 5 December 2017).

Suero MM, Castignani H, Teran TC and Marino MR (2012) La lechería Argentina: estado actual y su evolución (2008 a 2011). Instituto Nacional de Tecnología Agropecuaria. Available at https://inta.gob.ar/documentos/la-lecheria-argentina-estado-actual-y-su-evolucion-2008-a-2011 (Accessed 6 January 2018).

Tinsley M, Lewis FI and Brülisauer F (2012) Network modeling of BVD transmission. *Veterinary Research* **43**, 11.

UN (2017) World Population Prospects. The 2017 Revision. Department of Economic and Social Affairs. Available at https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_KeyFindings.pdf (Accessed 17 January 2018).

Vega S, Orden JA, García A, Pérez T, Ruiz-Santa-Quinteira JA and De la Fuente R (2004) Seroprevalencia de anticuerpos frente al virus de la diarrea vírica bovina en el ganado bovino de la Comunidad Autónoma de Madrid. *Laboratorio Veterinario AVEDILA* **28**, 2–8.

Voas S (2017) Scotland's BVD eradication scheme: an update. *Veterinary Record*. URL http://veterinaryrecord.bmj.com/content/180/18/451 (Accessed 29 November 2017).

Wernike K, Gethmann J, Schirrmeier H, Schröder R, Conraths FJ and Beer M (2017) Six years (2011–2016) of mandatory nationwide Bovine Viral Diarrhea Control in Germany – a success story. *Pathogens (Basel, Switzerland)* **6**, 50.

Woolums AR, Berghaus RD, Berghaus LJ, Ellis RW, Pence ME, Saliki JT, Hurley KA, Galland KL, Burdett WW, Nordstrom ST and Hurley DJ (2013) Effect of calf age and administration route of initial multivalent modified-live virus vaccine on humoral and cell-mediated immune responses following subsequent administration of a booster vaccination at weaning in beef calves. *American Journal of Veterinary Research* **74**, 343–354.

World Bank (2016) World Development Indicators 2016. Available at https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=AR (Accessed 16 November 2017).

World Bank (2017) World Development Indicators. Available at https://data.worldbank.org/indicator/AG.LND.AGRI.ZS (Accessed 29 December 2017).

World Bank; CIAT; CATIE (2014) *Climate-Smart Agriculture in Argentina*. CSA Country Profiles for Latin America Series. Supplementary Material. Washington D.C.: The World Bank Group. P7.