Bovine viral diarrhea (BVD) eradication in Switzerland—Experiences of the first two years

Patrick Presi, Rahel Struchen, Theodore Knight-Jones, Sabrina Scholl, Dagmar Heim

A national eradication programme was designed with the aim of achieving total freedom from bovine viral diarrhea virus (BVDV) infection in the Swiss cattle population. The eradication programme consisted of testing every Swiss bovine for antigen, culling virus-positive animals and applying movement restrictions. Starting in 2008, the campaign achieved the goal of reducing the proportion of newborn calves that were virus-positive from 1.8% to under 0.2% within two years (situation in September 2010). Both good data flow between the parties involved as well as speed and efficiency (e.g. concerning the application of tests, movement restrictions and slaughter) are central to the success of the programme. Since the beginning of the programme 2.85 million cattle have been tested for bovine viral diarrhea virus (BVDV).

The BVD-prevalence in cattle at the individual and herd levels following the implementation of the eradication programme was assessed. Using data collected during this campaign a risk factor analysis was conducted in order to identify factors associated with the appearance of virus positive newborn calves in herds where BVD had not previously been detected; these risk factors would allow targeting of future surveillance. Herd size, early death rate (i.e. the number of animals that either die before 15 days of age or are stillborn per number of newborns per year), buying in stock, using communal summer grazing, production type, age structure and management strategy were factors associated with the appearance of new cases of infection. Testing of newborn calves for antigen will continue to be conducted until the end of 2011, this is combined with outbreak investigation of newly infected herds (consisting of re-testing dams of virus-positive calves and if necessary all cattle on or that recently left the farm). This process is done to identify infected animals that may have been missed during prior testing (false negatives), it also serves to identify other factors that may be responsible for the introduction of BVDV onto the farm. Since October 2009, testing of calves for antigen combined with outbreak investigation has led to the detection of 55 infected animals that had tested negative (presumably false negative) during previous rounds of testing.

1. Introduction

Large scale bovine viral diarrhea (BVD) eradication programmes were initiated in the early 90s in Denmark, Finland, Norway and Sweden (Waage et al., 1996; Lindberg and Alenius, 1999; Nuotio et al., 1999; Syenge et al., 1999; Bitsch et al., 2000). Regardless of the initial prevalence, all eradication programmes took approximately ten years to reach the final stage (Lindberg et al., 2006). After regional eradication on the Shetland Islands (UK) (Synge et al., 1999), Norway was the first to achieve national eradication in 2006 (Sandvik, 2004). Austria scaled up a regional...
campaign to the national level in 2004 (Rossmanith et al., 2005, 2010) and Switzerland started a national eradication campaign in 2008 (Zimmerli et al., 2009). Other regional programmes also exist (Lindberg et al., 2006). The eradication campaigns are all done without vaccination using the following general outline: (a) identification of potentially infected and non infected herds using antibody screening at the herd-level; (b) identification and removal of persistently infected (PI) animals from infected herds and improvement of biosecurity with quarantine and testing of bought in stock; (c) monitoring of herds and certification of their status throughout the campaign. The first two steps are performed using different combinations of serological herd tests (e.g. bulk milk tests and testing animals of certain age groups). Regulatory frameworks are put in place to disrupt transmission between herds, particularly restricting contact between infected herds and herds where virus has not been detected (Moennig et al., 2005). Another important feature of these campaigns is the realisation of the importance of the farmer’s role in disease control through the day to day management decisions they make. Farmers have to be informed of not only the negative impact that BVD can have on their herd but also the high risk of infection associated with certain practices (Moennig et al., 2005).

In Switzerland, an alternative approach to BVD eradication is being used. This national and compulsory eradication programme is based on the identification and elimination of PI animals through antigen testing all cattle and newborns without initial antibody screening, a ban on BVD-vaccination and the use of appropriate movement restrictions (Presi and Heim, 2010).

The reasons for basing the Swiss eradication programme on antigen testing (during the initial years) are as follows: BVD sero-prevalence was estimated to be 60% at the individual level and 100% at the herd level (Rufenacht et al., 2000), therefore, initial antibody screening to distinguish infected and uninfected herds was deemed inefficient and unnecessary. In additional there is a high density of cattle farms in Switzerland, and the level of cattle movements is very high (1.3 million movements of cattle between holdings in 2009; Anonymous, 2009). Furthermore the use of shared summer grazing in mountain pastures is widespread (involving one third of the cattle population). Pre-movement testing was thought to be highly inconvenient to farmers and logistically unrealistic. Other considerations were the emergence of new BVD diagnostic tools (ear notch sampling) and the existence of a sophisticated veterinary services information system (connecting each regional veterinary service with the federal veterinary office [FVO]). When these factors were considered collectively, a programme based on antigen testing all cattle in a short time period appeared the most feasible, effective and acceptable method. The details of the BVD-eradication programme were discussed with national farming organisations from the outset. A series of regional meetings provided the opportunity to both inform farmers about the programme and for farmers to vote on aspects of the programme; this involvement helped to obtain cooperation from the farmers. One issue that was voted on and discussed was the level of financial contribution to be made by the cattle farmers to the programme (approximately one third of the eradication costs). Farmers overwhelmingly supported the programme, with only one region voting against it. To make the programme enforceable, the necessary legislation was put in place.

In 2008, 95% of the Swiss cattle population was tested for BVD virus within one year (phase 1). The next phase involved testing all newborn calves (phase 2). During these phases of the programme large amounts of data were collected. This data have been used to describe the epidemiology of BVD in the country at the beginning of the eradication programme and to evaluate the impact of the control measures implemented during the programme. Together with modeling, the data have been used for the analysis and planning of different surveillance strategies (phase 3).

This paper describes changes in the level of BVD infection in the Swiss national herd during the campaign and discusses the successes and problems encountered. In addition, risk factor analysis has been conducted in order to identify factors associated with the subsequent birth of PI calves in herds that were found to be BVD negative during the first two phases of the eradication programme.

2. Materials and methods

2.1. Use of databases

The aim of the eradication programme is to remove BVDV from the Swiss cattle population within a few years. To complete such an undertaking, a high level of coordination and communication is required between all parties involved. This was achieved with the aid of several databases and web tools. The Swiss FVO developed the “information system of the veterinary services” (ISVet) to connect all its partner organisations. It provides support to regional veterinary offices that organise sampling and implement control measures. Test results were transferred by the participating laboratories to a central lab database operated by the FVO. From there, they were sent to ISVet where the BVD status of each animal was recorded. Some information from ISVet was made available to those performing the sampling via a website (BVD-Web) from where lists of individual animals on each farm can be obtained. The Swiss animal movement database (AMD) records cattle movements between holdings; it is accessible to all farmers and also provides information about movement restrictions due to BVD. A more detailed overview of the databases and data flow can be found in Presi and Heim (2010).

2.2. Information campaign

Before and during the eradication programme, an information campaign was launched in order to enhance farmer awareness of BVD, as farmer collaboration is a key factor for a successful eradication programme (Lindberg et al., 2006).
Phase of the programme | Number of herds | Number of herds with virus positive animals | Comments |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1: eradication phase</td>
<td>42,070</td>
<td>7611</td>
<td>Of these, in 1404 herds BVD-virus positive animals already found during phase 1</td>
</tr>
<tr>
<td>Phase 2: calf phase</td>
<td>39,012</td>
<td>3032</td>
<td>81 herds were already virus positive in phase 1</td>
</tr>
<tr>
<td>Phase 3: surveillance phase</td>
<td>0</td>
<td>823 (353 exclusively in phase 3)</td>
<td>155 herds were already virus positive in phase 2</td>
</tr>
</tbody>
</table>

Phase 1: herds with animals that were born before 1st October 2008, phase 2: herds with animals that were born between 1st October 2008 and 1st October 2009, and phase 3: herds with animals that were born after 1st October 2009.

2.3. Test strategy

Samples were analysed by either enzyme-linked-immunosorbent-assay (ELISA) or real time reverse transcriptase PCR (rtRT-PCR) to detect virus-positive animals. In the case of an initially positive result, the farmer could decide whether to cull the animal directly or to verify the result through a confirmation test. This was done by taking a blood sample and using the rtRT-PCR test. Animals testing negative at the confirmatory test were considered uninfected. Clinically suspect animals and mothers of more than one virus-positive calf were retested if their initial test was negative, if the retest was positive they were considered to be PI animals. In phase 3 (newborn testing and outbreak investigations) it is obligatory to retest animals that test positive. According to scientific literature, the sensitivity and specificity of the ELISA are 98% and 99.8%, respectively; 97.1% and 100% for the rtRT-PCR (Fux, 2007; Hilbe et al., 2007; Wolf et al., 2007; Fux et al., 2007).

In the first phase, the whole Swiss cattle population was tested for BVD virus with the aim of finding and culling all PI animals except those still in utero (phase 1). Official sample takers collected ear-notch samples from all animals on a farm using special ear-tags and sent them to one of the certified laboratories for virus testing. In the case of an inadequate ear-notch sample, a blood sample would subsequently be collected. From when the samples were taken until the results had been reported, the whole herd was placed under movement restrictions. All restrictions were lifted on farms where all animals tested negative; on farms with positive tests, all pregnant females remained under movement restrictions until the end of 2010. Based on modeling (results not shown), comparing different control scenarios, testing newborn calves for BVDV combined with testing mothers of PI-animals was identified as the most efficient approach for the present situation. Therefore, it was decided to prolong the phase until the end of 2011. Starting in 2012, future surveillance will be based on antibody detection. An epidemiological model is being developed to compare different surveillance strategies and will be used to help plan this phase.

2.4. Data analyses

Since the beginning of the programme in early 2008, 2.85 million cattle have been tested (as of September 2010). Information, including date of birth, sex, date of slaughter and laboratory results was available for each animal that was examined. In addition, movement history was...
obtained for each animal. This dataset was divided into two parts: one comprising all tested animals born before the 1st October 2008, which corresponds approximately to all animals that were tested during the initial examination of the whole bovine population in 2008 (phase 1). The other part included all tested animals born after the 30th September 2008, which corresponds approximately to all the newborn calves tested during phases 2 and 3. The first data set provides an insight into the BVD situation at the beginning of the eradication programme whereas the second dataset allows evaluation of the effect of the control measures taken by looking at the distribution of virus positive animals and the prevalence of infected herds in the population.

2.5. Outbreak investigations

In phase 3, when a virus-positive calf is detected, the farm is placed under movement restrictions until detailed outbreak investigations of the potential source of infection have been completed. Mothers of virus-positive animals are retested. If a mother tests negative, animal movements are investigated. The prior and present BVD status of holdings visited by the mother of the infected calf during the pregnancy is checked. When required, animals present on these holdings are retested, including those that left the farm before the investigation. If the supposed source of infection is a summer pasture, all living cattle that visited this pasture are retested (rtRT-PCR on blood or tissue sample). Exceptions are made for animals that have subsequently had a BVD-antigen negative calf or those that have tested negative for BVD more than once.

2.6. Risk factor analysis

In order to target future surveillance on herds most likely to be infected, a risk factor analysis was performed to identify exposures associated with the birth of PI calves in herds previously found to be BVD free (during phases 1 and 2).

A total of 33,188 herds were included in the study. The unit of analysis was the herd and risk factors for herds having one or more PI animals born during the period of interest (since 1st October 2009) were examined. During this period 358 newly infected herds were identified (i.e. at least one virus positive calf was detected in the herd).

Based on a review of the literature, 13 explanatory variables were assessed (Table 2). For each herd, holding details, summer grazing practices, purchasing characteristics and disease history were available from existing databases.

Categorical and quantitative variables were initially assessed using chi-squared tests and t-tests, respectively. Factors with a p-value below 0.05 (two-sided) were further examined in a multivariable logistic regression model. A backward stepwise multivariable logistic regression analysis was implemented, removing variables one at a time, starting with the predictor with the largest p-value. The model with the lowest Akaike’s Information Criterion (AIC) (Harrell, 2001) was selected.

All statistical analyses were performed using R, a language and environment for statistical computing and graphics (R Development Core Team, 2007).

The area under the receiver operating characteristic curve (AUROCC) is a measure of the models ability to discriminate cases and non-cases. Initially, the AUROCC was calculated using the final model fitted and assessed using the original data.

By re-estimating the AUROCC for 150 non-parametric bootstrap samples (Efron and Tibshirani, 1993), it was possible to identify and adjust for any over-optimism in model performance that may be encountered when fitting and validating a model with the same data (Harrell, 2001).

3. Results

3.1. Phase 1 – situation in Switzerland at the beginning of the eradication

Testing the whole Swiss bovine population (animals born before the 1st October 2008) for BVD virus involved testing 1,493,440 animals from 38,009 farms (September 2010). From this 12,092 virus positive animals were detected, corresponding to a prevalence of 0.81%. Of the 7393 positive animals that had a confirmatory test, 6229 were confirmed positive, resulting in a confirmation rate of 84.3%. Regionally, the proportion of virus positive animals ranged from 0.55% to 1.13%. At the farm level, BVDV was detected on 7611 farms corresponding to 20.02% of the herds. The mean number of virus positive animals per holding was 1.6. The maximum number of PI animals on a farm was 14.

More than 80% of virus positive animals were under 2 years old, compared to less than 40% for the test negative animals. The mean age of virus positive animals was 9 months compared to 3 years for non-infected animals. The oldest PI animal was 15 years old.

The mean time elapsed between the last positive laboratory result and the slaughter of the PI animal was 15.7 days. The maximum number of days passed before slaughtering was 298 days. The recommended time between confirmation and slaughter was 2 weeks; however, implementation was at the discretion of the regional veterinary offices.

The mean proportion of sample containers received by the laboratories that were empty due to a failure to correctly collect the ear biopsy at sampling, was 0.83%. Over time, it decreased from an initial value of 1.47–0.52%.

3.2. Phase 2 – newborn calves testing

A total of 711,009 newborn calves (animals born between 1st October 2008 and 30th September 2009) were tested and 5199 virus positive animals were detected (0.73%). Of the 3291 positive calves tested twice, 2862 were confirmed positive, resulting in a confirmation rate of 87%. Regionally, the proportion of PI animals varied between 0.19% and 1.10%. The mean proportion of newborn calves not tested per month was 4.00%; early death accounts for 80% of these calves, the remainder were either untreated or were slaughtered before they could be tested.

Fig. 1 shows newborn calves that were found virus positive as a proportion of the total number of births per month.
Table 2
Variables retained for the multivariable analysis conducted to identify risk factors associated with the birth (after October 2009) of BVD infected calves in herds where no virus-positive animals had previously been detected since the beginning of the eradication programme (early 2008). Data obtained are from the Swiss BVD eradication programme.

<table>
<thead>
<tr>
<th>Group</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holding details</td>
<td>Herd size (number of cattle)</td>
</tr>
<tr>
<td></td>
<td>Herd type (dairy, suckler or mixed)</td>
</tr>
<tr>
<td></td>
<td>Proportion of animals younger than 2 years</td>
</tr>
<tr>
<td></td>
<td>Death rate (rate of newborns experiencing early death – within 15 days – or dead at birth)</td>
</tr>
<tr>
<td>Summer pasturing details</td>
<td>Is summer pasturing practiced (yes or no)</td>
</tr>
<tr>
<td></td>
<td>Number of cattle going to summer grazing</td>
</tr>
<tr>
<td></td>
<td>Number of other holdings that use the same summer grazing pastures</td>
</tr>
<tr>
<td>Purchasing characteristics</td>
<td>Were purchases made (yes or no)</td>
</tr>
<tr>
<td></td>
<td>Number of farms purchases were made from</td>
</tr>
<tr>
<td></td>
<td>Average age of purchased animals</td>
</tr>
<tr>
<td></td>
<td>Are cattle sent to markets or shows (yes or no)</td>
</tr>
</tbody>
</table>

* Categorical variable.

From October to December 2008 this figure reduced from 1.5% to 0.9%. In the following months, the curve settled at around 0.7% until July 2009 onwards when there was a further decrease to 0.15% by September 2010.

The proportion of virus positive calves that were born to cows under movement restrictions, i.e. cows that had potential contact with persistently infected animals, is shown in Fig. 2. In October 2008, only 11% of the virus positive calves originated from cows under movement restrictions, whereas after August 2009, this proportion oscillated between 50% and 72%.

The mean time elapsed between the last positive laboratory result and the slaughter of the virus positive calf was 12.5 days. The maximum for this figure was 311 days.

The proportion of samples received that did not contain an ear-notch sample decreased from 4.4% in October 2008 to 2.0% in September 2010. During this phase the ear-notch-samples were taken by the farmers.

3.3. Phase 3 – newborn testing and outbreak investigations

From 666,785 newborn calves (animals born after 30th September 2009) that have been tested, 1558 virus positive animals have been detected (0.24%) on 823 holdings. In 36% of cases the source of infection has been found by either retesting the mother of the PI calf, investigating animal movements and/or retesting the whole herd.

PI mothers that had incorrectly tested negative during earlier phases were identified in 46 holdings. Other sources of infection were illegal movements (21 cases; 14 pregnant cows and 7 virus positive cases moved from infected herds), false negative animals on the farm (22 cases) and contact with infected neighbouring herds (12 cases).

For 98 holdings, pregnant mothers had contact with false negative animals whilst at summer pasture. On such holdings, 50 PI calves were subsequently born to PI dams (identified by retesting mothers of infected calves); the source of BVDV for a further 61 PI calves born on these holdings was identified as 14 other animals (that tested false negative during prior phases) and not their mothers, these were identified by retesting all animals which visited the 14 summer pastures concerned. There was a strong suspicion of infection acquired at summer pasture for 23 other holdings (as yet unconfirmed). In 64% of cases the source of infection has not been identified. Other sources of infection could be PI animals that had died or been slaughtered prior to the outbreak investigation (and therefore
Indirect transmission by (e.g. by farmers or veterinarians) cannot be excluded. In some cases, molecular epidemiology helped to confirm suspected sources (conducted by the BVD-reference laboratory, Bern). Fig. 3 shows the number of herds (in phase 3) found with BVDV new-born calves per month since 1 October 2009.

3.4. Risk factor analysis

All cattle on eligible holdings in Switzerland with no BVD history in phases 1 and 2 were included (n = 33,188 holdings). Of 666,785 calves born on holdings during the assessed period, 1558 were virus positive. At the herd level, 358 were found to have one or more virus positive animals in phase 3.

The comparison of the mean for infected herds versus herds without detected virus-positive animals provides the following results: herd size (48.3 versus 33.2, p-value < 0.001); percentage of animals younger than 2 years (39% versus 43%, p-value < 0.001); early death rate, i.e. the proportion that either die before 15 days or are stillborn (0.06 versus 0.04, p-value < 0.001); number of animals sent to shared summer grazing (8.2 versus 7.3, p-value = 0.27); number of farms that a holding is connected to via shared summer grazing (10.5 versus 9.8, p-value = 0.47); number of animals from other farms that a holding is connected to via shared summer grazing (162 versus 85, p-value < 0.001); number of farms from which cattle were purchased in 2008 (13.6 versus 7.9, p-value = 0.005); mean age of cattle purchases in days (706 versus 702, p-value = 0.89). Binary variables are shown in Table 3.

Results from the multivariable model are shown in Table 4.

The predictive values were calculated for each herd, using the final model (i.e. the probability of being infected as predicted by the final model). The distribution of the values obtained for herds where no virus positive calves were found in comparison with herds experiencing new infection with virus positive calves in phase 3 is shown in Fig. 4.

The AUROCC was 0.74 for both the original and the bootstrap adjusted sample.

4. Discussion

The campaign, particularly phase 1, has shown that testing a large amount of animals in a short period of time is challenging but possible. During the initial testing of cattle going to pasture (phase 1a), a lot of experience was gained and improvements were made before phase 1b.

The cooperation of the farmers combined with an intense information campaign made them aware of the disease and how best to avoid it. Farmers were able to check the movement restriction status of cattle before purchasing them through the AMD, this was found to be helpful. The high level of awareness amongst farmers helped to keep illegal movements to a minimum; however, some farmers bought pregnant cattle and untested calves that were under movement restrictions that subsequently tested positive. False negative cattle are an issue as they have accounted for 57% of identified sources for newborn virus positive calves.
Table 3
Distribution of BVDV virus-positive (BVDV+) and virus-negative cattle (BVDV−) herds (n = 33,188) for the different categorical variables retained in the multivariable analysis. Data obtained are from the Swiss BVD eradication campaign.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Category</th>
<th>Number of herds</th>
<th>BVDV+ (%)</th>
<th>BVDV− (%)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herd type</td>
<td>Exclusively dairy</td>
<td>27,954</td>
<td>333 (1.19)</td>
<td>27,621 (98.81)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>5234</td>
<td>25 (0.47)</td>
<td>5209 (99.53)</td>
<td></td>
</tr>
<tr>
<td>Herd structure</td>
<td>Community herd</td>
<td>151</td>
<td>7 (4.6)</td>
<td>144 (95.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Non-community</td>
<td>33,037</td>
<td>351 (1.1)</td>
<td>32,686 (98.9)</td>
<td></td>
</tr>
<tr>
<td>Summer pasturing</td>
<td>No</td>
<td>17,368</td>
<td>125 (0.72)</td>
<td>17,243 (99.28)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>15,820</td>
<td>233 (1.47)</td>
<td>15,587 (98.53)</td>
<td></td>
</tr>
<tr>
<td>Purchase</td>
<td>No</td>
<td>3231</td>
<td>11 (0.34)</td>
<td>3220 (99.66)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>29,957</td>
<td>347 (1.16)</td>
<td>29,610 (98.84)</td>
<td></td>
</tr>
<tr>
<td>Market</td>
<td>No</td>
<td>23,949</td>
<td>222 (0.93)</td>
<td>23,727 (99.07)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>9239</td>
<td>136 (1.47)</td>
<td>9103 (98.53)</td>
<td></td>
</tr>
</tbody>
</table>

Table 4
Multivariable logistic-regression of variables associated with new infection of herds based on the detection of virus-positive calves in 2009–2010. Data obtained are from the Swiss BVD eradication campaign.

<table>
<thead>
<tr>
<th>Variables</th>
<th>OR</th>
<th>95% CI OR</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death ratea,b</td>
<td>26.7</td>
<td>5.7–124.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Herd sizea</td>
<td>1.01</td>
<td>1.01–1.01</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Nb other animals contacted via summer grazinga</td>
<td>1.001</td>
<td>1.001–1.001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Purchase (yes or no)</td>
<td>1.87</td>
<td>1.0–3.47</td>
<td>0.048</td>
</tr>
<tr>
<td>Summer pasturing (yes or no)</td>
<td>1.40</td>
<td>1.1–1.8</td>
<td>0.006</td>
</tr>
<tr>
<td>Dairy versus otherc</td>
<td>1.7</td>
<td>1.1–2.6</td>
<td>0.013</td>
</tr>
<tr>
<td>Proportion of animals younger than 2 yearsa</td>
<td>0.28</td>
<td>0.15–0.5</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

a Continuous variable – the odds ratio represents the change in odds for an additional unit.
b Number of deaths (died before 15 days of age or stillborn) per number of newborns per year.
c Baseline category.

During phase 3, by testing newborn calves it is possible to identify infected animals that were previously missed. The results of the outbreak investigations were constantly published in the farming press. This helped to make the farmers aware of both the risk posed by illegal movements and that false negative test results could occur.

Although it has been reported that the fast removal of PIs may be counterproductive (Lindberg and Alenius, 1999), minimising the time it takes for a PI animal to be slaughtered was seen as important for the success of this campaign. The longer a PI remains present in a herd, the greater the risk of transmitting the virus, not only within the herd but also to other farms; this is especially true in Switzerland where farm density is high and cattle movements frequent. The observed average of two weeks from detection to slaughter of PIs seems acceptable (Cherry et al., 1998). Looking at the time elapsed between birth and sampling, the main problem has been the frequency of incorrectly collected samples (where farmers fail to correctly take an ear notch sample), thus delaying the detection of PI animals. Often calves are moved to rearing farms when they are very young; if the test results are not available in a reasonable time, the chance of animals being moved (illegally) without test results increases. This problem also appeared during the initial examination of farms using official sample takers. The rate of empty samples drastically improved within two months (to 0.54%) as official samplers became more familiar with the technique. For the farmers testing newborn calves, the figure was rather high at the beginning of phase 2 (approximately 4.4%), falling to 2.2% within a year. As farmers do not carry out the technique as frequently as official testers they are unlikely to reach the same level of proficiency.

Testing all cattle in Switzerland during phase 1 revealed an overall prevalence of BVDV infection of 0.8%, similar.
to that found in other European countries (Lindberg et al., 2006).

As expected, PI animals were relatively young; however, as more than 10% of PI animals were older than 2 years, it was important to test both young and old animals.

The initial impact of the BVD eradication programme was shown by the reduction in the proportion of newborn calves that were infected with BVD in the months subsequent to the initial testing. The effort made to prevent PI animals going to shared summer grazing in 2008 is reflected by the first reduction in the proportion of virus positive newborn calves from October to December 2008 (see Fig. 1). The further decrease between July and August 2009 shows the impact of testing the whole cattle population. During this phase (phase 1) a large number of PI animals were culled with the effect of reducing BVD transmission and the generation of new PI calves. After this phase, more than 97% of PI animals should have been removed (considering the sensitivity of tests used (Fux, 2007; Hilbe et al., 2007)). The bulk of subsequent PI calves was expected to be born before October 2009 (from cows that became pregnant in December 2008 or earlier and had contact with PI animals before they were culled in phase 1). Therefore, a further reduction in the proportion of infected newborns was expected from October 2009 onwards. However, although a continuous decline in the proportion of infected newborns was observed, from April 2010 the proportion of virus positive calves stagnated at around 0.2%; this was due to ongoing new herd infections.

A positive development is the high proportion of PI calves born from cows under movement restrictions. Although the percentage dropped from 70% in June and July 2009 to around 50% in the following months, it prevented the birth of a considerable number of PI-calves on farms without a history of prior BVD infection. Although in principle restricting the movement of all pregnant cattle would have been ideal in terms of disease control, discussions at the beginning of the programme showed that this would significantly reduce the acceptance of the programme by farmers. Although not all movements of pregnant cattle with virus-positive calves in utero could be prevented, these results highlight the importance of such restrictions; as was the case for other countries, trading cows pregnant with PI foetuses is one of the most important causes of BVD re-infections (Lindberg and Alenius, 1999; Obstirzhauser et al., 2005). Testing newborn calves immediately after birth (within 5 days), minimises the contact that virus-positive animals have with other animals, either on their farm of origin or through movement to other herds. As mentioned, the existence of infected cattle that incorrectly tested negative during prior phases is a cause of ongoing cases of newborn PI calves. False negative results are not only due to the test sensitivity being below 100% (Fux, 2007), but also due to the difficulties encountered during the processing of samples, including sample taking, sample labeling, posting and reporting of the test results. Some of these false negative animals were later detected by clinical suspicion, identification of positive offspring or detection of a virus positive twin sibling; in such cases the potentially false negative animals were re-tested. When false negatives were detected it was important to investi-
power of the model in order to target farms at risk in the future.

One potential source of bias in the risk factor analysis could be the immune status of the herd. A farm may get away with high-risk activities if it has a high level of immunity. Furthermore, the risky activities that expose the holding to BVD may lead to immunity, thus factors that would be expected to increase the risk of disease may conversely also have a protective effect due to the immunity that exposure causes. This explanation was also proposed by Houe et al. (1995). A lack of strong risk factors shortly after "eradication", when levels of immune protection are still high, has been observed before (Goyal and Ridpath, 2005).

5. Conclusion

The success of a large scale programme has been dependent on, amongst other things, thorough preparation and effective communication before and during the programme. The use of ear-tag tissue sampling kits has been logistically much easier than using blood samples. A preliminary phase helped all parties involved to gain experience and gather useful information, thus avoiding problems later on when the programme was scaled up to the national level (e.g. during sampling, testing, and collection, collation and reporting of results). The use of a central database was crucial to the programme, allowing better control over data quality and improved programme management in general. This database also facilitates further data analysis with the aim of improving the efficiency of future BVD surveillance.

Blocking the movements of pregnant cattle was found to have a large impact on the spread of disease, reducing the transmission of infection to other herds.

The outbreak investigations in phase 3, with an emphasis on retesting mothers of PI-calves, were highly efficient and have prevented a large number of new infections. Ideally this procedure should have started earlier to speed up the eradication; however, further resources were not available during the intensive first two phases of the campaign.

Conflict of interest statement

None of the authors of this paper have a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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