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Factors associated with cattle necropsy submissions in Switzerland, and their importance for surveillance

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A R T I C L E I N F O

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A B S T R A C T

Pathology data have been reported to be important for surveillance, as they are crucial for correctly recognizing and identifying new or re-emerging diseases in animal populations. However, there are no reports in the literature of necropsy data being compared or complemented with other data. In our study, we compared cattle necropsy reports extracted from 3 laboratories with the Swiss fallen stock data and clinical data collected by the association of Swiss Cattle Breeders. The objective was to assess the completeness, validity and representativeness of the necropsy data, as well as evaluate potential factors for necropsy submission and how they can benefit animal health surveillance. Our results showed that, on average, 1% of Swiss cattle that die are submitted for post-mortem examinations. However, different factors influence cattle necropsy submissions, such as the age of the animal, the geographical location and the number of sick and/or dead animals on the farm. There was a median of five animals reported sick and two animals reported dead within 30 days prior to a necropsy submission, providing quantitative evidence of a correlation between on farm morbidity/mortality and post-mortem examination. Our results also showed that necropsy data can help improve the accuracy and completeness of health data for surveillance systems. In this study, we were able to demonstrate the importance of veterinary pathology data for AHS by providing quantitative evidence that necropsied animals are indicative of farms with important disease problems and are therefore critically important for surveillance. Furthermore, thanks to the amount of information provided by combined data sources, the epidemiology (e.g. season, geographic region, risk factors) of potential diseases can be analysed more precisely and help supporting animal health surveillance systems.

1. Introduction

In recent years, many new data sources, including data collected in near-real-time have become available for animal health surveillance (AHS) (Dórea and Vial, 2016). Clinical data (Anholt et al., 2014), production data (Veldhuis et al., 2016), and laboratory data (Dórea et al., 2013) have value for supporting early disease detection and strenghtening animal health surveillance (AHS) systems. Data related to dead animals such as data collected at the slaughterhouse (Dupuy et al., 2013; Vial and Reist, 2015), mortality data from fallen stock (Perrin et al., 2012; Santman-Berends et al., 2016; Struchen et al., 2017; Tapprest et al., 2019), or necropsy reports from veterinary diagnostic laboratories (Küker et al., 2018; O'Toole, 2010; Tapprest et al., 2019) also provide many opportunities for AHS. The latter are especially of interest because post-mortem examinations are an important diagnostic tool, and have been demonstrated to add value to clinical diagnoses (Wäsle et al., 2017). Necropsy reports contain information of value for AHS including information about the cause of death, underlying pathologies, associated information about the geographic location of the farm, breed, age, sex, and weight of the submitted animals, and information about other

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examinations (Dórea and Vial, 2016). Using data associated with post-mortem examinations has the potential for improving diagnostic approaches, monitoring changes in disease prevalence and incidence, as well as implementing targeted disease control programs (Küker et al., 2018; Tapprest et al., 2019). However, the value of necropsy reports, especially in terms of whether they are representative of a livestock population is still unknown (Küker et al., 2018).

The value of a data source for AHS can be assessed using different attributes. Data completeness and validity are important criteria to ensure that the collected data are meaningfull (European Centre for Disease Prevention and Control (ECDC), 2014). The representativeness of a source of information is an important attribute as it indicates whether the data source accurately describes the occurrence of a health-related event over time and its distribution in the population (European Centre for Disease Prevention and Control (ECDC), 2014). If data of the same animal/population are recorded in different data sources, differences can help identify bias in measurements and/or changes occuring in the population. Combining and comparing information reported in different data sources can be used to better assess the completeness, validity and representativeness of a data source for AHS. This can also help develop a more complete picture of a production system, confirm or refute previously established diagnoses, or provide additional information to accurately assess spatiotemporal patterns and trends. Many studies have shown that combining multiple routinely collected data from passive and active surveillance systems can be beneficial for early disease detection and trend monitoring, as each data source provides specific information about the animal population of interest (Alba et al., 2015; Küker et al., 2018; Santman-Berends et al., 2016). Combining multiple sources of information may help improve our knowledge of the quality and/or reliability of the data used (European Centre for Disease Prevention and Control (ECDC), 2014).

Over the last few years, efforts have been made in Switzerland to assess numerous data sources of potentiel interest for AHS (Küker et al., 2018; Muellner et al., 2015; Struchen et al., 2017, 2015; Vial and Berezowski, 2015; Vial and Reist, 2015; Vial et al., 2016). This aligns with the aims outlined in the Swiss Animal Health Strategy 2010+, where enhancement of the overall animal health surveillance capacity within the country was defined as a priority. Most of these efforts have focused on cattle as cattle are one of the most important livestock populations in Switzerland. As of June 30th 2019 there were approximately 1.5 million cattle in Switzerland (https://tierstatistik.identitas.ch/de/cattle) and the main production type was dairy (Schärrer et al., 2014). Many different data sources related to Swiss cattle have been collected and are stored centrally. However, many have never been combined or compared, leaving an unexplored opportunity to better understand the value of each data source for AHS.

The objective of our study was to compare information extracted from post-mortem examinations performed in three Swiss veterinary pathology laboratories to information reported to two national databases – the mortality database of Swiss cattle (Tierverkehrsdatenbank, TVD) and a clinical database (Association of Swiss Cattle Breeders, ASR) containing cattle health related data. In a first step we evaluated the completeness and validity of the necropsy data. In a second step, we combined information extracted from the three necropsy datasources, and investigated factors associated with necropsy submissions at three different levels – "national", "farm" and "individual" – and according to age, region and time of the year.

2. Material and methods

2.1. Data sources

2.1.1. Necropsy data

Cattle necropsy reports were collected from three of five Swiss veterinary diagnostic laboratories performing necropsies on cattle, over a period of six years (2012–2017). The three laboratories were the Institute of Animal Pathology (ITPA) of the University of Bern, the Institute for Veterinary Pathology (IVP) of the University of Zürich and the Food Safety and Animal Health Office (ALT) of the Canton of Graubünden.

The data from ITPA and ALT were automatically extracted as Microsoft Excel (Microsoft Excel MSO 64-bit, 2016) files from their respective user software. The reports from IVP were initially provided as Microsoft Word (Microsoft Office 365 MSO 32-bit, 2016) documents. The reports were first automatically converted to plain text, ignoring the layout information because the structure of these reports changed many times during the study period. Reports were then split into 13 predefined sections (e.g. "necropsy findings" and "morphological diagnoses") using regular expressions, which were sequences of characters defining a search pattern.

All three necropsy datasets contained various information about the animal (e.g. breed, sex, weight, age), the farm (e.g. owner address, premise ID, identification number), as well as diagnostics performed on the submitted carcass (e.g. virology, parasitology). However, the three necropsy datasets differed in layout, content and format. The data were cleaned and standardized to allow combination and comparison of the three datasets. The animal and premise identification (ID) numbers were cleared of characters and punctuation. Age was reported as the date of birth or the number of months or years. Characters and punctuation in age variables were removed or homogenized in order to allow categorization of cattle into five age groups: Abortions (including stillbirths), Neonates (0–28 days), Juveniles (1–6 months), Young Adults (6 months – 2 years) and Adults (> 2 years). Sex was harmonized by adapting genders to f (= female) and m (= male). Breeds were categorized into the following types: dairy, beef, mix (dual-purpose cattle breeds) and undefined (breeds which could not be classified into one of the before mentioned groups) (the complete list is available in supplementary material 3).

The three datasets were then combined, keeping only variables of interest, including animal and farm identification, age, sex and geographical location.

2.1.2. On-farm mortality data (TVD)

Since 2000, every non-slaughter cattle death in Switzerland is required to be reported to a national database (Tierseuchengesetz, 2018)[2] . This database (Tierverkehrsdatenbank (TVD)), is a cattle identification and traceability database. It has a good geographic coverage and timely reporting of deaths (Struchen et al., 2015). It is composed of two distinct datasets: one for non-slaughter on-farm deaths (for purpose of simplicity only called "on-farm deaths") and one for stillbirths and abortions. Every on-farm death (slaughter excluded) must be reported to the TVD by the owner of the animal within 3 days (Animal Diseases Ordinance (ADO), 916.401). Stillbirths and abortions are reported to the TVD by the farmers, but they are not required to by law. By definition, an abortion is the expulsion of an immature, non-viable foetus before the end of a normal gestation period (Ordonnance on epizootic diseases (OED); Art. 6z[bis55]). A stillbirth is defined as a progeny which is stillborn after a normal gestation period or dies within 24 h after birth (OED; Art. 6z[ter56]). All animals within the TVD are reported using the premise ID of their death location. This also applies to animals that died in one of the veterinary clinics (Bern & Zürich). However, it must be noted that the location of death and the location of the farm that owned the animal are not always the same, as the animals do not always die at the location where the animals are owned.

Our study included 508,702 on-farm deaths and stillbirths (incl. abortions) reported to the TVD database between 1st of January 2012 and 31st of December 2017. As the TVD data does not differentiate between stillbirths and/or abortions, they were combined into one variable named "abortion/stillbirth" for this study. The dataset provided

[2] See https://biblio.parlament.ch/e-docs/393874.pdf (German)

information on identification numbers (animal ID and ID of the farm that owned the animal at the time of death), birth and death dates and location, and the identification number of the calf's mother for stillbirths. Data was classified into the same age groups as the necropsy data.

2.1.3. Clinical data (ASR)

The Association of Swiss Cattle Breeders (ASR)[3] collects production performance and clinical data from three cattle breeds (Braunvieh, Holstein, and Fleckvieh) in Switzerland. For this study we only used ASR clinical data which consisted of clinical diagnosis and treatments recorded electronically, on a voluntary basis by farmers or veterinarians.

The clinical dataset provided by ASR contained 246,237 reports (from 1st of January 2013 to 31st of December 2017). It included data about the farm and individual animal identification numbers, date of record entry, illness, treatment, and predefined age categories. The age categories were: Abortion (= different types of foetal deaths), Calves (< 6 months) and Adults (> 6 months).

Comparison between necropsy and ASR data was made using only data collected after January 2013. The ASR database did contain reported cases for 2012, however these were very few in number as 2012 was the first year of implementation of the database. The authors therefore decided to exclude the 2012 data from analysis.

2.2. Data quality and descriptive analysis of the necropsy data

Data quality was assessed by evaluating the completeness, and validity of the data, focusing on the following variables: sex, age, postal code, production type, and individual animal and farm identification numbers. Completeness was assessed by checking for missing values. Identification numbers were considered complete if they consisted of 7 (for the premise ID) or 12 digits (individual animal ID).

Validity related to whether the information recorded about the cases was correct (European Centre for Disease Prevention and Control (ECDC), 2014). The validity of ID numbers was assessed by comparing the IDs recorded in the necropsy data with those recorded in the TVD data. The TVD database is considered the gold standard for animal and premise ID numbers in Switzerland, as farmers and others (for example veterinarians) are required by law to record location such as premise ID or veterinary clinic ID, and cattle IDs to this database. When the ID numbers reported in the necropsy data were not found within the TVD data, these IDs were considered invalid. When valid animal IDs were identified, they were used to identify a subset of pathology submissions that were used to estimate differences between the information in terms of age group classification and postal codes reported in the two datasets. The date of death reported in the TVD data and the date of necropsy were also compared.

Descriptive statistics focused on the spatiotemporal distribution of necropsied cases per age group, sex and production type. The percentage of necropsied on-farm dead animals per canton was assessed by calculating the total number of necropsied animals divided by the total number of on-farm dead animals multiplied by 100.

2.3. Comparison with on-farm mortality and clinical data

Comparison between the necropsy data and the two other datasets was performed at a national, farm, and animal level. Abortions/stillbirths and on-farm deaths (for both necropsy and mortality data) were considered separately, as the TVD dataset consisted of two separate databases: on-farm dead and abortions/stillbirths.

2.3.1. National level

2.3.1.1. On-farm dead cattle. Logistic regression models were fit to the data to determine the association between age, canton of origin, linear trend, season and alpine pasture (explanatory variables) on the proportion of on-farm dead cattle submitted for necropsy (outcome variable). The outcome variable was a binary variable aggregated at the monthly, cantonal and age group levels. The two values were: 1) the on-farm dead animal that was recorded in the TVD dataset was submitted to a laboratory for necropsy, or 2) the on-farm dead animal was not submitted for necropsy. The period on alpine pasture was defined as a binary variable where the animals were considered to be on alpine pasture between June and September and on the farm for the rest of the year. Seasonality was modelled using months grouped into four seasons: spring (March, April, May), summer (June, July, August), autumn (September, October, November) and winter (December, January, February).

2.3.1.2. Abortion/stillbirth. Because it was not mandatory to report every abortion or stillbirth to the TVD database, regression models were fit to the number of abortions/stillbirths submitted for necropsy. Because this outcome variable consisted of over dispersed count data, negative binomial regression models were used. As in the previous section, the outcome variable was aggregated at the monthly and cantonal levels. The explanatory variables were the number of necropsied abortions/stillbirths reported to the TVD database at the country level per month and canton, the canton of origin of the abortion submitted for necropsy, the trend, season and alpine pasture. Season and alpine pasture were defined as explained in the previous section.

For both the mortality and abortion/stillbirth models, we performed bivariate analyses to assess the association between each independent variable and the outcome variable (animal sent to necropsy). Likelihood ratio tests were used to test for the significance of each predictor by comparing each univariate model with the null model (i.e., model with zero predictor). When the p-value of the likelihood test was equal to or below 0.025, the predictor tested was included in the multivariate model. To identify the final model, all possible combinations of the predictors previously selected were tested. Nested models were compared using a likelihood ratio test with a p-value of 0.05 as cut-off value. When the p-value was above 0.05, the two models compared were considered equivalent and only the most parsimonious model was kept for the rest of the analysis.

2.3.2. Farm and animal level

Due to missing or falsely transcribed animal ID's, and a big discrepancy between the necropsy and TVD reporting of premise ID's, a statistical comparison similar to that done at the national level was not possible. We chose a simpler approach, by joining the combined necropsy dataset with the TVD and ASR datasets using the premise and the animal ID (see supplementary material 1).

At the farm level, we assessed whether a submission for necropsy was associated with an excess of on-farm dead or sick animals by computing the number of reported deaths and sick animals for each farm on which a necropsy submission occurred, for three time windows: 7, 14 and 30 days prior to necropsy. Comparison of on-farm mortality and on-farm sick animals was done using validated premise ID's. Differences in necropsy submissions between farms that were members of ASR and those that were not members of ASR was also assessed. Farms which reported cases to ASR were classified as ASR-farms. The average number of animals submitted for necropsy by ASR-farms was compared to the average number of animals submitted by non-ASR farms using a *t*-test. The type of animals submitted for necropsy by ASR-farms was compared to the type of animals submitted by non-ASR farms using chi-square test.

For the animal level analysis, we investigated the number of treatments received per animal prior to its necropsy. Comparison was made

[3] See https://asr-ch.ch/en/asr/

by combining the necropsy and ASR datasets using complete animal ID's (see supplementary material 1). For every necropsied animal submitted by an ASR-farm, the number of treatments received prior to post-mortem examination was determined.

All statistical analyses were performed in R Version 3.6.1 (R Core Team, 2017) using the package {lmer} (Zeileis and Hothorn, 2002).

3. Results

3.1. Data cleaning and quality assessment

After cleaning and merging the three necropsy datasets, a total of 3981 cattle deaths and abortion/stillbirths combined, from 1978 different farms were included in the analysis. The overall completeness of the necropsy data ranged from 58.7 % (for premise ID) to 99.3 % (for postal code) (see Table 1). Abortions/stillbirths and on-farm dead animals are reported separately.

3.1.1. On-farm dead animals

For the on-farm dead animals, 2858 out of 3489 reports had a complete 12-digit animal ID reported (see Table 1). These were then compared to the TVD data, where a total of 2330 (81.5 %) animals had a valid animal ID. The subset of 2330 necropsied animals that were found in the TVD database was used to estimate the validity of the information recorded in the necropsy reports. Most of them (94.6 %) had the same age classification recorded in both datasets. The time difference between the date of death reported in the TVD and date of necropsy was less than 3 days for 94.7 % of the animals. Comparison of postal codes and premise ID's at the time of death was done after validation of animal ID's. The postal code and premise ID of death recorded in the two datasets were different for 78.8 % and 89.4 % of the animals respectively. Additionally, only 54.8 % of the canton names were the same in the two datasets. Complete entries for the sex of the animal were computed based on the number of non-missing entries (n = 3489).

3.1.2. Abortions/stillbirths

There were 492 abortions in the necropsy data, of which 200 had a valid dam ID present in the TVD data. Nine of these cows had 2 or 3 abortions reported within the TVD data during the study period. We considered that abortions reported within the TVD database and occurring more than 200 days before or after the submission of an abortion to a necropsy laboratory were not linked to the same event. Using this decision rule, 76 abortions were matched between the necropsy and the TVD datasets. The 124 remaining abortions (62 %) sent to necropsy were not recorded in the TVD. For the 76 matched abortion necropsy cases, a high consistency between the two datasets was observed. The time difference between necropsy submission and date of abortion reported in the TVD data was below 6 days for 92.5 % of the reports and approximately 95 % of the reports had the same postal code reported in both datasets. The premise ID number was missing in 62.8 % of the necropsy reports, but when the premise ID was present, it was the same premise ID for 95.7 % of the TVD data.

Table 1
Complete and valid entries for on-farm dead animals and abortions, after comparison between necropsy and TVD data. Valid entries were calculated as a percentage of the complete entries.

		Complete entries	Valid entries
On-farm dead animals (n = 3′489)	Age	93.7 %	94.6 %
	Sex	96.4 %	NA
	Animal ID	81.9 %	81.5 %
	Premise ID	56.5 %	68.6 %
	Postal code	99.3 %	NA
Abortion (n = 492)	Dam ID	44.7 %	96.0 %
	Premise ID	37.2 %	30.2 %
	Postal Code	99.8 %	NA

3.2. Descriptive statistics of necropsy data

Most necropsies of on-farm dead animals came from the cantons of Zürich (ZH, n = 923) and Bern (BE, n = 887). However, when looking at the percentage of on-farm dead animals that were necropsied, the canton of Zürich still had one of the highest (3.1 %), as did the canton of Basel (BS, 5.1 %). But in the canton of Bern only 1.3 % of on-farm dead animals were necropsied (see Fig. 1 and supplementary material 7 for canton abbreviations). Most necropsies of abortions (n = 492) also came from the cantons of Bern (n = 191) and Zürich (n = 168). Zürich had the highest percentage of necropsied abortions compared to the total number of abortions/stillbirths reported in the TVD (1.6 %), followed by Ticino (TI, 0.6 %) and Bern (BE, 0.5 %) (see Fig. 2 and supplementary material 7 for canton abbreviations).

The most frequently submitted age group was Adults (n = 1,865, 56.8 %), followed by Juveniles (571; 14.3 %), Abortions (492; 12.3 %), Neonates (466; 11.7 %) and Young Adults (365; 9.1 %). A total of 222 cases (5.5 %) could not be classified due to missing age information. In all age groups, except for abortions, females represented more than 53 % of the cases. In the abortion category, males and females were distributed more or less evenly, with one third of the cases missing the gender. The highest male percentage of all age groups (42.5 %) was seen in the Juvenile group, with the ratio males to females being nearly 1:1.

The largest proportion of necropsied animals were dairy cattle breeds (51.7 %), which also represented the largest production group within all age categories except for abortions. Beef and mixed breeds represented 8.7 % and 16.9 % respectively of the necropsy cases. The remaining reports (22.5 %) could not be categorized into any production type. Most of the necropsied dairy and beef cattle came from the canton of Zürich (dairy = 456, beef = 93). Dual-purpose breeds and breeds that were classified as "undefined" originated mainly from the canton of Bern (n = 226 and 270, respectively).

3.3. Datasets comparison

3.3.1. National level

3.3.1.1. On-farm dead cattle. The canton of origin for on- farm dead cattle was excluded from the analysis because of the uncertainty regarding the place of death of the animals. Results of the univariate analysis indicated that animal age ($p < 0.001$), season of death ($p < 0.001$), alpine pasture ($p = 0.026$) and linear trend ($p < 0.001$) all had statistically significant associations with an on-farm dead animal being submitted for necropsy. Animal age, and alpine pasture were the only statistically significant variables that remained in the final selected multivariable model (see supplementary material 2). On average, one out of 102 (approx. 0.97 %) on-farm dead cattle in Switzerland was sent for necropsy to one of the three laboratories included in the study. The odds of an on-farm dead adult cattle being sent to necropsy was 8.64 (95 % Confidence Interval [CI] = 7.81–9.58) times greater than for neonatal calves (see supplementary material 3). The odds of an on-farm dead cattle being sent to a necropsy laboratory outside of the alpine pasture season was 1.11 (95 % CI = 1.03–1.20) times higher than during the alpine pasture season.

3.3.1.2. Abortions/stillbirths. The six cantons (Appenzell Ausserrhoden (AR), Geneva (GE), Basel City (BS), Glarus (GL), Nidwalden (NW), Obwalden (OW)) that didn't submit any abortion/stillbirth cases for necropsy during the study period were removed from the abortion/stillbirth analysis. The results of the univariate analysis indicated that canton ($p = < 0.001$), number of abortions/stillbirths reported to the TVD dataset ($p = < 0.001$), and linear trend ($p = 0.001$) had statistically

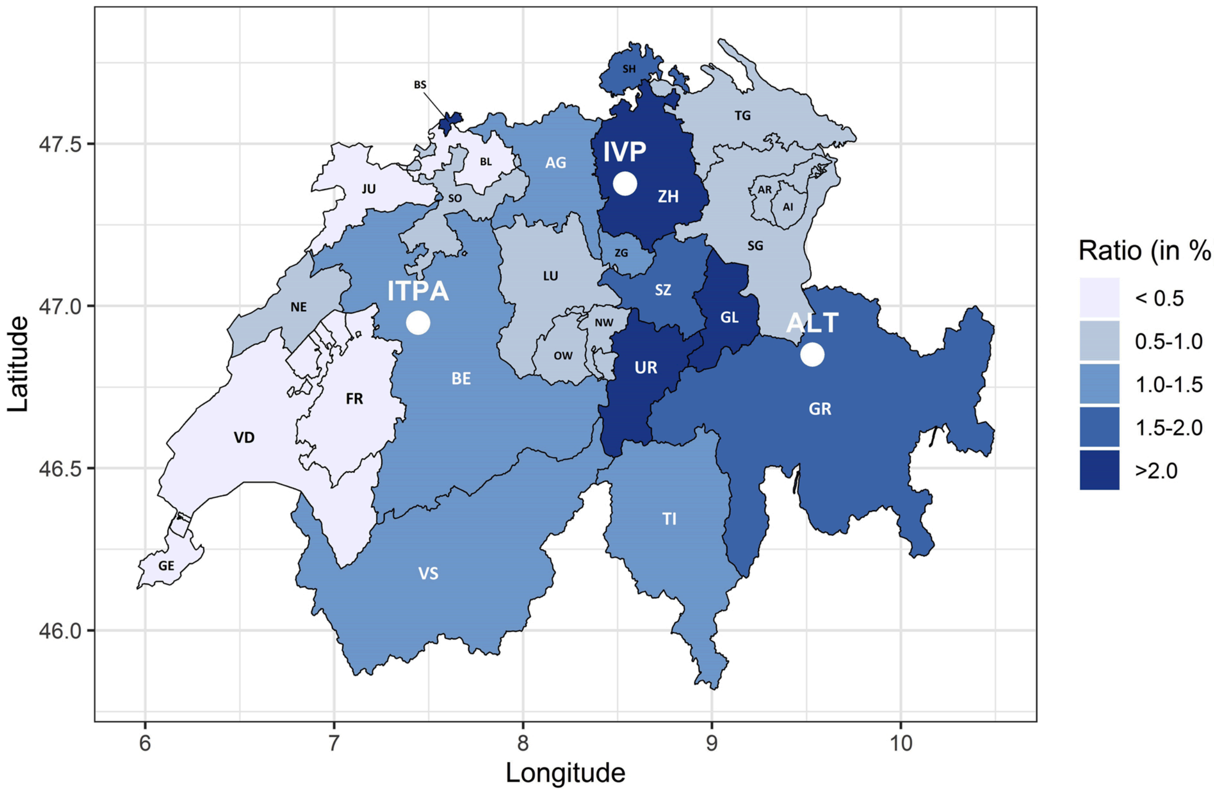

Fig. 1. Map showing the percentage of necropsy cases of on-farm dead animals collected between 2012 and 2017. The ratio was calculated by dividing the total number of necropsied cattle (excluding abortion) to the total number of on-farm dead cattle reported in the TVD.

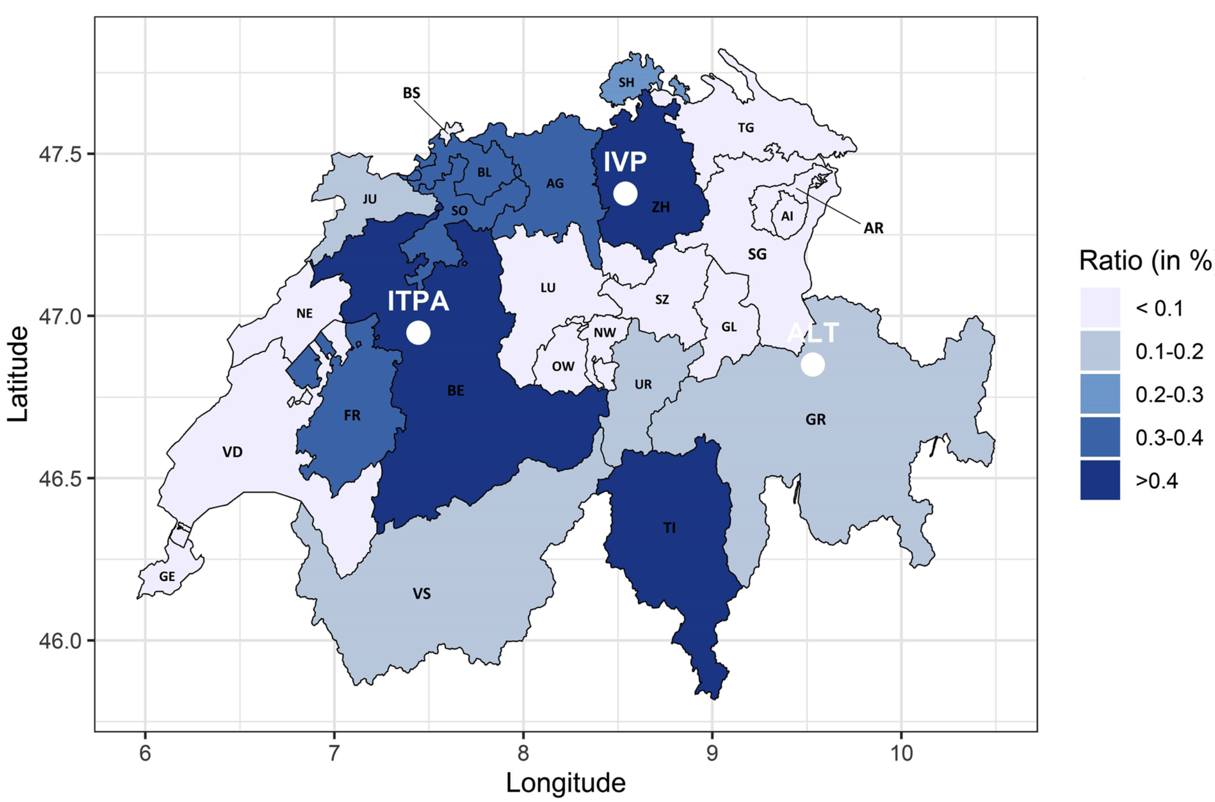

Fig. 2. Map showing the percentage of necropsy cases of abortions/stillbirths collected between 2012 and 2017. The ratio was calculated by dividing the total number of necropsied abortions to the total number of on-farm abortions/stillbirths reported in the TVD.

significant associations. The variables season (p = 0.483), and alpine pasture (p = 0.625) were not significant. The canton of origin, the linear trend, and the number of abortions/stillbirths reported within the TVD dataset were all statistically significant in the multivariate model (see details in supplementary material 4). The association between the number of abortions/stillbirths sent to necropsy and number of abortions/stillbirths reported to the TVD dataset was however small. The number of abortions/stillbirths submitted to necropsy increased on average by 0.003 for each abortion/stillbirth reported in the TVD dataset. A slight decreasing linear trend in the number of abortions/stillbirths submitted for necropsy was also identified over the entire study period (-0.015 abortions/stillbirths sent to necropsy per month). The canton of origin had the largest influence on the number of abortions/stillbirths sent for necropsy. The cantons submitting the greatest number of abortions/stillbirths were the cantons of Zürich (ZH) and Bern (BE) (see Fig. 2 and supplementary material 4). The cantons of Zug (ZG), St. Gallen (SG) and Appenzell Innerrhoden (AI) submitted the smallest number of abortions/stillbirths for necropsy to the three laboratories, in addition to the cantons that never submitted an animal for necropsy (see above).

3.3.2. Farm level

The median number of dead animals on a farm (excluding abortions/stillbirths) within 7 and 14 days prior to and after a necropsy submission, was one (range: 1–20) (see Fig. 3). For the period of 30 days before or after a necropsy, the median number of dead animals was 2 (range: 1–39) (see Fig. 3).

The analysis of the ASR data showed that a total of 10,699 animals were reported within the ASR data by farms that also submitted animals to necropsy. On an individual animal level, only a small proportion of necropsied cases were recorded within the ASR data (4.2 %). Among the farms with a complete premise ID number (n = 1971), 13 % (n = 261) reported cases to the ASR database. These 261 ASR-farms submitted 24 % (n = 331) of the animals necropsied from farms with a valid premise ID number (n = 1352). The remaining 76 % of the cases were submitted by farms defined as non-ASR farms. A significant difference was observed between the two types of farms (ASR-farms and non-ASR-farms) regarding the average number of animals submitted for necropsy (p-value = 0.02): In total, 9.8 % of all farms within the ASR data submitted more than one animal for necropsy. ASR farms submitted on average 1.27 cases per farm whereas non-ASR farms only submitted 1.12 cases on average per farm.

Differences were observed in the type of animals submitted for necropsy by the two types of farms. ASR farms submitted a significantly higher proportion of abortions/stillbirths and neonatal calves for necropsy compared to non-ASR-farms (p-value Chi-square tests respectively equal to <0.00001 and 0.0004). The ASR-farms submitted 14.9 % of all necropsied abortions/stillbirths and 18.1 % of all necropsied neonatal calves, whereas the non-ASR-farms submitted only 7.4 % and 10.9 % respectively. The non-ASR-farms submitted a significantly higher proportion of all necropsied adult and young adult cattle than ASR-farms (p-value Chi-square tests 0.002 and 0.036 respectively). The proportion of all adult cattle submitted for post-mortem examination by non-ASR-farms was of 52.1 %, and 9.9 % for all necropsied on-farm dead young adults. The ASR-farms only submitted 42.6 % and 6.0 % of all necropsied adult and young adults, respectively. The proportion of all on farm juvenile animal submissions was similar for the two types of farms (p-value Chi-square test 0.875).

The number of animals reported sick (including abortions) per farm prior to a necropsy submission was assessed for the 261 ASR-farms included in the study. The median number of animals reported sick prior to a necropsy submission varied depending on the time frame: seven days prior to a necropsy submission, there were a median of two animals reported sick on the same farm (range from 1 to 28), whereas 14 days and 30 days prior to necropsy submission a median of three and five animals were reported sick, respectively (range from 1 to 30 and 1–39, respectively)(see Fig. 4). For 24 of these ASR-farms (9.2 %), there were more than 10 animals reported sick 30 days prior to necropsy submission. The median number of treatments received by the animals reported sick on the farm prior to necropsy submission was on average 1 and ranged between 1 and 5. Most necropsied animals were treated only once before submission and only 23 % of these cases received more than one treatment.

3.3.3. Animal level

Among the 331 animals submitted for necropsy by ASR-farms, only

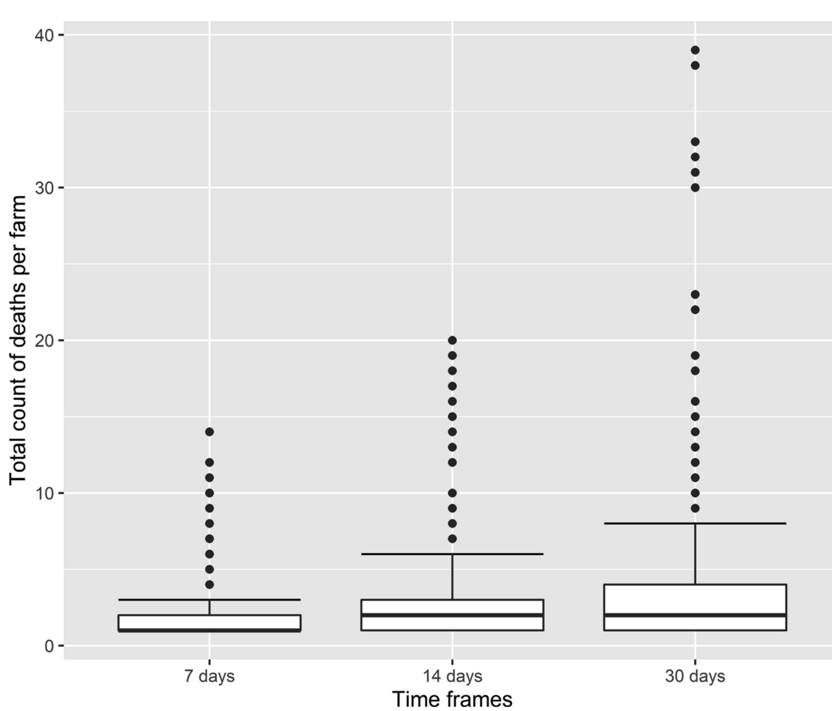

Fig. 3. Boxplot of the distribution of on-farm mortalities (excluding abortions/stillbirths) on farms within 7, 14 and 30 days prior to a necropsy submission.

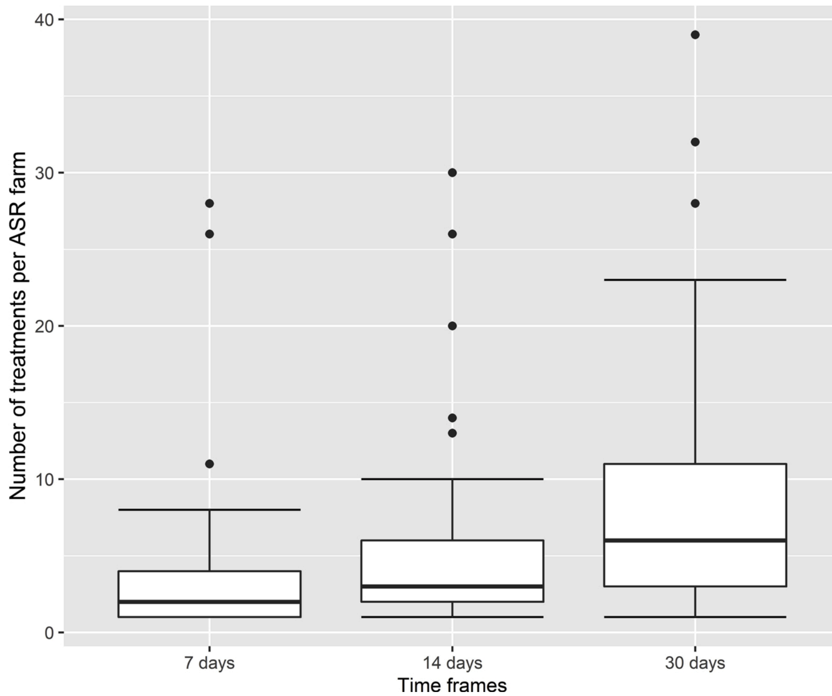

Fig. 4. Boxplot of the distribution of treatments on ASR farms, for the same time periods as defined for Fig. 4.

123 (37 %) were reported sick within the ASR data prior to submission. The overall number of treatments received by these animals ranged from 1 to 16 (one case), with a median of one treatment per animal over the whole study period. The last treatments recorded in the ASR data occurred on average 198 days (median: 115 days) before submission for necropsy with 53.6 % of the treatments recorded within 30 days prior to necropsy. In 22.7 % of the cases (n = 28), the necropsied animal was treated more than once (range 1–5) within seven days prior to necropsy submission and up to 7 times within 30 days prior to necropsy (range 1–7; see Fig. 5).

4. Discussion

In this study, we identified different factors that influence the submission of cattle for post-mortem examination, such as age, geographic location or season, by combining data from different sources such as necropsy report, clinical and mortality data. The necropsy reports in our study contained a large amount of information, with high completeness for geographical data. We were also able to show that during the study period abortions/stillbirths were inadequately reported within the Swiss cattle population, as there was a very low association observed between

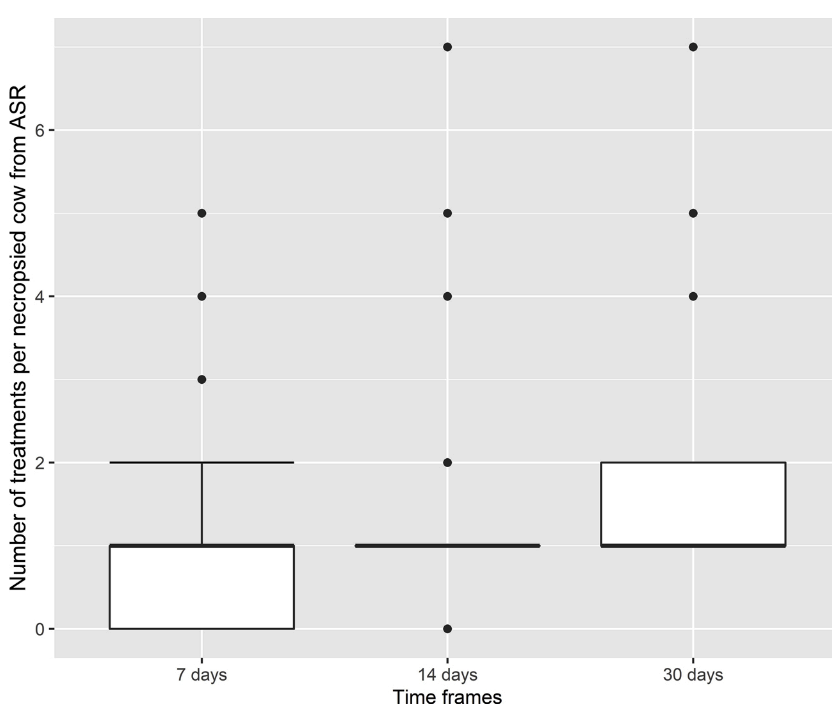

Fig. 5. Boxplot of the distribution of treatments per necropsied cow, for the same time periods as defined for Fig. 4.

the number of abortions/stillbirths sent to necropsy, and the number of abortions/stillbirths reported to the TVD.

Necropsies are an important tool in veterinary medicine to investigate causes of death, refute or confirm clinical diagnoses, or monitor (re-)emerging diseases in animal populations (Nietfeld, 2010; Wäsle et al., 2017). Unfortunately, these data often lack timeliness or information on previous health events. They are often a biased sample as they are not representative of the population (Dórea and Vial, 2016), and are therefore not well suited for a single, population-wide surveillance system. However, previous studies have demonstrated that necropsy data contain a lot of information that could provide valuable additional information for AHS, such as geographical data or the causal agent of a disease (Küker et al., 2018; Warns-Petit et al., 2010). A possible approach for using necropsy data for surveillance purposes could be to combine these data with other animal health related information (e.g. clinical data). This could improve the accuracy and completeness of health data for surveillance systems. In this study there was a median of two dead and five sick animals on each farm 30 days prior to a necropsy submission, suggesting there may have been an underlying on farm health problem which lead to the necropsy submission. With an average dairy herd size of 26 animals (Swissmilk[4]), this would mean that approximately 8% and 20 % of the herd were dead or sick, respectively prior to a necropsy submission. For such small herds, these numbers are significant, and to our knowledge have not been reported before. This study provides quantitative evidence that some necropsied animals come from farms with an existing, often significant health issue. These data could be used to help assess health and disease status at the herd level and could be used to help develop tools to support clinicians in establishing a differential diagnosis. For example, assessing whether the clinical observations and diagnostics made on-farm prior to a necropsy submission are consistent with pathological findings. These findings could be used to develop decision-making tools for clinicians. As the health of an animal is also a welfare issue, an unhealthy or sick animal could indicate a possible management problem on the farm.

Most of the animals submitted for necropsy in our study were adults. However calves and young animals were under represented compared to the overall Swiss cattle population (Schärrer et al., 2014) and to previously reported overall cattle mortality (Struchen et al., 2015). The low proportion of calves submitted for necropsy in our and other studies may be explained by the type of cattle in Switzerland being mostly dairy cattle. Calves from dairy cattle are often seen as by-products of milk production, which end up as fattening calves for veal production (especially the males) and are economically of lesser value. In some cases, female calves will be used as replacement for dairy herds. Most adult cattle usually have a higher economic value than calves and for this reason are more likely to be submitted for necropsy (Wäsle et al., 2017). However, the costs of transport and necropsy submission may outweigh the benefits, and farmers may opt for slaughter or euthanasia of the animal without having a necropsy performed. Our results suggest that cattle necropsy reports are of higher value for disease surveillance in adults but may have less value in younger animals. These results should be interpreted with caution, as not all Swiss veterinary laboratories were included in this study. Except for the two university pathology laboratories, most other veterinary pathology laboratories are not equipped to receive adult cows for necropsy except in ill-equipped rendering plants and are therefore only able to necropsy calves and abortions/stillbirths. This may indicate that there were more young animals necropsied than in our study, and representativeness could therefore be improved by including more laboratories in further studies.

Abortions/stillbirths were analysed independently, as they were recorded individually within the mortality data. The association between the number of abortions submitted for necropsy and the number of abortions/stillbirths reported to the TVD was low. This result may be because not all pathology laboratories that perform necropsies on abortions/stillbirths in Switzerland were included in our study. However, in our study 62 % of the 200 abortions/stillbirths submitted for necropsy with a valid dam ID were not reported to the TVD. This percentage was calculated based on a relatively small number of cases, but it highlights the level of under reporting of abortions/stillbirths to the TVD. These results may be due to reporting of abortions and stillbirths to the TVD not being mandatory in Switzerland. Making reporting of abortions/stillbirths compulsory may help to produce a better estimation of the true numbers of abortions/stillbirths occurring in the cattle population. However, mandatory reporting programs are known to be difficult to enforce as illustrated by the example of the mandatory reporting system of cattle abortions in France, which suffers from a high level of underreporting (Bronner et al., 2014, 2013). Our results demonstrate that necropsy reports can provide additional information on the occurrence of abortions and stillbirths in Switzerland, as the submitted cases for post-mortem examination included both reported and non-reported abortions/stillbirths. Combined with the TVD data, these data have the potential to improve the surveillance of abortions/stillbirths at the national level and might help early detection of (re)emerging diseases, as they take into consideration not only cases which were reported to the mortality database, but unreported cases as well. By complementing mortality data with necropsy reports, a more accurate estimation of the true population of abortions/stillbirths can be achieved. Cases that are not reported to the TVD but which were sent in for necropsy would be included into the surveillance system and could contribute useful information on potential causes of death.

Combining data from multiple sources can have numerous advantages, such as gaining new knowledge about the different data sources and their potential use and benefit for surveillance (Houe et al., 2019). Comparison of necropsied animals to the overall on-farm mortality on a national level allowed us to report that on average, 1% of Swiss cattle that die are submitted for post-mortem examinations. However, the regression models demonstrated that these submissions depended on multiple factors, such as age of the dead animal, as well as time and location of the death. Age had the biggest influence on whether a dead animal was submitted for necropsy or not, with dead adult cattle having the highest odds of being necropsied (OR 8.6) compared to dead neonates. There are several possible explanations for this disparity. For example, many necropsied adult cattle originated from one of the two university clinics and were not sent in by farmers directly, but rather by the attending clinician. Animals sent to the clinics were often valuable animals, where the farmer was prepared to invest in further treatment (Wäsle et al., 2017). If these animals die or if they must be euthanized due to their condition, they are usually sent for a post-mortem examination, often for teaching purposes. Such teaching necropsies are not initiated by the farmer and are used to teach students, assistants and faculty. These submissions may bias the sample, as it is not the owner submitting the animal for a diagnostic reason but rather the clinic requesting a necropsy mostly for educational purposes. Unfortunately, it was not possible to differentiate cases submitted by animal owners from those submitted by the university clinics in our study. Including the animal history in future studies would help to better understand this potential bias.

Season and geographical area were also associated with significant variations in necropsy submission. The odds of cattle being submitted for necropsy outside of alpine pasture season rather than during the months of alpine pasture (June – September) were 1.11 times higher. There are many possible explanations for this result. One may be that many alpine pastures in Switzerland are very remote and difficult to access. Transportation of a dead animal is laborious, time-consuming and expensive. Also, many cows and heifers calve between October and March, and most cattle diseases are related to the puerperal phase, indicating a higher prevalence of morbidity during winter, and thus potentially higher numbers of necropsy submissions outside of pasture

[4] See: https://www.swissmilk.ch/de/schweizer-milch/unsere-kuehe/tierfreundliche-milchkuhhaltung/

season. Another factor influencing the submission of an animal for necropsy was the canton of origin which showed that most necropsies were submitted from the cantons of Bern and Zürich. This could be explained by the high cattle population density in these areas and in the surrounding cantons (see supplementary material 6), as well as by the presence of the two university clinics in Bern and Zürich, as they submit the most cattle for post-mortem examinations in Switzerland. These spatiotemporal variations of necropsy submissions should be taken into account when using necropsy reports for AHS, as there are big cantonal differences in population size and necropsy submissions. For AHS, data from other laboratories should be included in order to increase population representativeness and have better geographical coverage. Potential approaches to reduce these biases could be to introduce incentives for submissions occurring during alpine season, e.g. free transportation of the carcass or a special fee for necropsy examination, or for submissions of young animals

These results indicate that a post-mortem examination is rarely undertaken when an animal has already undergone multiple treatments. Explanations could be that many farmers, who have already invested in treatment of an animal, will not have the financial incentive to send it for necropsy. Another reason may be that the farmer was already aware of the animal's underlying problem and did not see any value in the added cost of a necropsy submission. Furthermore, it is usually not recommended to send in chronically ill animals, as it is difficult to determine the initial cause of the condition/disease. In certain cases (mainly accidents), farmers can get financial support from insurance in cases of emergency slaughter and euthanasia, making this option appealing. These results should be however interpreted with caution because reporting treatments and illness to the ASR database is voluntary and only approximately 5% of farmers who report to the ASR database report in a consistent manner. At the time of writing, the ASR database only covers three breeds and only contains a small number of participating farms, and only a portion of these farms submit cases to necropsy. Therefore, the ASR database is not yet fully representative of the whole cattle population. Great efforts are being made to increase the number of participating farmers, and to enable regular and complete reporting to the ASR in order to expand the database, which could be beneficial for future health surveillance systems. An attempt to create an interface between veterinary software and the ASR database is being made, in order to facilitate the reporting and exchange of information. It could be interesting for future studies to investigate whether the discrepancies observed between ASR and non-ASR farms are due to differences in herd size, management practices or other risk factors.

When looking at the farm level comparison between ASR and non-ASR farms, important differences between age groups of necropsied animals and the types of farms that submitted animals for necropsy were present. The ASR-farms submitted significantly more abortions and neonatal calves to necropsy (p-value Chi-square test < 0.05), whereas non-ASR farms submitted significantly more adult cattle (p-value Chi-square test 0.002). Furthermore, ASR-farms submitted more cases to necropsy than non-ASR farms did (1.27 versus 1.12 cases, respectively). However, these results should be interpreted with caution, as the ASR database is still growing and not yet a representative clinical database of the Swiss cattle population. Nevertheless, they suggest that farmers, who actively record health events on their farms may be more likely to submit abortions and stillbirths for necropsy. This might be explained by a higher awareness of the importance of disease by the farmers, who are more receptive and inclined to further diagnostics, such as post-mortem examinations.

Our results show that information recorded in necropsy reports and extracted using automated data cleaning and pre-processing procedures are a useful source of information for AHS. First, the overall data completeness was good to very good. For example, completeness of data containing geographical information (owner name, address, postal code) was above 99 %, which is consistent with a previous study in Switzerland (Küker et al., 2018). The greatest number of missing values was found within premise ID numbers (37.5 %). However, these significantly improved (approximately 47 %) compared to the previous study where around 80 % of farm ID's were missing. These results can be explained by the implementation in our study of in-depth automatic data cleaning and pre-processing approaches, and by the resources invested within the last few years by the cantonal and federal offices to improve tracing of animals, resulting in increased requirements for the laboratories to collect complete farm and animal ID's. Second, comparison of necropsy reports with the TVD data showed a high consistency between the two datasets in terms of age group and timeliness of death reporting. This result highlights that information extracted from necropsy reports are reliable and can be used for AHS.

The time lag between the date of death and the date of necropsy was short, being less than 3 days in approximately 95 % of the on-farm deaths that were necropsied. Abortions/stillbirths were submitted for necropsy within 6 days after being reported to the TVD, indicating a slightly lower timeliness compared to the reporting of stillbirths described by Struchen et al. (2015). These results highlight the value of necropsy for early disease epidemic detection, as they provide timely information about underlying cause of death/illness. In addition, the faster a necropsy is initiated, the higher the probability of finding the underlying cause of the disease as autolysis impairs diagnostics due to tissue autolysis and bacterial overgrowth. Furthermore, timeliness is critically important in detection of infectious disease agents, as the timelier a diagnosis can be made, the quicker decisions about control measures can be undertaken (World Organisation for Animal Health (OIE), 2019).

Including reports from three of the five Swiss veterinary pathology laboratories performing necropsies in cattle allowed us to collate data from most of Switzerland. Combining the data from different laboratories however comes with challenges. For example, all three laboratories used different software and different ways of data recording, resulting in different dataset layouts and content. For example, records of age, breed and identification numbers were highly variable. The different datasets had to be harmonized in order to be used for further analysis resulting in time-consuming data cleaning and pre-processing steps. These steps are widely recognized as the most time-consuming steps in Data Sciences (Schutt and O'Neil, 2013), but our study showed that they can be successfully implemented and automatized to enable system interoperability. At the end of the data cleaning and pre-processing steps, 95 % of the age related data could be collated using the same format despite their initial discrepancies (e.g., age could be reported as free text ("adult"), numeric ("3 months"), or date data ("17.05.2015″)). In order to avoid data inconsistencies, data collection and reporting could be standardized by using the same software and terminology as proposed by Tapprest et al., 2019. This approach has the advantage of producing homogeneous data, which is easily comparable. However, it is very demanding, requiring cooperation from the laboratories and software providers. Due to the many different requirements and preferences that different laboratories have towards laboratory managing software system (LMS), creating a new software incorporating all these requirements and preferences would be a very costly undertaking.

While analysing and comparing the different data sources with each other, we identified various inconsistencies between the datasets. The most striking differences between the necropsy and TVD data were within postal codes and premise ID numbers. Only 21.2 % of postal codes and 10.6 % of premise ID numbers matched between the two datasets. Incorrect transcription, e.g. typing mistakes, is one possible explanation. Another could be due to the route by which dead cattle arrive at the pathology laboratory. One route is a direct submission of a dead animal by a farmer. In this case, the TVD is reported by the owner of the dead animal using his/her premise ID. The second route is a submission of a dead animal through the university ruminant clinics who also possess a unique premise ID. Two of the participating institutes (ITPA and IVP) are affiliated with university ruminant clinics and many necropsies originated directly from these clinics. When an animal dies at one of the clinics, the death is reported to the TVD by the clinics, using the clinic premise ID and address. However, for billing purpose, the premise ID and zip code of origin of the animal are recorded in the necropsy data. In this case, the premise ID and postal code recorded in the necropsy report does not match the premise ID and postal code recorded in the TVD data. This difference in reporting poses a challenge for epidemiological analysis, as the geographical localization varies between mortality and necropsy data and a geographical comparison between these two data sets is therefore impeded. However, it also highlights the usefulness of pathology data for AHS, as these data can contribute additional information on the true geographical origin of dead animals.

Pathology data has been previously reported to be important for surveillance, as they are crucial for correctly recognizing and identifying new or re-emerging diseases in animal populations (O'Toole, 2010). However, to our knowledge, there are no published reports of studies that compared pathology data to other data or complemented pathology data with other data. In our study, by comparing and combining clinical with pathology data, we show that animals were more often submitted for post-mortem examinations when increased on-farm morbidity was observed, rather than in the cases of increased mortality. For each animal sent to necropsy, there was a median of two animals reported dead on the same farm in the last 30 days, whereas a median of five animals were reported sick 30 days prior to a necropsy. Even though the sample of necropsied animals is biased, the cattle that were submitted for necropsy may be used for AHS. For example, by complementing clinical or mortality data with information from necropsy reports, it is not only possible to identify the cause of an underlying disease problem, but to assess the morbidity/mortality of a farm as well. Furthermore, thanks to the amount of information provided by the combined data sources, the epidemiology (e.g. season, geographic region, risk factors) of diseases can be analysed more precisely and help farmers develop long term mitigation strategies to prevent such diseases occurring or to mitigate losses from them. All of these reasons indicate that necropsy reports can help strengthen surveillance systems and support early detection of (re-) emerging diseases. A next step could be to identify clinical symptoms which are more often associated with animals being submitted for post-mortem examination. Evaluation of the type of treatments and clinical diagnosis prior to necropsy submission could be a way to validate clinical diagnosis by post-mortem examination and to compare how often these coincide.

5. Conclusion

In this study, we were able to demonstrate the importance of veterinary pathology data for AHS by providing quantitative evidence that necropsied animals often originate from farms with important disease problems and are therefore critically important for surveillance. This information could not have been obtained without the combination and comparison of multiple data sources. The necropsy data in this study contained a lot of information that could be used for AHS, but it needed to be combined and complemented with other data sources in order to achieve its full potential. Even though our data is not representative and needs further investigation, we nevertheless regard these results as an important contribution to the animal health surveillance literature and a first step toward an improved international surveillance strategy.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.prevetmed.2020.105235.

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