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Quantification of the impact of infectious diseases on animal welfare in livestock

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Summary

Control of infectious diseases in livestock has often been motivated by their food safety and financial impact on livestock production. However, the impact on animal welfare may also be severe. Here, we present an approach to quantify the effect of six infectious diseases on animal welfare in cattle (four diseases) and pigs (two diseases). We grouped clinical manifestations that often occur together into lists of clinical entities for each disease based on literature reviews, and subsequently estimated "suffering scores" based on an aggregation of duration, frequency and severity. The duration and severity were based on literature reviews and expert knowledge elicitations, whereas frequencies were mainly from literature. The estimated suffering scores on animal level were accumulated to country level and used to estimate the total impact of organised disease control efforts for the diseases included. Furthermore, the roughly estimated effect of disease control on animal welfare in Denmark and other countries were compared.

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Preface

This report was compiled based on a project on quantification of animal welfare in relation to infectious diseases in cattle and pigs. The project was funded by the Knowledge Centre for Animal Welfare, The Danish Veterinary and Food Administration and was planned for 2020, while this report was completed in January 2021. The funders had no influence on the study results.

Introduction

Infectious diseases are common in livestock, from which they may be controlled or eradicated due to the impact on food security, food safety or other types of societal impact. These motivations have been the main drivers of organised control of infectious diseases in livestock. However, animal welfare is also a reason mentioned in the European Union Animal Health Law, a regulation that was adopted by the European Parliament in 2016 for implementation by 2021. Although specific diseases may have been associated with animal welfare consequences in the individual, the impact of livestock diseases on animal welfare has to our knowledge not been quantified on population level.

Animal welfare may be affected by infectious diseases in multiple ways, e.g. reduced comfort of the individual due to the acute pathologies caused by the infectious agent resulting in clinical signs such as fever, weakness, diarrhoea, or long-term effects where weight-loss may put the animal in a lower ranking in an animal group. There may also be reduced animal welfare resulting from lack of social interaction due to disease control measures imposed on the entire population, e.g. if calf and dam are separated to mitigate the risk of transmission from dam to calf.

Assessment of the impact of specific diseases on animal welfare has not been systematically done before and is likely subject to interpretation from different assessors. Quantification of animal welfare is a challenge, but expert judgement is commonly used in food and feed safety risk assessments, and has also been used in animal welfare judgements (EFSA AHAW Panel, 2017a, 2020). Different expert elicitation methods include the Sheffield method, where behavioural aggregation is obtained through face-to-face discussions between experts, and the Cooke method, which employs mathematical aggregation. The Delphi-method lies in-between these options, as it allows some restricted interaction between experts (EFSA, 2014).

The aim of this project was develop and illustrate a new approach to assess the impact of infectious diseases on animal welfare in livestock. The six diseases are Bovine Virus Diarrhoea (BVD), Infectious Bovine Rhinotracheitis (IBR), infection with *Mycobacterium avium* subsp. *paratuberculosis* (MAP), infection with *Salmonella* Dublin in dairy cattle, and Aujeszky's Disease, Porcine Respiratory and Reproductive Syndrome (PRRS) in pigs.

The objectives of the study were for these six diseases to:

a) Summarise the clinical entities (disease stages) of each disease, and the disease frequency for each of the six diseases based on literature summary;
b) Estimate the duration and animal severity scores for each disease and clinical entity based on expert knowledge elicitation (EKE);
c) Estimate animal suffering scores for common non-infectious welfare challenges in pig and cattle production to provide perspective (such as broken femur, lack of access to water, separation of dam and offspring etc.); and

d) Assess the effect of disease control programmes on animal welfare at population/national level in various countries in comparison to the effect that the disease control programmes are assessed to have had in Denmark.

Materials and Methods

Overview of the project

The work was done in three work packages (WP), where WP1 included summary of the literature of disease manifestations that were grouped into different clinical entities (disease stages with clinical signs that typically occur together for the disease in question), summary of disease occurrence and duration of the diseases. WP2 included assessment using EKEs, which were performed based on a derivative of the Delphi-method, which has previously used for infectious diseases and animal welfare in judgements for the Animal Health Law. The approach consists of a two-step individual followed by collective behavioural aggregation (EFSA AHAW Panel, 2017b). WP3 included the assessment of the effect of disease control programmes in Denmark, which were compared to programmes on the same diseases in other countries selected for the purpose and exemplification.

WP1. Literature summary of diseases and their clinical entities.

Literature reviews for BVD virus, IBR virus, and MAP infections in dairy cattle, and Aujeszky's disease and PRRS in pigs were carried out in a previous project (Houe et al., 2020) with e.g. resulting information on clinical entities and the related typical signs[1], their duration and frequency. An additional literature review was performed for *S.* Dublin before the welfare assessment was performed. The needed information was extracted from these reports to the extent that it existed, with an aim to do an assessment of the welfare consequences (welfare scoring) of each of the clinical entities.

An additional 10 welfare hazards, five for cattle and five for pigs, not related to the infectious diseases were selected for assessment for comparative purposes.

WP2. Animal welfare scoring and assessment

Expert knowledge elicitation of severity

An EKE with subsequent behavioural aggregation of the experts were carried out with the following steps and contents. Each of the eight experts (BF, HH, JFA, LRN, MD, NDO, SSN and a final year veterinary student) were asked to make a score for each clinical entity based on the following instruction: Imagine that "severity" is described on a scale from 0 to 10, where 0 is "no noticeable affect" and 10 is "unbearable pain or other negative affect" on the animal. The question to be addressed for each clinical entity was then:

Imagine that 1000 animals are affected with this clinical entity for a period with the duration described by duration_q1, duration_q2 and duration_q3, i.e. the interquartile range (q1-q3) and the median (q2). What would be the distribution of the combined severity of the typical signs during this period?

Please describe the severity distribution with the 2.5-percentile, the median, and the 97.5-percentile.

This first step was done for each disease and constituted the individual assessment. Step 2 was a group discussion, which occurred in virtual group meetings (due to restrictions imposed due to national management of SARS-CoV-2 circulation in Denmark in 2020). The participants saw the scores of the others

[1] The term "clinical entity" is used to cover disease manifestations, where multiple clinical signs are present at the same time, e.g. "diarrhoea and emaciation" or "nasal discharge and pneumonia". Two clinical entities for the same disease had to be mutually exclusive.

and were asked to verbally motivate their choices, ask questions to other participants for their motivation and ultimately re-score if they felt they had not taken sufficient aspects into account during their initial individual scoring. It was stressed that all participants were entitled to keep their original score. Ultimately, a distribution of scores for each disease and clinical entity was included.

A similar approach was taken for the welfare hazards, which however only had one group of welfare effects to score per welfare hazard. Furthermore, for each clinical entity and welfare hazard, the duration of the impact on animal welfare within each clinical entity or hazard was agreed among the experts.

Disease occurrence

Disease occurrence was calculated as the total number of events per year for a given clinical entity /welfare hazard in a given animal group. This occurrence was then aggregated with severity and duration to obtain the total "suffering" score for the specific clinical entity and animal group. The following groups of animals were used: for cattle, cows (female animals > 2 years); heifers 1-2 years; heifer calves < 1 year, bull calves < 1 year; foetuses: animals preterm); for sows (females>201 days), boars (>201 days), finishers (99-201 days), weaners (25-98 days) and piglets (0-25 days of age).

BVD

The calculations are made separately for postnatal infections and foetal infections. For postnatal infections and in endemic situations with no systematic control programme in place, the annual incidence risk of infection has been estimated as 34%, which was shown to be similar across age groups (Houe and Meyling, 1991). This annual incidence risk was then converted to an annual incidence risk for each clinical entity (i.e. the effective incidence risk (EIR), where the occurrence of the specific clinical entity was estimated based on the infection occurrence and information in literature). As some clinical entities (e.g. retained placenta and abortions) only occur if the animal is infected in certain risk periods, it is necessary to take this risk period into account. As the calculations addressing risk periods are easier to perform using rates, the incidence risk was changed to incidence rate, then risk periods were addressed and then the rate was re-calculated to an annual incidence risk. Therefore, the following steps were used: a) Annual incidence risk of infection obtained from literature; b) Risk of clinical entity occurring **if animal infected** in risk period (based on expert opinion (HH); c) Calculation of annual incidence risk of **clinical** entity: a x b; d) Calculation of annual incidence rate of clinical entity (i.e. clinical events per animal year at risk): Calculated from c using the formula $I_{rate} = \frac{-\ln(1-I_{risk})}{t}$,where t is the risk period and $I_{risk}$is the annual incidence risk (p. 84 in Houe et al., 2004); e) estimation of the risk period based on expert opinion (HH), measured first in days then years; f) calculation of the effective incidence rate (EIR) as $EIR = I_{rate} \times t\ years$, i.e. the actual rate given the animals is not at risk for an entire year is therefore the expressed as "effective" IR or EIR; g) conversion of EIR to effective annual incidence risk (EAIR) using: $I_{risk} = 1 - e^{I_{rate} \times t}$ (Formula 6.2 in Houe et al., 2004); h) total number of events = population size (from Statistics Denmark) multiplied by EAIR.

For foetal infections a more direct calculation was used. It has been estimated that the risk of foetal infection during the three first months of pregnancy is approximate 3%, i.e. the risk of a calf being a persistently infected (PI) animal is 3% (Houe and Meyling, 1991). In order to address the risk of congenital defects being induced during approximately two months in pregnancy a risk of 2% was used for these animals. As the risk periods are now already addressed, the EIR were obtained by multiplying these incidence risks with the estimation of probability of occurrence of clinical entity if infected.

IBR

There are no estimates of the annual incidence risk of IBR infection at the animal level in the Danish cattle population prior to the initiation of a control and eradication programme in 1985. Therefore, the best

expert guess was based on a) an estimate of the within herd incidence risk in test positive herds in 1995 assuming this would be similar to the within-herd incidence risk in 1985, and b) information from 1985 (Landbrugsstatistik 1985) about the number of IBR test positive dairy cattle herds, the number of dairy cattle herds and the population of dairy cattle.
The estimation was as follows:

a) A recurrent outbreak of IBR in 1995 (after having been eradicated from the Danish cattle population in 1992) in 61 dairy herds comprised 1560 test positive cattle (Nylin et al. (1998). An estimate of the population at risk in the 61 dairy herds was based on information (Landbrugsstatistik 1995) about the total number of cattle (2,090,373) and the total number of herds (30,250). This gives an average herd size of 2,090,373/30,250 = 69.1 cattle. The population at risk in the 61 dairy herds was therefore estimated to be 61x69.1 = 4215 cattle. Thus, in 1995 the estimated animal level annual incidence risk of being test positive was 1560 cases/4215 = 0.37.
b) In 1985, there was approximately 31,773 dairy herds with 896,358 dairy cows, and the number of IBR test positive dairy herds was 2667.

Based on a) and b) the annual incidence risk of IBR infection in 1985 was estimated to be
Irisk = (# cows that got the infection) / (population of cows) = (2667 herds x (896,358 cows/31,773 dairy herds) x 0.37 cases per cow) / (896,358 cows) = 0.031 or 3.1%. Based on literature it was assumed that all age groups were at the same risk of infection.
The number of clinical events was then calculated based on the probabilities for clinical signs among infected. There were three clinical entities identified for IBR. There was 90% probability for one or more of the clinical entity (acute respiratory disease) grouping signs reduced appetite, dullness, salivation, nasal and ocular discharge, lachrymation, conjunctivitis, rapid respiration, coughing and pyrexia, 10% probability for the clinical entity (acute gastro-intestinal disease) group with diarrhea and dehydration, and 5% probability of the clinical entity abortion among pregnant cows during 2nd and 3rd trimester.

Paratuberculosis

MAP infections were only deemed relevant for adult cattle. The annual incidence risk of clinical cases has been reported to 3.6% prior to establishment of a control programme (Ferrouillet et al., 2009). This was used to calculate the total number of events per year by multiplying with the population size for the clinical entity Stage III paratuberculosis. However, because not all cattle will proceed to the clinical entity Stage IV, the effective annual incidence rate was considered only 50% of the effective annual incidence rate for cattle in Stage III: The total number of events in Denmark was established by multiplying with the adult population of cattle, because only these are considered to succumb from clinical disease in Stage IV.

Salmonella Dublin

The following animal groups were used to reflect the pathogenesis: a) Newborn (0-14 days of age); b) Calves (15 days to 1 year old); c) Heifers (1-2 years old); d) Cows (>2 years old). *S*. Dublin presents different clinical entities. The following five clinical entities were defined for *S*. Dublin: i) Peracute infection (occurring in all animal groups); ii) Acute infection (all animal groups), iii) Abortion due to acute infection (cows only), iv) Chronic infection (calves only); and v) Mild transient infection (all animal groups).
The calculations were made separately for each animal group and clinical entity combination.

Peracute infection. Case-fatality is close to 100% and there is little effect of treatment (Wray and Sojka, 1977; Wray and Davies, 2000). However, peracute infections are relatively rare and mostly occur in acute clinical outbreaks in fully susceptible herds or groups of cattle. The number of peracute infection events was calculated as described above for BVD. The number of events were calculated by multiplying the annual incidence risk of new infections at dairy herd level (i.e. 7.5% estimated from surveillance data) with the estimated risk of the animals in each age group at risk of developing peracute infection (i.e. 0.1 in

neonatal calves, 0.05 in calves, 0.01 in heifers and 0.02 in cows) to get the annual incidence risk of peracute infections. From this, the annual incidence rate was calculated, which was then multiplied with the risk period, i.e. the average duration of clinical outbreaks (30 days = 0.082 years) to get the EIR and EAIR. This was multiplied with the total population at risk within each age group.

Acute infection. In adult animals/cows, it leads to profuse diarrhoea/dysentery, anorexia, fever and weight-loss with case-fatality risk around 25% (Wray and Sojka, 1977; Wray and Davies, 2000). Acute infections occur both during clinical outbreaks after introduction to susceptible herds and in persistently infected herds, in which herd immunity fluctuates over time leading to waves of new infections within-herd, typically every or every other year (Nielsen et al., 2013). Case-fatality is 25-50% and treatment is difficult and must be initiated early to have an effect (Rings, 1985). Before the Danish national surveillance programme was initiated in 2002, one out of four dairy herds were test-positive to *S.* Dublin based on repeated bulk-tank milk sampling. On an annual basis, 7.5% of the dairy herds were estimated to experience new infections, and 18% were estimated to be persistently infected. In the newly infected herds, the annual incidence risk of acute infections were estimated to be higher than in persistently infected herds. However, persistently infected herds had longer risk periods (9 months per year was assumed because acute infections are rare in the Spring season) than the newly infected herds (30 days risk periods on average).

The number of acute infection events were calculated by multiplying the 7.5% annual incidence risk of new infections at dairy herd level plus the 18% persistently infected herds with the estimated risk of the animals in each age group developing acute infections within those two herd level infection types. For neonatal calves, this resulted in 0.18*2%+0.075*6% equal to an annual incidence risk of 0.8%. Going through the annual incidence rate calculations with a risk period of 202 days on average across all the infected herds, this led to an EAIR of 0.45%, which was multiplied with the population at risk (all new-born calves in a year). In calves, 2.5% incidence risk was assumed in persistently infected herds and 22% in newly infected herds. In heifers and cows, an average 0.5% incidence risk was assumed in persistently infected herds and 3% in newly infected herds.

Abortion. Acute *S*. Dublin infections also sometimes lead to abortion in adult cows (Hinton, 1974). The abortion incidence risk has been reported to be around 2-8% in *S*. Dublin infected herds (mainly in outbreak-like situations) (VLA, 2010). The EAIR was estimated using the same calculation method as above, but only including cows and (pregnant) heifers, and reducing the risk period further to 152 days, because the animals are only at risk of aborting while pregnant.

Chronic infection. A small proportion of calves that get acutely infected with *S*. Dublin progress to a chronic clinical infection characterised by polyarthritis with swollen knees and fetlocks, gangrene with sloughing of the skin on ear and/or tail tips, sometimes with osteomyelitis leading to arched back and forelimbs extended forward. The calves may be tender on their feet and have a tendency to knuckle or kneel on forelimbs, be slow to rise and become recumbent. Pain can sometimes be elicited on manipulation of the neck (Gitter et al., 1978; Healy et al., 1997). The number of chronic infection events were calculated as described for acute infections, but only for the calves. It was assumed that on average 1 out of 200 (0.5%) of calves in persistently infected herds and 2 out of 200 (1%) of calves in newly infected outbreak herds would become chronically infected.

Mild transient infection. Mild transient infection is a commonly occurring clinical entity in *S*. Dublin infected herds. These are characterised by transient anorexia and fever and therefore may not be spotted by farmers and veterinarians and are likely underreported. Hence, the assumptions used in the calculations are uncertain and are mainly based on serological prevalence studies of infected cattle herds (Nielsen, 2013a; Nielsen, 2013b) showing between 18 and 44% seropositive animals within infected farms. Some of these are already counted for under acute and chronic infections. Hence, for the calculations average annual incidence risks of 10% and 20% mild transient infections were assumed in persistently and newly infected outbreak herds, respectively for all age groups.

Aujeszkys's disease

The following age groups of pigs were used: a) Piglets infected in utero; b) Piglets less than 3 weeks of age; c) Weaners and finisher pigs (> 3 weeks); and d) Adult pigs.

The annual incidence risk of Aujeszky's disease virus infection in Danish pig herds prior to the initiation of the eradication programme in 1982 was reported to be 90 positive herds (Bitsch, 1984) out of the total 55.000 pig holdings, yielding annual incidence risk of 0.16 % similar across all age groups. The morbidity is generally high at 100% (EFSA, 2017), while mortality is considered highest in young animals (e.g. piglets < 3 weeks= 100%) and declining with increasing age (e.g. weaners and finishers= 50 %, adult pigs less than 5 %). Adult pigs show a varying morbidity ranging from 10-30 %. Based on these estimates the effective incidence risk prior to eradication of Aujeszky's disease virus from the Danish population were calculated using an annual incidence risk of 0.16 % multiplied by the estimated age group specific prevalence of animals showing clinical manifestations among infected pigs. Finally, the EAIR was multiplied by the total number of animals in each age category to obtain the total number of clinical events.

PRRS

There are four clinical entities for which frequency estimates are needed for PRRS: epidemic disease in adult pigs, and endemic disease in each of sows, nursery piglets, and weaners/finishers. Estimation of the required frequencies are greatly facilitated by the work of de Paz (2015), who provides direct estimates for the proportion of animals in Denmark affected with clinical signs (relating to endemic disease) as being 5% for weaners/finishers and 10% for sows (note: the table given by de Paz (2015) states that this is a prevalence estimate but given the description of the numbers in the text the interpretation appears to be closer to an incidence risk). These estimates are therefore used directly as the effective incidence risk for endemic disease in sows (0.05) and weaners/finishers (0.1). For endemic disease of clinical disease in piglets, it was assumed that the proportion of nursery piglets exposed to disease is the same as that in sows, and using the approximate ratio of morbidity between sows (reported as 100%) and nursery piglets (reported as up to 80%) to adjust the effective incidence risk to 75% of 0.01 = 0.075. For epidemic disease of clinical disease in adult pigs, an average morbidity estimate of 27.5% (based on the 5-50% range of Done et al. (1996)) was combined with the expert guess that 1% of farms experience an epidemic outbreak annually, to arrive at an effective incidence risk of 0.00275. These incidence risks were then multiplied by the total number of animals in each category within Denmark.

Welfare hazards

The calculations of EAIR for the 10 welfare hazards were primarily based on expert judgements.

No access to water – cattle was considered to occur annually in 1% of 2,800 dairy herds, of which the average herd size is 200 adult cattle. This equals 5,600 total events per year.

Broken femur – cows and sows was considered to have an EAIR of 0.1% in populations of 650,000 cows and 1,020,000 sows, respectively.

Lying on concrete floor with no bedding material was considered to occur with an EIR of 1% of dairy cows per day in a population of 650,000 dairy cows. Thereby, the number of cow-days at risk is 365 x 650,000=237,250,000, and the total number of events is 2,372,500.

Too hot weather conditions. Heat stress generally occurs at 22^{o}C and is considered to affect the majority of dairy cattle when temperatures increase to above 25^{o}C. Therefore, we deemed that at 25^{o}C, heat stress occurs in 90% of dairy cows 0.9x 650,000 events = 585,000 total events.

Separation of cow and calf occurs once in 95% of calves born to dairy cows and each cow was assumed to get one calf per year, thus the total number of events is population size x 0.95

Weaning of piglets occurs once in 95% of piglets born, thus the total number of events is population size x 0.95

Tail biting occurs with a prevalence of 3% of weaners and finishers, thus the total number of events is population size x 0.03.

Crating of sows. It was assumed that sows farrow 2.5 times per year in 95% of the population of sows, i.e. total number of events is 2.5 x population size x 0.95
Feed restriction. Occurs 2.5 times per year in 98% of the population of sows, i.e. total number of events is 2.5 x population size x 0.98.

Aggregation of suffering scores based on severity, duration and occurrence

The estimation of the suffering scores was done using Monte-Carlo simulations. For each disease and clinical entity, aggregation of suffering scores was done based on the severity scores (from each expert), the duration and the occurrence as described above. The aggregation was done as follows: for a given disease and clinical entity, a randomly theoretical animal of a given species and age group was picked. Then, it was randomly chosen if the animal got the clinical entity based on the disease occurrence (total number of events per year). Then, it was randomly chosen how long the animal would suffer from the disease based on the distribution given by the experts. This distribution was derived from the 2.5, 50 and 97.5 percentiles elicited by the experts, and mapped into a triangular distribution fitted using the triangle-package in R (Carnell, 2019).

The total suffering was then calculated by integration by calculating the total suffering per animal and expert using 1000 iterations for each disease. This resulted in a distribution of suffering per clinical entity and expert. The combined expert score was used, if no systematic effect of expert occurred.

WP3. Effect of control programmes on animal welfare in selected countries

The aggregated suffering scores from WP2 were subsequently used to compare to the effect of disease control programmes in selected other countries, considering that the population sizes differ between countries. The disease reduction was as given in Table 1. For example, AD is mostly eradicated in most countries and therefore the reduction is 1 (100 %), except for PT and ES, where 0.95 (95 %) reduction is the case. However, only the overall population size of a given species was taken into account (Table 2) as we did not have knowledge about the stratified age group populations for each other country. For example, if the welfare score in Denmark for disease A was 1×10^6, Denmark had 1 million animals, and disease A was eradicated, then the reduction (or gain in animal welfare) in Denmark would be 10^6 fewer severity points. If Country X had the same starting prevalence/incidence risk as in Denmark, had a reduction of the disease occurrence of 50%, and had a population of 2 million animals, then the animal welfare gain in Country X would also be 10^6 fewer severity points, because the population was twice as big.

Table 1. Assumed reduction achieved in disease occurrence following establishment of disease control programmes in selected countries based on start prevalence/incidence risk and end prevalence/incidence risk after reduction.

Disease	DK	AT	BE	FI	DE	IE	NL	PT	ES	SE	UK	Scotland
Reduction achieved												
Aujeszky's disease (AD)	1	1	1	1	1	1	1	0.95	0.95	1	1	1
BVD	1					1	0.75			1		0.9
IBR	1		0.654			0	0.182					
Paratuberculosis	0.5	0.2		0			0.2			0	0.1	
PRRS	0.674	0.558	0.058		0.379		0.279				0.479	
S. Dublin	0.64						0.88			0.88		
Start values												
AD	0.002									0.09	0.002	
BVD	1					1	1			1		1
IBR	0.031		0.52			0.75	0.33					
ParaTB	0.1	0.1		0			0.1			0	0.1	
PRRS	0.95	0.95	0.95		0.95		0.95	0.95	0.95		0.95	
S. Dublin	0.25						0.25			0.25		
Values after reduction												
AD	0									0	0	
BVD	0					0	0.25			0		0.1
IBR	0		0.18			0.75	0.27					
ParaTB	0.05	0.08		0			0.08			0	0.09	
PRRS	0.31	0.42	0.895		0.59		0.685				0.495	
S. Dublin	0.09						0.03			0.03		

Table 2. Population sizes in selected countries based on EuroStat for 2019

Country	Country code	n pigs	n cattle
Denmark	DK	12,431,000	1,427,000
Austria	AT	2,773,230	1,879,520
Belgium	BE	6,085,100	2,373,100
Finland	FI	1,062,200	870,740
Germany	DE	26,053,400	11,639,530
Ireland	IE	1,613,270	6,559,650
Netherlands	NL	11,921,000	3,721,000
Portugal	PT	2,216,480	1,674,970
Spain	ES	3,1246,040	6,600,330
Sweden	SE	1,481,200	1,404,670
United Kingdom	UK	4,741,000	9,459,000

Results

WP1. Literature summary of diseases and their clinical entities.

The identified typical clinical entities with associated clinical signs were tabulated in Table 3 for each disease and age group. The additional 10 welfare hazards that are not related to infectious diseases are listed in Table 4.

WP2. Animal welfare scoring and assessment

The distributions of the duration of each clinical entity for each disease and welfare hazard as agreed by the experts through the EKE are shown in Table 5. These were combined with the calculated number of events for each clinical entity (Table 6) and the combined severity scores from the EKE are shown in Table 7. The distribution in the scores for the eight experts are shown in Figure 1. Because of the general overlap and because no expert seemed to be systematically different from others, the combined scores were used for the remaining of the reporting. In Figure 2, the severity scores for all clinical entities and welfare hazards are shown. The summarised scores are also shown in Table 8, and the ranking of the means of the summarised severity scores are as follows (from lowest to highest): Broken femur in cattle < Separation of cow and calf < No access to water < Aujeszky's disease < *Salmonella* Dublin < IBR < Too hot weather conditions (for cattle) < Paratuberculosis < BVD < Cattle lying on concrete floor with no bedding material < Broken femur in pigs < Tail biting in pigs < PRRS < Crating of sows < Weaning of piglets < Feed restriction. These are the conditions for an average single affected animal for the duration that this animal would on average be expected to endure the condition within a year, which are then summarised for the population.

WP3. Effect of control programmes on animal welfare in selected countries

The effect of disease control based on the occurrence reduction in selected countries listed in Table 3 are shown in Table 9. For example, the mean effect of the eradication of Aujeszky's Disease in Denmark was 1 x 10^6 suffering score points, whereas it was only 22% as high in Austria due to a smaller pig population, even though both countries eradicated Aujeszky's Disease.

Table 3. Typical clinical signs and clinical disease entities for each of the six diseases.

Disease	Clinical entity	Age group	Typical signs
AD	Encephalitis	Piglets infected in utero	Weak piglets ; Shaking/shivering / Sudden death
AD	Encephalitis	Weaners & finisher pigs (>3 weeks)	Loss of appetite; Somnolence; Trembling/convulsions; Paralysis; high temperature (up to 42°C)
AD	Encephalitis	Adult pigs	Incoordination of hind limbs and febrile response (up to 42°C)
AD	Respiratory signs	Weaners & finisher pigs (>3 weeks)	Sneezing /Nasal discharge; Coughing; Dyspnoea
AD	Encephalitis	Piglets (< 3 weeks)	Lethargy; Weakness/appetite loss; Incoordination/convulsions (vomitus, diarrhoea), incl. Febrile response (up to 42°C)
AD	Reproduction		Vaginal discharge; Mummification; Agalactia
BVD	Transient infection	Calves	Diarrhoea
BVD	Transient infection	Heifers	Diarrhoea
BVD	Transient infection	Cows	Diarrhoea
BVD	Transient inf. with erosions	Calves	Mucosal erosions
BVD	Transient inf. with erosions	Heifers	Mucosal erosions
BVD	Transient inf. with erosions	Cows	Mucosal erosions
BVD	Co-morbidity	Heifers	Retained placenta
BVD	Co-morbidity	Cows	Mastitis
BVD	Co-morbidity	Cows	Retained placenta
BVD	Co-morbidity	Calves	Respiratory disease, diarrhoea
BVD	Co-morbidity	Heifers	Respiratory disease, diarrhoea
BVD	Repeat breeding	Heifers	Subclinical
BVD	Repeat breeding	Cows	Subclinical
BVD	Abortion	Heifers	Early or late after infection
BVD	Abortion	Cows	Early or late after infection
BVD	Congenital defects and weak born calves, incl. Congenital Tremor	In the new born	Miscellaneous malformations
BVD	PI: animals unthrifty	Calves and heifers	Weight loss
BVD	PI: mucosal disease	Calves and heifers	Severe diarrhoea and erosion
IBR	Acute phase	calves, heifers & cows	Reduced appetite, dullness, salivation, nasal and ocular discharge, lachrymation, conjunctivitis, rapid respiration, coughing and pyrexia, may lead to death
IBR	Acute phase	calves, heifers & cows	Diarrhoea and dehydration
IBR	Abortion	Cows	2nd and 3rd trimesters
ParaTB	Stage III	Cows	Weight loss/ Poor condition (BCS 1-2) /Chronic wasting
ParaTB	Stage III	Cows	Intermittent diarrhoea
ParaTB	Stage IV	Cows	Emaciation (BCS 0-1)
ParaTB	Stage IV	Cows	Pipe stream diarrhoea
ParaTB	Stage IV	Cows	Lethargic
PRRS	Epidemic	Sows and boars	Anorexia, fever, lethargy, respiratory difficulties, cyanosis
PRRS	Endemic	Sows	Reproductive problems incl. abortion, still-birth, and returns to service
PRRS	Endemic	Nursery	Poor growth, anorexia, fever, respiratory distress, diarrhoea, anaemia, congenital abnormalities, weakness, ataxia, haemorrhage, immunomodulation
PRRS	Endemic	Weaner and finisher	Transient anorexia, respiratory disorders, and discolouration of the ears
S. Dublin	Peracute	New-born	
S. Dublin	Peracute	Calves	Anorexia, signs of endotoxic shock (salivation, shaking, cold skin, ears), hyper- or hypothermia, lethargy, recumbent, shallow respiration, high pulse, dehydration, bloat, spasms, leading quickly to death (case-fatality 100%)
S. Dublin	Peracute	Heifers	
S. Dublin	Peracute	Cows	
S. Dublin	Acute infection	New-born	Pyrexia (fever), respiratory symptoms (nasal and ocular discharge, coughing), pneumonia, omphalitis, diarrhoea, dysentery, malaise, dehydration, and less

S. Dublin	Acute infection	Calves	commonly with central nervous signs and polyarthritis (swollen, sore joints and lameness) (case-fatality 25-50%)
S. Dublin	Acute infection	Heifers	
S. Dublin	Acute infection	Adult cattle	Profuse diarrhoea/dysentery in adult cows, anorexia, fever, weight-loss (case-fatality around 25%)
S. Dublin	Abortion due to acute infection	Heifers	Abortion in adult heifers and cows. Often without other clinical signs.
S. Dublin	Abortion due to acute infection	Adult cattle	Abortion in adult heifers and cows. Often without other clinical signs.
S. Dublin	Chronic infection	Calves	Polyarthritis with swollen knees and fetlocks. Gangrene with sloughing of the skin on ear and/or tail tips. Sometimes with osteomyelitis -arched back and forelimbs extended forward. Tender on feet, tendency to knuckle or kneel on forelimbs, slow to rise -> become recumbent, pain elicited on manipulation of the neck.
S. Dublin	Mild transient	New-born	Transient anorexia and fever
S. Dublin	Mild transient	Calves	Transient anorexia and fever
S. Dublin	Mild transient	Heifers	Transient anorexia and fever
S. Dublin	Mild transient	Adult cattle	Transient anorexia and fever

Table 4. Ten welfare hazards occurring in dairy cattle and pig production

Hazard	**Age group**	**Scenario**
No access to water - cattle	Cows	Dairy cattle left with no access to water due to broken pipes
Broken femur - cattle	Cows	Dairy cow fell on slippery floor and is left until euthanized within a period of time
Broken femur - pigs	Sows	Sow fell on slippery floor with other sows - she is pushed around
Lying on concrete floor with no bedding material	Cows	Dairy cows resting in a free stall environment
Too hot weather conditions	Cows	Warm summer days in Denmark (>25 °C) interrupted by cooler nights. No access to shade during daytime.
Separation of cow calf	Calves	Calf separated within 24h after birth
Weaning of piglets	Piglets	Piglets are weaned 3-4 weeks after birth
Tail biting	Weaner and finisher	Ongoing severe tail biting (part of tail bitten off, blood present)
Crating of sows	Sows	Sows are crated in farrowing section (from 1 week prior to farrowing)
Feed restriction	Sows	Feed provision is reduced to 30% of ad lib during gestation. Sows are housed together, but most often feed provision is individual

Table 5. Distribution (2.5, 50 and 97.5 percentiles (p)) of the duration (days) of clinical entities based on literature and expert knowledge elicitation

Disease	Clinical entity	Age group	Typical signs	2.5 p	50 p	97.5 p
AD	Encephalitis	Piglets infected in utero	Weak piglets ; Shaking/shivering / Sudden death	0.1	1	2
AD	Encephalitis	Weaners & finisher pigs (>3 weeks)	Loss of appetite; Somnolence; Trembling/convulsions; Paralysis; high temperature (up to 42°C)	1	4	8
AD	Encephalitis	Adult pigs	Incoordination of hindlimbs and febrile response (up to 42°C)	1	4	8
AD	Respiratory signs	Weaners & finisher pigs (>3 weeks)	Sneezing /Nasal discharge; Coughing; Dyspnea	1.5	6	14
AD	Encephalitis	Piglets (< 3 weeks)	Lethargy; Weakness/appetite loss; Incoordination/convulsions (vomitus, diarrhoea), incl. Febrile response (up to 42°C)	1	4	8
AD	Reproduction		Vaginal discharge; Mummification; Agalactia	1	4	8
BVD	Transient infection	Calves	Diarrhoea	5	10	35
BVD	Transient infection	Heifer and cows	Diarrhoea	5	10	35
BVD	Transient inf. with erosions	Calves	Mucosal erosions	8	14	45
BVD	Transient inf. with erosions	Heifer and cows	Mucosal erosions	8	14	45
BVD	Co-morbidity	Cows	Mastitis, retained placenta	2	3	14
BVD	Co-morbidity	Calves	Respiratory disease, diarrhoea	7	20	56
BVD	Co-morbidity	Heifer and cows	Respiratory disease, diarrhoea	7	20	56
BVD	Repeat breeding		Subclinical	1	4	6
BVD	Abortion		Early or late after infection	1	4	35
BVD	Congenital defects and weak born calves, incl. Congenital tremor	In the new born	Miscellaneous malformations	1	2	3
BVD	PI: animals unthrifty		Weight loss	100	400	700
BVD	PI: mucosal disease		Severe diarrhoea and erosion	4	21	45
IBR	Acute phase (respiratory)		Reduced appetite, dullness, salivation, nasal and ocular discharge, lachrymation, conjunctitivis, rapid respiration, coughing and pyrexia, may lead to death	7	42	100
IBR	Acute phase (GI-disease)		Diarrhoea and dehydration	7	49	100
IBR	Abortion		2nd and 3rd trimesters	0	14	30
ParaTB	Stage III	Cows	Weight loss/ Poor condition (BCS 1-2) /Chronic wasting	15	120	240
ParaTB	Stage III	Cows	Intermittent diarrhoea	15	120	240
ParaTB	Stage IV	Cows	Emaciation (BCS 0-1)	1	10	60
ParaTB	Stage IV	Cows	Pipe stream diarrhoea	1	10	60
ParaTB	Stage IV	Cows	Lethargic	1	4	5
PRRS	Epidemic	Sows and boars	Anorexia, fever, lethargy, respiratory difficulties, cyanosis	2	5	14
PRRS	Endemic	Sows	Reproductive problems including abortion, still-birth, and returns to service	1	1	1

PRRS	Endemic	Nursery	Poor growth, anorexia, fever, respiratory distress, diarrhoea, anaemia, congenital abnormalities, weakness, ataxia, haemorrhage, immunomodulation	2	7	28
PRRS	Endemic	Weaner and finisher	Transient anorexia, respiratory disorders, and discolouration of the ears	5	6	7
S. Dublin	Peracute	All age groups	Anorexia, signs of endotoxic shock (salivation, shaking, cold skin, ears), hyper- or hypothermia, lethargy, recumbent, shallow respiration, high pulse, dehydration, bloat, spasms, leading quickly to death (case-fatality 100%)	0.1	0.5	2
S. Dublin	Acute infection	Calves < 3 months old	Pyrexia (fever), respiratory symptoms (nasal and ocular discharge, coughing), pneumonia, omphalitis, diarrhoea, dysentery, malaise, dehydration, and less commonly with central nervous signs and polyarthritis (swollen, sore joints and lameness) (case-fatality 25-50%)	1	7	28
S. Dublin	Acute infection	Adult cattle	Profuse diarrhoea/dysentery in adult cows, anorexia, fever, weight-loss (case-fatality around 25%)	1	7	21
S. Dublin	Abortion due to acute infection	Adult cattle	Abortion in adult heifers and cows. Often without other clinical signs.	0.1	1	2
S. Dublin	Chronic infection	Calves 2-10 weeks (sometimes older)	Polyarthritis with swollen knees and fetlocks. Gangrene with sloughing of the skin on ear and/or tail tips. Sometimes with osteomyelitis -arched back and forelimbs extended forward. Tender on feet, tendency to knuckle or kneel on forelimbs, slow to rise -> become recumbent, pain elicited on manipulation of the neck.	2	21	90
S. Dublin	Mild transient	All age groups	Transient anorexia and fever	0.5	7	21
WH cattle	No access to water - cattle	Cows	Scenario: dairy cattle left with no access to water due to broken pipes	0.25	1	3
WH cattle	Broken femur - cattle	Cows	Scenario: dairy cow fell on slippery floor and is left until euthanised within a period of time	0.1	0.5	3
WH cattle	Lying on concrete floor with no bedding material	Cows	Scenario: dairy cows resting in a free stall environment	90	1000	3000
WH cattle	Too hot weather conditions	Cows	Scenario: warm summer days (>25 oC) interrupted by cooler nights. No access to shade during daytime.	1	7	21
WH cattle	Separation of cow calf	Calves	Scenario: calf separated within 24h after birth	1	5	12
WH pigs	Broken femur - pigs	Sows	Scenario: sow fell on slippery floor with other sows - she is pushed around	0.25	1	6
WH pigs	Weaning of piglets	Piglets	Scenario: piglets are weaned 3-4 weeks after birth	1	3	8
WH pigs	Tail biting	Weaner and finisher	Scenario: ongoing severe tail biting (part of tail bitten off, blood present)	1	5	28
WH pigs	Crating of sows	Sows	Scenario: sows are crated in farrowing section (from 1 week prior to farrowing)	28	32	45
WH pigs	Feed restriction	Sows	Scenario: feed provision is reduced to 30% of ad lib during gestation. Sows are housed together, but most often feed provision is individual	80	85	95

Table 6. Total number of events for each clinical entity

Disease	Clinical entity	Age group	Typical signs	Incidence risk	No. of events
AD	Encephalitis	Piglets infected in utero	Weak piglets ; Shaking/shivering / Sudden death	0.0001097	4163.1033
AD	Encephalitis	Weaners & finisher pigs (>3 weeks)	Loss of appetite; Somnolence; Trembling/convulsions; Paralysis; high temperature (up to 42°C)	0.000146	5686.1671
AD	Encephalitis	Adult pigs	Incoordination of hindlimbs and febrile response (up to 42°C)	0.00056	577.36
AD	Respiratory signs	Weaners & finisher pigs (>3 weeks)	Sneezing /Nasal discharge; Coughing; Dyspnea	0.0008113	31600.045
AD	Encephalitis	Piglets (< 3 weeks)	Lethargy; Weakness/appetite loss; Incoordination/convulsions (vomitus, diarrhoea), incl. Febrile response (up to 42°C)	0.0001097	4163.1033
AD	Reproduction		Vaginal discharge; Mummification; Agalactia	0.00032	326.4
BVD	Transient infection	Calves	Diarrhoea	0.0312496	16312.305
BVD	Transient infection	Heifers	Diarrhoea	0.034	8670
BVD	Transient infection	Cows	Diarrhoea	0.034	22100
BVD	Transient inf. with erosions	Calves	Mucosal erosions	0.0062428	3258.7647
BVD	Transient inf. with erosions	Heifers	Mucosal erosions	0.0068	1734
BVD	Transient inf. with erosions	Cows	Mucosal erosions	0.0068	4420
BVD	Co-morbidity	Heifers	Retained placenta	0.0017104	436.15522
BVD	Co-morbidity	Cows	Mastitis	0.0408	26520
BVD	Co-morbidity	Cows	Retained placenta	0.0017104	1111.7682
BVD	Co-morbidity	Calves	Respiratory disease, diarrhoea	0.0469082	24486.069
BVD	Co-morbidity	Heifers	Respiratory disease, diarrhoea	0.017	11050
BVD	Repeat breeding	Heifers	Subclinical	0.0014206	362.24185
BVD	Repeat breeding	Cows	Subclinical	0.0014206	923.36158
BVD	Abortion	Heifers	Early or late after infection	0.0135074	3444.3988
BVD	Abortion	Cows	Early or late after infection	0.0135074	8779.8402
BVD	Congenital defects and weak born calves, incl. Congenital tremor	In the new born	Miscellaneous malformations	0.002	1096.2
BVD	PI: animals unthrifty	Calves and heifers	Weight loss	0.012	9324
BVD	PI: mucosal disease	Calves and heifers	Severe diarrhoea and erosion	0.0036	2797.2
IBR	Acute phase	calves, heifers & cows	Reduced appetite, dullness, salivation, nasal and ocular discharge, lachrymation, conjunctivitis, rapid respiration, coughing and pyrexia, may lead to death	0.0279	39813
IBR	Acute phase	calves, heifers & cows	Diarrhoea and dehydration	0.0031	4424
IBR	Abortion	Cows	2nd and 3rd trimesters	0.0007647	497

ParaTB	Stage III	Cows	Weight loss/ Poor condition (BCS 1-2) /Chronic wasting	0.036	23400
ParaTB	Stage III	Cows	Intermittent diarrhoea	0.036	23400
ParaTB	Stage IV	Cows	Emaciation (BCS 0-1)	0.018	11700
ParaTB	Stage IV	Cows	Pipe stream diarrhoea	0.018	11700
ParaTB	Stage IV	Cows	Lethargic	0.018	11700
PRRS	Epidemic	Sows and boars	Anorexia, fever, lethargy, respiratory difficulties, cyanosis	0.00275	2835
PRRS	Endemic	Sows	Reproductive problems incl. abortion, still-birth, and returns to service	0.1	102000
PRRS	Endemic	Nursery	Poor growth, anorexia, fever, respiratory distress, diarrhoea, anaemia, congenital abnormalities, weakness, ataxia, haemorrhage, immunomodulation	0.075	2847000
PRRS	Endemic	Weaner and finisher	Transient anorexia, respiratory disorders, and discolouration of the ears	0.05	1947545
S. Dublin	Peracute	New-born	Anorexia, signs of endotoxic shock (salivation, shaking, cold skin, ears), hyper- or hypothermia, lethargy, recumbent, shallow respiration, high pulse, dehydration, bloat, spasms, leading quickly to death (case-fatality 100%)	0.0006186	322.89366
S. Dublin	Peracute	Calves		0.0003088	161.16795
S. Dublin	Peracute	Heifers		3.083E-05	7.8609419
S. Dublin	Peracute	Cows		6.167E-05	40.08229
S. Dublin	Acute infection	New-born	Pyrexia (fever), respiratory symptoms (nasal and ocular discharge, coughing), pneumonia, omphalitis, diarrhoea, dysentery, malaise, dehydration, and less commonly with central nervous signs and polyarthritis (swollen, sore joints and lameness) (case-fatality 25-50%)	0.0070784	3694.9407
S. Dublin	Acute infection	Calves		0.0116804	6097.1442
S. Dublin	Acute infection	Heifers		0.001745	444.98093
S. Dublin	Acute infection	Adult cattle	Profuse diarrhoea/dysentery in adult cows, anorexia, fever, weight-loss (case-fatality around 25%)	0.001745	1134.2651
S. Dublin	Abortion due to acute infection	Heifers	Abortion in adult heifers and cows. Often without other clinical signs.	0.0013091	333.80855
S. Dublin	Abortion due to acute infection	Adult cattle		0.0018483	1201.4193
S. Dublin	Chronic infection	Calves	Polyarthritis with swollen knees and fetlocks. Gangrene with sloughing of the skin on ear and/or tail tips. Sometimes with osteomyelitis -arched back and forelimbs extended forward. Tender on feet, tendency to knuckle or kneel on forelimbs, slow to rise -> become recumbent, pain elicited on manipulation of the neck.	0.0006854	357.77528
S. Dublin	Mild transient	New-born		0.033	17226
S. Dublin	Mild transient	Calves	Transient anorexia and fever	0.0184051	9607.4511
S. Dublin	Mild transient	Heifers		0.0184051	4693.2951
S. Dublin	Mild transient	Adult cattle		0.0184051	11963.301
WH Cattle	No access to water - cattle	Cows	Scenario: dairy cattle left with no access to water due to broken pipes		5600
WH Cattle	Broken femur - cattle	Cows	Scenario: dairy cow fell on slippery floor and is left until euthanized within a period of time	0.001	650
WH Cattle	Lying on concrete floor with no bedding material	Cows	Scenario: dairy cows resting in a free stall environment	0.01	6500
WH Cattle	Too hot weather conditions	Cows	Scenario: warm summer days (>25 °C) interrupted by cooler nights. No access to shade during daytime.	0.9	585000
WH Cattle	Separation of cow calf	Calves	Scenario: calf separated within 24h after birth	0.95	495900

WH Pigs	Broken femur - pigs	Sows	Scenario: sow fell on slippery floor with other sows - she is pushed around	0.001	1020
WH Pigs	Weaning of piglets	Piglets	Scenario: piglets are weaned 3-4 weeks after birth	0.95	36062000
WH Pigs	Tail biting	Weaner and finisher	Scenario: ongoing severe tail biting (part of tail bitten off, blood present)	0.03	1168526.8
WH Pigs	Crating of sows	Sows	Scenario: sows are crated in farrowing section (from 1 week prior to farrowing)	0.95	2422500
WH Pigs	Feed restriction	Sows	Scenario: feed provision is reduced to 30% of ad lib during gestation. Sows are housed together, but most often feed provision is individual	0.98	2499000

Table 7. Combined distributions of severity for 6 diseases, their associated clinical entities and 10 welfare hazards as assessed by expert knowledge elicitation. The severity scores given are based on the median of the scores of the 8 experts, where 2.5 p is the median of the 2.5 percentiles of the 8 experts, and 50 p and 97.5 p are the median and 97.5 percentile

Disease	Clinical entity	Age group	Typical signs	Severity		
				2.5 p	50 p	97.5 p
AD	Encephalitis	Piglets infected in utero	Weak piglets ; Shaking/shivering / Sudden death	5	7	8.5
AD	Encephalitis	Weaners & finisher pigs (>3 weeks)	Loss of appetite; Somnolence; Trembling/convulsions; Paralysis; high temperature (up to 42°C)	5	7	9
AD	Encephalitis	Adult pigs	Incoordination of hind limbs and febrile response (up to 42°C)	5	6.5	8
AD	Respiratory signs	Weaners & finisher pigs (>3 weeks)	Sneezing /Nasal discharge; Coughing; Dyspnoea	3	5	6
AD	Encephalitis	Piglets (< 3 weeks)	Lethargy; Weakness/appetite loss; Incoordination/convulsions (vomitus, diarrhoea), incl. Febrile response (up to 42°C)	4.5	6	8
AD	Reproduction		Vaginal discharge; Mummification; Agalactia	1	2	3
BVD	Transient infection		Diarrhoea	1	3	5
BVD	Transient inf. with erosions		Mucosal erosions	3.5	5	7
BVD	Co-morbidity	Cows	Mastitis, retained placenta	2	5	6
BVD	Co-morbidity	Calves	Respiratory disease, diarrhoea	3	4.5	7
BVD	Repeat breeding		Subclinical	0	0	0.5
BVD	Abortion		Early or late after infection	1	2.5	4
BVD	Congenital defects and weak born calves, incl. Congenital tremor	In the new born	Miscellaneous malformations	1.5	4	7
BVD	PI: animals unthrifty		Weight loss	1	4	7
BVD	PI: mucosal disease		Severe diarrhoea and erosion	7	8	9.5
IBR	Acute phase		Reduced appetite, dullness, salivation, nasal and ocular discharge, lachrymation, conjunctivitis, rapid respiration, coughing and pyrexia, may lead to death	2.5	6	8
IBR	Acute phase		Diarrhoea and dehydration	2	3.5	5
IBR	Abortion		2nd and 3rd trimesters	1	3	5
ParaTB	Stage III	Cows	Weight loss/ Poor condition (BCS 1-2) /Chronic wasting	2	3.5	5
ParaTB	Stage III	Cows	Intermittent diarrhoea	1	3	4.5
ParaTB	Stage IV	Cows	Emaciation (BCS 0-1)	5	7.5	8.5
ParaTB	Stage IV	Cows	Pipe stream diarrhoea	3.5	5.5	7
ParaTB	Stage IV	Cows	Lethargic	6	8	9
PRRS	Epidemic	Sows and boars	Anorexia, fever, lethargy, respiratory difficulties, cyanosis	2	4.5	7
PRRS	Endemic	Sows	Reproductive problems including abortion, still-birth, and returns to service	1	2	3
PRRS	Endemic	Nursery	Poor growth, anorexia, fever, respiratory distress, diarrhoea, anaemia, congenital abnormalities, weakness, ataxia, haemorrhage, immunomodulation	2.5	5.5	8.5
PRRS	Endemic	Weaner and finisher	Transient anorexia, respiratory disorders, and discolouration of the ears	2.5	4	6
S. Dublin	Peracute	All age groups	Anorexia, signs of endotoxic shock (salivation, shaking, cold skin, ears), hyper- or hypothermia, lethargy, recumbent, shallow respiration, high pulse, dehydration, bloat, spasms, leading quickly to death (case-fatality 100%)	6.5	8	9

S. Dublin	Acute infection	Calves < 3 months old	Pyrexia (fever), respiratory symptoms (nasal and ocular discharge, coughing), pneumonia, omphalitis, diarrhoea, dysentery, malaise, dehydration, and less commonly with central nervous signs and polyarthritis (swollen, sore joints and lameness) (case-fatality 25-50%)	3.5	6	8
S. Dublin	Acute infection	Adult cattle	Profuse diarrhoea/dysentery in adult cows, anorexia, fever, weight-loss (case-fatality around 25%)	3.5	5	7.5
S. Dublin	Abortion due to acute infection	Adult cattle	Abortion in adult heifers and cows. Often without other clinical signs.	1	2	3
S. Dublin	Chronic infection	Calves 2-10 weeks (sometimes older)	Polyarthritis with swollen knees and fetlocks. Gangrene with sloughing of the skin on ear and/or tail tips. Sometimes with osteomyelitis - arched back and forelimbs extended forward. Tender on feet, tendency to knuckle or kneel on forelimbs, slow to rise -> become recumbent, pain elicited on manipulation of the neck.	5.5	7.5	9.5
S. Dublin	Mild transient	All age groups	Transient anorexia and fever	1	3	4
Welfare hazards - Cattle	No access to water - cattle	Cows	Scenario: dairy cattle left with no access to water due to broken pipes	1	5	9
Welfare hazards - Cattle	Broken femur - cattle	Cows	Scenario: dairy cow fell on slippery floor and is left until euthanised within a period of time	6	7.5	9.5
Welfare hazards - Cattle	Lying on concrete floor with no bedding material	Cows	Scenario: dairy cows resting in a free stall environment	3	5	6.5
Welfare hazards - Cattle	Too hot weather conditions	Cows	Scenario: warm summer days (>25 oC) interrupted by cooler nights. No access to shade during daytime.	3.5	5.5	8
Welfare hazards - Cattle	Separation of cow calf	Calves	Scenario: calf separated within 24h after birth	2	4	6
Welfare hazards - Pigs	Broken femur - pigs	Sows	Scenario: sow fell on slippery floor with other sows - she is pushed around	6	8	9.5
Welfare hazards - Pigs	Weaning of piglets	Piglets	Scenario: piglets are weaned 3-4 weeks after birth	2	4	5
Welfare hazards - Pigs	Tail biting	Weaner and finisher	Scenario: ongoing severe tail biting (part of tail bitten off, blood present)	4	6	8
Welfare hazards - Pigs	Crating of sows	Sows	Scenario: sows are crated in farrowing section (from 1 week prior to farrowing)	3	4	6.5
Welfare hazards - Pigs	Feed restriction	Sows	Scenario: feed provision is reduced to 30% of ad lib during gestation. Sows are housed together, but most often feed provision is individual	2.5	4.5	5

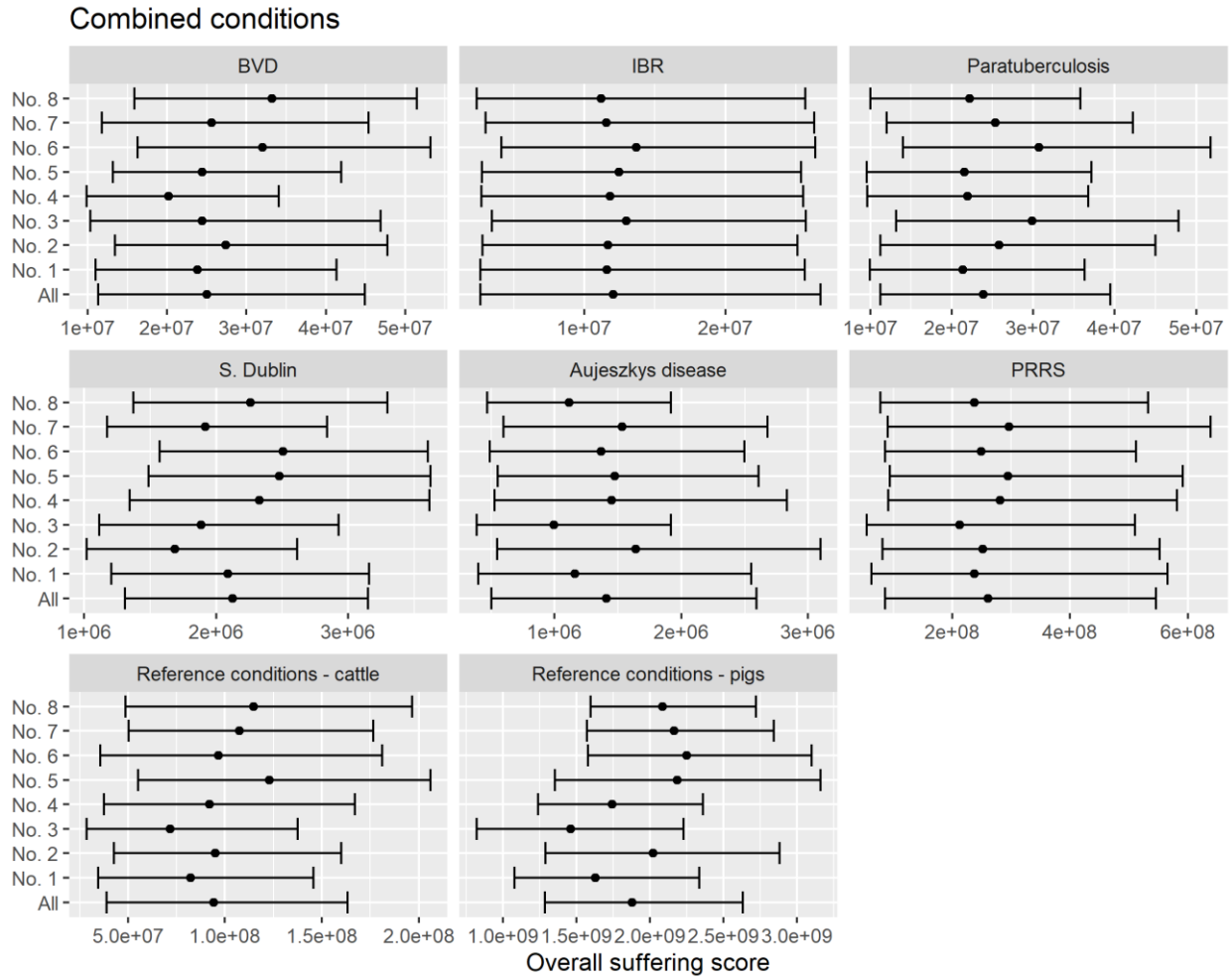

Figure 1. The aggregated severity scores by expert. Note the scale on the horizontal axes differs.

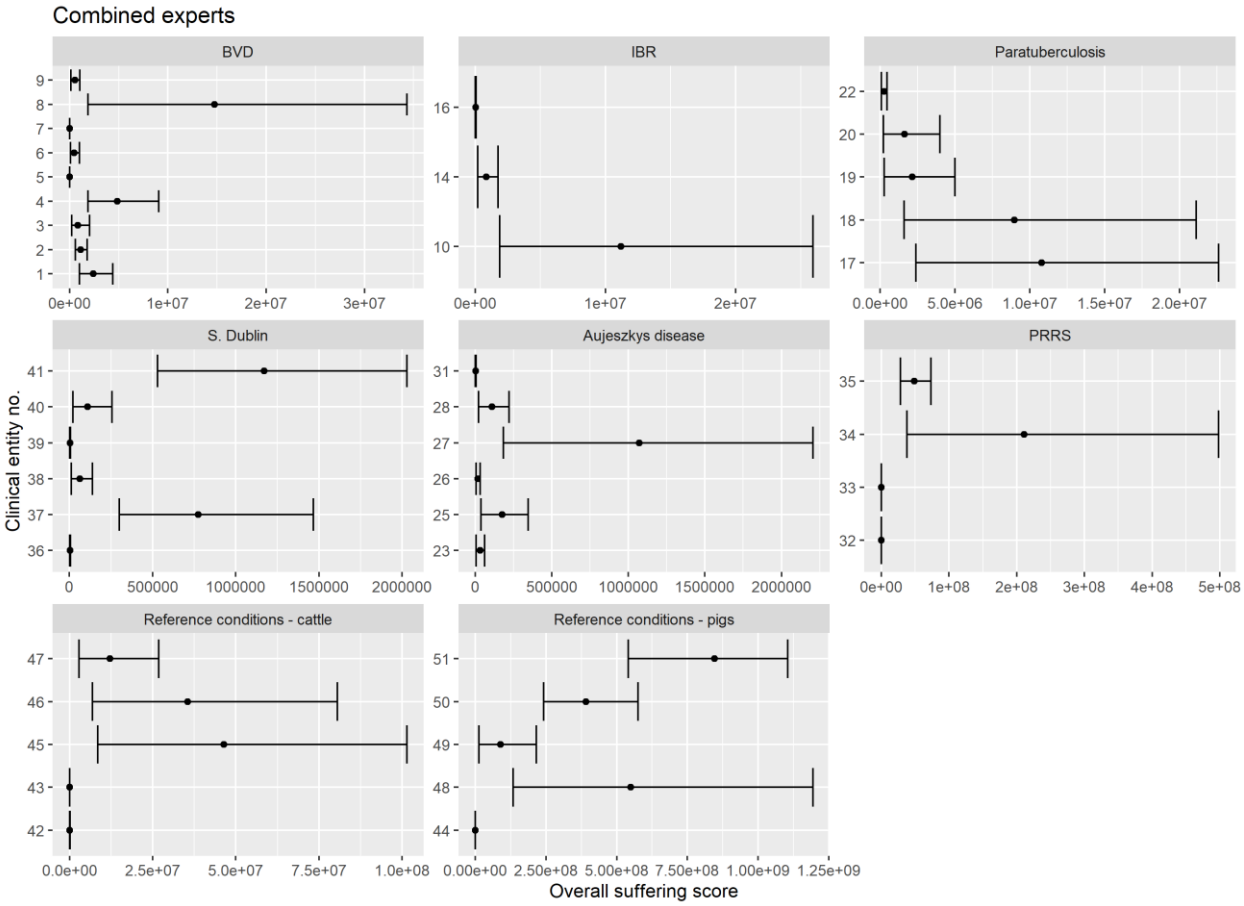

Figure 2. Aggregated suffering scores by disease condition. The numbering for the disease conditions are given in Appendix 1. Note that the scale on the horizontal axes differs.

Table 8. Suffering scores for four infectious diseases in cattle and two infectious disease in pigs, five welfare hazards in cattle and five welfare hazards in pigs. The suffering scores pertain to the Danish population in a year, but because the durations vary, the effect of short incidents (such as no access to water) can be shorter than for long incidents (such as lying on concrete floor)

Disease /welfare hazard	**Welfare score**		
	2.5 lower CL	**Mean**	**97.5 upper CL**
BVD	1×10^7	3×10^7	4×10^7
IBR	3×10^6	1×10^7	3×10^7
Paratuberculosis	1×10^7	2×10^7	4×10^7
S. Dublin	1×10^6	2×10^6	3×10^6
Aujeszky's disease	5×10^5	1×10^6	3×10^6
PRRS	8×10^7	3×10^8	5×10^8
WH Cattle: No access to water	4×10^3	4×10^4	1×10^5
WH Cattle: Broken femur	1×10^3	7×10^3	2×10^4
WH Cattle: Lying on concrete floor with no bedding material	6×10^6	3×10^7	8×10^7
WH Cattle: Too hot weather conditions	2×10^6	1×10^7	3×10^7
WH Cattle: Separation of cow calf	4×10^3	2×10^4	5×10^4
WH Pigs: Broken femur - pigs	9×10^6	5×10^7	1×10^8

WH Pigs: Weaning of piglets	1×10^8	5×10^8	1×10^9
WH Pigs: Tail biting	1×10^7	9×10^7	2×10^8
WH Pigs: Crating of sows	2×10^8	4×10^8	6×10^8
WH Pigs: Feed restriction	5×10^8	9×10^8	1×10^9

Table 9. Effect of disease control in Denmark compared to other selected countries. "Impact" describes the impact in other countries compared to Denmark. "n" is the population size for pigs (Aujezsky's disease (AD) and PRRS) or cattle (BVD, paratuberculosis, *Salmonella* Dublin and IBR).

			Suffering score			
Country	**Disease**	**n**	**Lower**	**Mean**	**Upper**	**Impact**
AT	AD	2773230	1×10^5	3×10^5	6×10^5	0.22
BE	AD	6085100	3×10^5	7×10^5	1×10^6	0.49
DE	AD	2.6E+07	1×10^6	3×10^6	5×10^6	2.1
DK	AD	1.2E+07	6×10^5	1×10^6	3×10^6	1
ES	AD	3.1E+07	1×10^6	3×10^6	6×10^6	2.39
FI	AD	1062200	5×10^4	1×10^5	2×10^5	0.09
IE	AD	1613270	7×10^4	2×10^5	3×10^5	0.13
NL	AD	1.2E+07	5×10^5	1×10^6	2×10^6	0.96
PT	AD	2216480	9×10^4	2×10^5	4×10^5	0.17
SE	AD	1481200	7×10^4	2×10^5	3×10^5	0.12
UK	AD	4741000	2×10^5	5×10^5	1×10^6	0.38
AT	PRRS	2773230	1×10^7	3×10^7	7×10^7	0.18
BE	PRRS	6085100	2×10^6	7×10^6	2×10^7	0.04
DE	PRRS	2.6E+07	6×10^7	2×10^8	5×10^8	1.18
DK	PRRS	1.2E+07	5×10^7	2×10^8	4×10^8	1
NL	PRRS	1.2E+07	2×10^7	7×10^7	2×10^8	0.4
UK	PRRS	4741000	1×10^7	5×10^7	1×10^8	0.27
DK	BVD	1427000	1×10^7	3×10^7	5×10^7	1
IE	BVD	6559650	5×10^7	1×10^8	2×10^8	4.6
NL	BVD	3721000	2×10^7	5×10^7	9×10^7	1.96
SE	BVD	1404670	1×10^7	2×10^7	5×10^7	0.98
BE	IBR	2373100	3×10^6	1×10^7	3×10^7	1.09
DK	IBR	1427000	3×10^6	1×10^7	3×10^7	1
IE	IBR	6559650	0	0	0	0
NL	IBR	3721000	1×10^6	6×10^6	1×10^7	0.47
AT	ParaTB	1879520	3×10^6	6×10^6	1×10^7	0.53
DK	ParaTB	1427000	5×10^6	1×10^7	2×10^7	1
FI	ParaTB	870740	0	0	0	0
NL	ParaTB	3721000	5×10^6	1×10^7	2×10^7	1.04
SE	ParaTB	1404670	0	0	0	0
UK	ParaTB	9459000	7.E+06	2.E+07	3.E+07	1.33
DK	S. Dublin	1427000	8.E+05	1.E+06	2.E+06	1
NL	S. Dublin	3721000	3.E+06	5.E+06	7.E+06	3.59

SE	S. Dublin	1404670	1.E+06	2.E+06	3.E+06	1.35

Discussion

This report provides – to our knowledge - the first attempt to quantify the impact of specific diseases on animal welfare. For example, it appears that Aujeszky's disease has a smaller impact on pigs than PRRS at population level, whereas the ranking for cattle is that BVD is worse than paratuberculosis, which is worse than IBR, which is worse than *Salmonella* Dublin in the endemic situation with no organised control effort/programme. If these assessments are considered valid, the data can be aggregated to country level and estimation of the effect of disease control on animal welfare can be estimated. For example, eradication of Aujeszky's disease resulted in a reduction in animal welfare points of 10^6 in Denmark, whereas the current reduction of PRRS from 67% to 31% has resulted in a reduction in welfare points of 2 x 10^8. These numbers can also be compared between countries and be used for benchmarking on the effect of disease control. For example, the effect of the Danish paratuberculosis programme may have been bigger than in Austria, despite that Austria has a bigger cattle population (Table 9).

Generally, some surprising results were seen due to the fact that clinical entities with a short duration had a smaller effect on animal welfare, although the prevalence has an effect if this is high.

The numbers may be used for comparison of diseases, welfare hazards and comparison between countries. However, caution should be exerted. Firstly, limited data on clinical signs and their distributions are available in the literature, and the distributions are often only vaguely described. Second, the durations and frequencies are often only vaguely described as well. Therefore, the aggregation of severity scores with duration and frequency results in major uncertainty. Similarly, the reductions are often guestimates as well, and therefore differences in suffering scores could easily occur.

Nonetheless, the model presented provides insight into how animal welfare consequences of infectious diseases can be aggregated and quantified on population level.

References

Bitsch, V., 1984:*The main epidemiological features of Aujeszky's disease.* Proc. 11th Conference of the OIE Commission for Europe, Vienna 1984, 381-391.

Carnell R (2019). triangle: Provides the Standard Distribution Functions for the Triangle Distribution. R package version 0.12. https://CRAN.R-project.org/package=triangle

de Paz, X. et al. (2015) 'PRRS prevalence in Europe: Perception of the pig veterinary practitioners - PRRS.com', Esphm 2015, 24(2), p. 1. Available at: https://www.prrs.com/en/publications/abstracts/prrs-prevalence-europe-perception-the-pig-veterinary-practitioners/.

Done, S. H., Paton, D. J. and White, M. E. G. (1996) 'Porcine reproductive and respiratory syndrome (PRRS): A review, with emphasis on pathological, virological and diagnostic aspects', British Veterinary Journal, 152(2), pp. 153–174. doi: 10.1016/S0007-1935(96)80071-6.

EFSA Panel, 2017: "Assessment of listing and categorisation of animal diseases within the framework of the Animal Health Law (Regulation (EU) No 2016/429): Aujeszky's disease". *EFSA Journal 15(7),* https://doi.org/10.2903/j.efsa.2017.4888

EFSA (European Food Safety Authority), 2014. Guidance on Expert Knowledge Elicitation in Food and Feed Safety Risk Assessment. EFSA J, 12:3734. doi:10.2903/j.efsa.2014.3734

EFSA AHAW Panel (EFSA Panel on Animal Health and Animal Welfare), More, S, Bicout, D, Botner, A, Butterworth, A, Calistri, P, Depner, K, Edwards, S, Garin-Bastuji, B, Good, M, Gortazar Schmidt, C, Michel, V, Miranda, MA, Saxmose Nielsen, S, Velarde, A, Thulke, H-H, Sihvonen, L, Spoolder, H, Stegeman, JA, Raj, M, Willeberg, P, Candiani, D and Winckler, C, 2017a. Scientific Opinion on the animal welfare aspects in respect of the slaughter or killing of pregnant livestock animals (cattle, pigs, sheep, goats, horses). EFSA J, 15:4782. https://doi.org/10.2903/j.efsa.2017.4782

EFSA Panel on Animal Health and Welfare, More, S, Bøtner, A, Butterworth, A, Calistri, P, Depner, K, Edwards, S, Garin-Bastuji, B, Good, M, Gortázar Schmidt, C, Michel, V, Miranda, MA, Nielsen, SS, Raj, M, Sihvonen, L, Spoolder, H, Stegeman, JA, Thulke, H-H, Velarde, A, Willeberg, P, Winckler, C, Baldinelli, F, Broglia, A, Candiani, D, Gervelmeyer, A, Zancanaro, G, Kohnle, L, Morgado, J and Bicout, D, 2017b. Scientific opinion on an ad hoc method for the assessment on listing and categorisation of animal diseases within the framework of the Animal Health Law. EFSA J; 15:4783. https://doi.org/10.2903/j.efsa.2017.4783

EFSA Panel on Animal Health and Welfare, Nielsen SS, Alvarez J, Bicout DJ, Calistri P, Depner K, Drewe JA, Garin-Bastuji B, Gonzales Rojas JL, Gortázar Schmidt C, Michel V, Miranda Chueca MÁ, Roberts HC, Sihvonen LH, Spoolder H, Stahl K, Velarde Calvo A, Viltrop A, Buijs S, Edwards S, Candiani D, Mosbach-Schulz O, Van der Stede Y, Winckler C, 2020. Health and welfare of rabbits farmed in different production systems. EFSA J. 18:e05944. doi: 10.2903/j.efsa.2020.5944.

Ferrouillet C, Wells SJ, Hartmann WL, Godden SM, Carrier J, 2009. Decrease of Johne's disease prevalence and incidence in six Minnesota, USA, dairy cattle herds on a long-term management program. Prev Vet Med. 88:128-37.

Houe H, Ersbøll AK, Toft N, 2004. Introduction to Veterinary Epidemiology, p. 84. Biofolia, Frederiksberg, Denmark.

Houe H, Agger JF, Nielsen SS, Forkman B, Nielsen LR, Otten ND, Denwood MJ, Andersen AKM, 2020. Literature reviews of clinical manifestations with qualitative assessment of impact on animal welfare for Bovine Viral Diarrhea in Cattle, Infectious Bovine Rhinotracheitis in Cattle, Paratuberculosis in Cattle, Aujeszky's Disease inSwine and Porcine Reproductive and Respiratory Syndrome in Pigs. Appendix to the final report of the project Infectious Livestock Diseases and Welfare. Knowledge Centre for Animal Welfare.

Gitter, M., Wray, C., Richardson, C and Pepper, R.T., 1978. Chronic *Salmonella* Dublin infection in calves. Br Vet J, 134, 113-121.

Healy, A.M., Doherty, M.L., Monaghan, M.L. and McAllister, H., 1997. Cervico-thoracic vertebral osteomyelitis in 14 calves. Vet J, 154, 227-232.

Hinton, M., 1974. *Salmonella* Dublin abortion in cattle: Studies on the clinical aspects of the condition. Br Vet J, 130, 556-562.

Nielsen, L.R., 2013a. *Salmonella* Dublin faecal excretion probabilities in cattle in 14 endemically infected dairy herds. Epidemiol Infect, 141, 1937-1944.

Nielsen, L.R., 2013b. Within-herd prevalence of *Salmonella* Dublin in endemically infected dairy herds. Epidemiol Infect, 141, 2074–2082.

Nielsen, L.R., Kudahl, A.B. and Østergaard, S., 2012. Age-structured dynamic, stochastic and mechanistic simulation model of *Salmonella* Dublin infection within dairy herds. Prev Vet Med, 105, 59–74.

Nylin B, Madsen KG, Rønsholt L 1998: Reintroduction of Bovine Herpes Virus Type 1 into Danish cattle herds during the period 1991-1995: A review of the investigations in the infected herds. Acta. Vet. Scand. 1998, 39, 401-413.

Rings, D.M., 1985. Salmonellosis in calves. Veterinary Clinics of North America: Food Animal Practice 1, 529–539.

VLA, 2010. Surveillance report published in Veterinary Record: High incidence of *Salmonella* Dublin in cattle and sheep, page 190, February 2010.

Wray, C. and Davies, R.H., 2000. *Salmonella* infections in cattle. In *Salmonella* in domestic animals. C. Wray and A. Wray, ed. CABI publishing, Wallingford, pp. 169-190.

Wray, C. and Sojka, W.J., 1977. Reviews of the progress of Dairy Science: Bovine salmonellosis. J Dairy Res, 44, 383-425.

Appendix

Appendix 1. Numbering of clinical entities

No.	Disease	Clinical entity	Age group
1	BVD	Transient infection	Calves
1	BVD	Transient infection	Heifers
1	BVD	Transient infection	Cows
2	BVD	Transient inf. with erosions	Calves
2	BVD	Transient inf. with erosions	Heifers
2	BVD	Transient inf. with erosions	Cows
3	BVD	Co-morbidity	Heifers
3	BVD	Co-morbidity	Cows
4	BVD	Co-morbidity	Calves
4	BVD	Co-morbidity	Heifers
5	BVD	Repeat breeding	Heifers
5	BVD	Repeat breeding	Cows
6	BVD	Abortion	Heifers
6	BVD	Abortion	Cows
7	BVD	Congenital defects and weak born calves, incl. Congenital tremor	In the new born
8	BVD	PI: animals unthrifty	Calves and heifers
9	BVD	PI: mucosal disease	Calves and heifers
10	IBR	Acute phase	calves, heifers & cows
14	IBR	Acute phase	calves, heifers & cows
16	IBR	Abortion	Cows
17	ParaTB	Stage III	Cows
18	ParaTB	Stage III	Cows
19	ParaTB	Stage IV	Cows
20	ParaTB	Stage IV	Cows
22	ParaTB	Stage IV	Cows
23	AD	Encephalitis	Piglets infected in utero
25	AD	Encephalitis	Weaners & finisher pigs (>3 weeks)
26	AD	Encephalitis	Adult pigs
27	AD	Respiratory signs	Weaners & finisher pigs (>3 weeks)
28	AD	Encephalitis	Piglets (< 3 weeks)
31	AD	Reproduction	
32	PRRS	Epidemic	Sows and boars

33	PRRS	Endemic	Sows
34	PRRS	Endemic	Nursery
35	PRRS	Endemic	Weaner and finisher
36	S. Dublin	Peracute	Newborn
36	S. Dublin	Peracute	Calves
36	S. Dublin	Peracute	Heifers
36	S. Dublin	Peracute	Cows
37	S. Dublin	Acute infection	Newborn
37	S. Dublin	Acute infection	Calves
37	S. Dublin	Acute infection	Heifers
38	S. Dublin	Acute infection	Adult cattle
39	S. Dublin	Abortion due to acute infection	Heifers
39	S. Dublin	Abortion due to acute infection	Adult cattle
40	S. Dublin	Chronic infection	Calves
41	S. Dublin	Mild transient	Newborn
41	S. Dublin	Mild transient	Calves
41	S. Dublin	Mild transient	Heifers
41	S. Dublin	Mild transient	Adult cattle
42	WH - Cattle	No access to water - cattle	Cows
43	WH - Cattle	Broken femur - cattle	Cows
45	WH - Cattle	Lying on concrete floor with no bedding material	Cows
46	WH - Cattle	Too hot weather conditions	Cows
47	WH - Cattle	Separation of cow calf	Calves
44	WH - Pigs	Broken femur - pigs	Sows
48	WH - Pigs	Weaning of piglets	Piglets
49	WH - Pigs	Tail biting	Weaner and finisher
50	WH - Pigs	Crating of sows	Sows
51	WH - Pigs	Feed restriction	Sows