Bluetongue surveillance in Belgium: A stochastic evaluation of its risk-based approach effectiveness

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Evaluation of the different surveillance components in Belgium according EC Regulation (EC 1266/2007)

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Short Title: **Bluetongue surveillance evaluation in Belgium**

Abstract

The aim of this study was to evaluate the four major surveillance system components (SSC) of BTV surveillance in Belgium in 2007 (winterscreening, sentinel, outbreaks report, export testing) and to determine the relative importance of each SSC in the context of freedom from disease and early detection using scenario tree simulations. Relative risks based on outbreak data, as well as on empirical data were fitted to each of the tree nodes and enabled to partition the herd population and sampled herds with regard to the differential risk of infection and detection. SSC's sensitivity and whole system sensitivity to detect the disease at the required legal design prevalence were computed; following which, efficiency of each surveillance SSC in terms of early detection was estimated. The results demonstrated that the winterscreening and sentinel SSCs had the best herd's sensitivities, while outbreaks reports showed poor herd sensitivity. However the latter turned out to be very efficient as an early detection tool, taking in account the sampling frequency, providing high disease awareness. The present study revealed interesting features and provided insight on key elements to account for when setting up a surveillance program. The use of empirical data based on field observations provided further reliability to the results.

Keywords: **Bluetongue/surveillance/risk based/sensitivity**

1. Introduction

Bluetongue (BT) is an arthropod-borne viral disease of both wild and domestic ruminants. BT virus (BTV) is the type species of the genus *Orbivirus* within the *Reoviridae* family. Recently, it was suggested to add the Toggenburg virus as 25th serotype to the 24 distinct BTV-serotypes already identified. Biting gnats of the genus *Culicoides* (Diptera: Ceratopogonidae) are, until now, the only known vectors in the transmission of BTV from ruminant to ruminant. The distribution of the virus is therefore limited to those regions where competent vector species are present and its transmission to those times of the year when the climatic conditions are favorable to the cycle of transmission [1]. BTV can cause mild to spectacular outbreaks and has an adverse impact on worldwide trade due to restrictions on the source of animals. It thus appears on the list of diseases notifiable to the World Organization for Animal Health (OIE). The vast majority of BTV infections are clinically unapparent. Cattle can act as a reservoir while sheeps are more prone to show clinical signs. When the disease does occur, common clinical signs are pyrexia, inflammation of the oral mucosa, excessive salivation, oedema of the head [2].

BTV is considered as an “emerging virus” since it has recently expanded its range northwards in Europe. Starting in August 2006 from the original focus in the area where Belgium, the Netherlands and Germany share borders, an epidemic of BTV serotype 8 gradually disseminated throughout the North-Western European

65 countries [3], causing the most severe outbreak of this disease ever recorded [4].
66 In 2007, BTV-8 re-emerged, even in a higher degree, in the same countries and
67 was also reported in the United Kingdom, Switzerland, Denmark and the Czech
68 Republic [5, 6]. In 2008, in order to control BTV-8, several European Member
69 States (MS) decided to start vaccination before the next vector season. The
70 campaign intended to reach a target of at least 80% of vaccination coverage [7, 8].
71 The European Union (EU) regulation 1266/2007/ EC [9] modified by
72 789/2009/EC [10] prescribes the implementation of i) passive clinical
73 surveillance, ii) sentinel surveillance, iii) a combination of serological and/or
74 virological surveillance, iiii) as well as a targeted risk based monitoring. A
75 distinction between regulated zones and non-regulated zones exists. In the
76 regulated zones an entomological surveillance is prescribed and further
77 investigation for each serotype isolated during the sentinel surveillance or the
78 serological and/or virological surveillance is required.
79 Rather than prescribing fixed guidelines the aim of the current regulations are
80 oriented towards minimum requirements to be fulfilled. As a consequence
81 regulations are flexible in order to allow each MS to adapt its surveillance
82 activities in order to meet the objectives and prove the efficacy of its system. The
83 present study has been done in this context and aimed at evaluating
84 the four major surveillance system components (SSC) of BTV surveillance in
85 Belgium and to determine the relative importance of each component in the
86 context of freedom from disease.

Scenario trees as illustrated by Martin et al. [11, 12] were used to conduct this study, as these have proven their efficacy already in the same context [11, 12, 13, 14, 15, 16, 17, 18, 19].

2. Materials and Methods

2.1. The major SSCs of BTV surveillance in Belgium in 2007

Surveillance data of 2007 were investigated in order to estimate the relative sensitivities of the four following surveillance SSCs for BTV in Belgium:

-Yearly cross sectional serological/virological survey in cattle herds during the winter season ('winterscreening' (WS))

-Monthly sentinel surveillance in cattle herds, during the high vector activity period [9, 20] (Sentinel)

-Outbreaks reports following passive clinical surveillance of all ruminant herds (sheep, cattle) (OutB)

-Export testing, the majority of animals exported being cattle (Export)

The whole population in Belgium was constituted of approximately 36,894 cattle herds and 31,416 small ruminant herds in 2007.

2.2. Design of the whole disease process in a scenario tree

A scenario tree for each surveillance SSC (WS, Sentinel, OutB, Export) was designed in different Excel spread sheets. The general structure of scenario tree is shown in figure 1. All factors interfering with the probability of infection or detection were taken in account. In this study it was assumed the SSCs were all independent. Only one combination of nodes branches is displayed for clarity purpose, but all pathways were considered in the simulations.

Within each SSC, the first node was the "Country Status" to which the minimum design prevalence at herd (DPh) and animal level (DPa) was attributed (2% as prescribed by the EU regulation [9].

The following major factors retained in the tree of this SSC influencing the risk of infection, were accounted in the category nodes "Zone" (Risk/Non Risk), "Vector Activity period" (Low/High) "Species"(Sheep/Cattle). To each of these category nodes parameters were attributed: relative risks (RR_i) of infection of a herd and respective herd population proportions (PPr_i) as well as sampled herd proportion (SPr_i), which is the number of herds sampled in one node branch over the total number of herds sampled in that node.

Each possible combination of category nodes was defined as a different risk group.

127 **2.3. Model description: Rationales for RR and Cut offs**

128 The parameters entered above enabled the calculation of the adjusted risk of
129 infection (AR_i) for each risk group which in turn would provide the effective
130 probability of infection ($EPIH_i$) for each risk group (Eq. 1 and 2).

131

132 $$AR_i = \frac{RR_i * PPr_i}{\sum(RR_i * PPr_i)} \quad \text{(Eq. 1)}$$

133 $$EPIH_i = DPh_i * AR_{RiskZone_i} * AR_{VectorActivity_i} * AR_{AnimalSpeecie_i} \quad \text{(Eq. 2)}$$

134

135 For each risk group, a category node "Diagnostic Process" (TSe_i) was entered.
136 This last category node differed according to the SSC considered. For the
137 diagnostic process considered in each SSC only those factors that determine the
138 sensitivity were considered. A specificity of 100 % was assumed, as each positive
139 result was further investigated. TSe_i for WS, Sentinel and Export was the
140 antibody ELISA BTV (ID-VET®, France) (Ab-ELISA) test. In the passive
141 clinical surveillance SSC, the probability of a farmer noticing clinical symptoms
142 and calling a veterinarian, the probability of a vet coming on the farm and taking a
143 sample as well as the probability of the sampling reaching the laboratory and
144 analysed were all taken in account in one single distribution parameter for
145 characterizing TSe_i.

146

147

2.4. Different nodes and their parameters

2.4.1. *Risk status of zone*

Results of the spatial risk factor analysis described by Faes, et al. [21] were used to define the Belgian risk zones. Specifically for this objective, the probability of a farm being infected in a municipality was modeled taking only into account land cover variables and altitude. A map representing the obtained predicted probability of an infected farm in each Belgian municipality was produced using ArcView GIS 3.2. (ESRI). The municipality was considered to be a risk zone if the predicted probability of infection was above 1%. The non-risk zone used as reference was attributed a uniform distribution of 1(Uni Distr (1; 1)). The province delimitations were overlaid on this map in order to delimit provinces belonging to "Risk" and "Non Risk" Zones (Figure 2). If the average municipality predicted probability of infection per province was above 10%, the province was considered as risk province. As a result, provinces of Antwerp (3), Brabant (4), Limburg (5) and Liege (8) were designated as part of the "Risk Zone", whereas provinces West Flanders (1), East Flanders (2), Hainaut (6), Namur (7) and Luxemburg (9) belonged to the "Non Risk Zone". A pert distribution (was used to describe the relative risk of being infected in a risk zone (minimum value of 1, thus risk zone having the same risk as non-risk zone, most likely value 1, maximum value of 2) (Pert Distr (1; 1; 2)) (Table 1).

2.4.2. Vector activity

Two vector activity periods were distinguished, as in Belgium from the 30th march till the 13th of December is considered to be the high vector activity period, and the remaining of the year is considered to be the non-vector activity period [9, 20]. The non-vector activity period used as reference was fitted with a uniform distribution of 1 (Uni Distr (1; 1)). In order to estimate the difference in infection of both periods, the export dataset was chosen because this dataset was not influenced by seasonal trends (increased disease awareness or targeted sampling) thus enabled to compare objectively the relative proportions of infection in both periods. For the characterization of the RR a pert distribution with the minimum, maximum, most likely proportion of positive serology in both periods were chosen from the export dataset in 2007 during the high vector activity period and the non-vector activity period (Pert Distr (1; 2; 3)) (Table 1).

2.4.3. Animal Species

In order to quantify the risk of cattle relative to sheep, the minimum, maximum, most likely values of seroprevalence proportions in both groups, found in literature, were used to model the relative risk with a pert distribution [22, 23, 24, 25, 26] (Table 1). The small ruminant category used as reference was attributed a risk uniform distribution of 1 (Uni Distr (1; 1; 1)). Higher risk was attributed to cattle as they tend to exhibit less clinical signs and yet, show a higher seroprevalence (Pert Distr (1; 3.6; 4.2)).

193 *2.4.4. Diagnostic process sensitivity*

194 For the diagnostic process in sentinel, export and WS SSC Ab-ELISA serology
195 was used as reference with triangular distribution (Triang Distr (0.85; 0.89; 0.92))
196 for cattle, and triangular distribution (Triang Distr (0.78; 0.85; 0.91)) for sheep
197 [27]. Within the passive clinical SSC, the probability of a farmer noticing clinical
198 symptoms and calling a veterinarian (vet), the probability of a vet coming on the
199 farm and taking a sample as well as the probability of the samples reaching the
200 laboratory and analyses were all taken in account in one single distribution
201 parameter with a wide range of uncertainty (Triang Distr (0.01; 0.5; 0.99)).
202
203 *2.4.5. The population proportion and sampled proportion*

204 Table 2 represents the number of herds for each herd risk group within each SSC
205 as well as the number of herds sampled in 2007. The data were extracted from the
206 National Animal Identification and Registration System (SANITEL) and the
207 National Laboratory Information Management System (LIMS). For OutB SSC to
208 situations were considered, one where all herds were actually looked at and
209 showing clinical signs, and one where only 2% of the herds were infected and
210 showed clinical signs.
211
212

2.5. Obtaining sensitivities and posterior probabilities of disease freedom for each SSC

The combination of the TSe_i of each herd risk group to the relative proportions of herds tested in each risk group, SPr_i, allowed the calculation of an effective probability of detection (EPD_i) for each limb of the tree (Eq. 3).

$$EPD_i = SPr_{RiskZone_i} * SPr_{VectorActivity_i} * SPr_{AnimalSpecie_i} TSe_{\ Diagnostic\ Process_i} \quad \text{(Eq.3)}$$

In turn these EPD_i were used to obtain the respective mean herd sensitivities (HSe_i) for each risk group, taking in account the average number of animals sampled "n_a" in each herd of average size "N_a". Subsequently the mean risk group sensitivity (GSe_i) for each risk group was obtained, taking in account the average number of herds "n_h" of risk group size "N_h" within each SSC in 2007. Because the fraction of animals or herds tested on the total population has an influence on the sensitivity, appropriate methods were used as described below.

If a high number of animals are tested within the herds, the hypergeometric approach was applied (WS, Sentinel) (Eq. 4), if the number of animals (Export) or herds (WS, Sentinel, Export) tested was smaller than 10% the binomial approach was applied (Eq. 5, 6). The exact approach was applied if all animals and herds were tested (OutB) (Eq. 7, 8).

$$HSe_i = 1 - (1 - (EPD_i * \frac{n_{a_i}}{N_{a_i}}))^{DPa_i * N_{a_i}} \quad \text{(Eq. 4)}$$

$$HSe_i = 1 - (1 - (EPD_i * DPa_i))^{n_{a_i}} \quad \text{(Eq. 5)}$$

236 $HSe_i = 1 - (1 - EPD_i)^{DPa_i * N_{a_i}}$ (Eq. 6)

237 $GSe_i = 1 - (1 - (HSe_i * EPIH_i))^{n_{h_i}}$ (Eq. 7)

238 $GSe_i = 1 - (1 - HSe_i)^{EPIH_i * N_{h_i}}$ (Eq. 8)

239

240 For the WS SSC, the mean number of sampled animals n_a was fixed at 50, in
241 average herd size at 70 N_a. For the sentinel SSC, n_a was fixed at 15 (in accordance
242 with EU regulation 1266/2007/EC [9]) in an average herd size at 70 N_a. The n_a, in
243 the Export SSC, was considered as 2 in average herd size of 70 N_a, because on
244 average 1 or 2 animals per herd were tested for export per year. In the OutB SSC,
245 n_a was equivalent to N_a of 70, as all animals were considered.
246 These estimations were obtained following univariate studies which enabled to
247 estimate the 50th percentile herd size and number of animals sampled in the
248 population and in each SSC. The number of herds tested n_h in each herd risk
249 group of size N_h over the year 2007 is shown in table 2 for each SSC respectively
250 and the whole population.
251 Following this, the monthly trend in 2007 of the posterior probability of freedom
252 ($PFree_i$), was estimated using the ongoing collection of data. Each HSe_i was
253 estimated separately for each herd tested each month in each risk group, based on
254 the respective EPD_i as well as the number of animals sampled n_a within the
255 respective herd of size "N_a". The GSe_i was also estimated for each herd risk
256 group, each month in 2007, based on the number of herds sampled and the
257 respective HSe_i in each risk group.

The probability of infection ($PInf_i$) for the first month of the present study was considered as 0,5. This $PInf_i$, was chosen as it was assumed no prior knowledge over the disease status of the country existed. This value $PInf_i$ changes as the data is collected each month providing a posterior probability of freedom for the given month and hence the following month's prior probability of infection. The posterior probability of freedom ($PFree_i$) was obtained for each month of 2007, given GSe_i, $Pinf_{ti-1}$ of each previous month and probability of introduction ($PIntro_i$) (Eq. 9, 10).

$$PFree_i = \frac{1-PInf_{t_i-1}}{1-PInf_{t_i-1}*GSe_i} \quad \text{(Eq. 9)}$$

$$PInf_i = \left(1 - PFree_{t_i-1}\right) + PIntro_i - \left(PIntro_i * \left(1 - PFree_{t_i-1}\right)\right) \quad \text{(Eq. 10)}$$

The SSC sensitivity (CSe_i) was obtained by the combination of each GSe_i for each month of 2007 by the following equation (Equation 11).

$$CSe_i = 1 - \prod(1 - GSe_i) \quad \text{(Eq. 11)}$$

The monthly posterior probability for each SSC was also estimated with the same formula as above (Eq. 9), replacing in this case GSe_i by CSe_i freedom for each SSC.

The scenario trees were modeled in Microsoft Excel using @risk 5.0 software, taking the uncertainty and variability of parameters into account by fitting appropriate parameter distributions. The sensitivity estimates for the different

281 SSCs were obtained by separate hypergeometric simulation for each SSC with
282 10,000 iterations in each simulation. This offers the opportunity to consider all the
283 possible pathways in the scenario by sampling from the parameter distributions.
284
285 **2.6. Sensitivity analysis**
286 To determine what input parameter affected most the SSC sensitivity output, a
287 sensitivity analysis was carried out for each SSC. Regression coefficient enabled
288 to measure how sensitive the input variable was on the output variable of interest.
289
290 **3. Results**
291 **3.1. Herd and risk group's sensitivities**
292 Table 3 illustrates the respective herd and risk group sensitivities obtained for
293 each risk group in each SSC, after a full year surveillance.
294 These results showed that WS, only conducted in winter months (VAL), and
295 Sentinel, done in summer months (VAH) had the best HSe_i, providing samples are
296 taken in the respective risk group. Null values appeared for sheep, because no
297 sheep were sampled within these SSCs. The GSe_i ranged within 85-99%
298 confidence interval for most of the risk groups identified in most of the SSCs. In
299 the Export SSC, the risk group sensitivities were low with the highest sensitivity
300 in a non-risk zone with high vector activity. In the other SSCs the smaller values
301 during the low vector activity period for cattle and during the whole year for
302 sheep reflected the fact that less samples were taken during those periods, and in
303 sheep. The OutB SSC showed lower HSe_i then Sentinel and WS. The individual

304 GSe_i in the OutB SSC were of high value providing all herds were tested, this was
305 no longer the case when only 2% of the herds were considered. A wide range of
306 uncertainty is present around the mean HSe_i GSe_i values in OutB, this uncertainty
307 ranged was all the more evident when only 2% of the herds were considered.
308
309 **3.2 Component sensitivities**
310 WS and Sentinel system appeared very powerful tools for detecting the disease
311 after a whole year of surveillance. However, it's important to know the
312 sensitivities of a SSC within the concept of early detection. Therefore, the
313 monthly simulations shown in figure 3 accounted for this ongoing collection of
314 surveillance data in each SSC.
315 The OutB SSC appeared the most sensitive, although the EPD was low in that
316 SSC (Table 3), the large amount of sheep and cattle herds processed monthly in
317 that SSC over the year 2007 (the whole population is actually processed as
318 sampled data) enabled to raise the total SSC sensitivity and maintain it high. In
319 the WS SSC the CSe was high in January, and then dropped down when no more
320 samples were taken in the following months. The sentinel SSC sensitivity rised up
321 in March and remained high till September October.
322
323 **3.3 Posteriors probabilities of freedom**
324 The $PFree_i$ at the end of each month in each SSC following the ongoing collection
325 of data process is shown in figure 4. The initial $PFree_i$ was set to 0.5 as it was
326 assumed that no prior information existed towards the probability of freedom. As

data was collected each month, the certainty of $PFree_i$ increased or decreased depending on the level of the CSe_i that month. In the WS SSC, the $PFree_i$ was the highest in January, but later decreased. The Export SSC offered only very limited guarantee towards the country $PFree_i$ throughout the whole year, while the sentinel SSC offered good guarantee during spring and summer. In the OutB SSC, data was collected all year around; the level of confidence towards $PFree_i$ was maintained high all year around.

3.4. Sensitivity analysis

The sensitivity analysis results showed that the most influential parameters were the AR obtained for RZ, RZVAH, RZVALB, followed by the TSe_i in the different SSC. The range of values were different in each SSC the impact the highest was for OutBreak SSC, followed by Sentinel and ended with Export, where the impact of the input parameters were the smallest. The respective regression coefficients were ranging from 0.69 to 0.99.

4. Discussion

This study provided good insight on sensitivity of Belgium surveillance system regarding the detection of Bluetongue over the year 2007. Furthermore the simulations carried out per month enabled to have a clear idea on how much each SSC contributed to the sensitivity in early detection.

Good levels of HSe_i for WS and Sentinel SSCs were obtained whilst this was not the case for OutB SSC, due to the low EPD_i of that SSC. The reason for this might

350 be the TSe attributed to reflect the farmer, veterinary and laboratory sensitivity in
351 that SSC.
352 When taking a look at the GSe_i, the OutB SSC had high sensitivity. The large
353 amount sheep and cattle herds processed monthly in that SSC over the year 2007
354 (whether the whole population, or only 2% of it were considered as sampled data)
355 probably contributed to the raise and maintenance of the high level of total SSC
356 sensitivity, despite the low EPD_i. However values of HSe_i and GSe_i were lower
357 when only 2% of the herds were considered. The value of 2% of herds was chosen
358 in this case as it was thought that if the country was infected at a 2% prevalence
359 probably only 2% of the herds could be infected and display clinical signs that
360 could be detected. Thus considering all the population was sampled in that SSC
361 was not correct, therefore simulations were carried out to measure the impact on
362 the individual HSe_i and GSe_i. It appears clear that OutB plays a major role
363 providing all the assumptions set in this study are met. If this condition is not met
364 anymore the GSe_i is no longer as good. The importance of disease awareness has
365 already previously been demonstrated [28, 29, 30, 31]. More in depth study of this
366 parameter would be requested, in order to better estimate the sensitivity of this
367 SSC. Passive clinical surveillance could appear to be a seducing alternative, but
368 not only is it strongly dependent on the ability of showing clinical symptoms
369 when animals are infected, but also the level of disease awareness amongst
370 farmers and efficiency of communication between farmers, veterinarians and
371 authorities but will influence the efficiency of this SSC. It has been noticed in the
372 past that in southern countries with extensive farming, thus less contact between

373 farmers and animals, that the first cases were noted by serological surveillance
374 whereas in northern countries with more intensive farms and higher media
375 communication, thus disease awareness the first cases were noticed by passive
376 clinical surveillance. Farmers could be reluctant to report in some situations by
377 fear of ethical and economic repercussions. Also one could wonder if is it ethical
378 to wait till animals show clinical symptoms before detecting the disease and
379 taking appropriate measures. Furthermore in a situation where vaccination is
380 applied, clinical signs might not be any longer appearing, in which case disease
381 awareness will decrease.
382 Using samples taken for other diseases could be an interesting opportunity to early
383 detect the occurrence of BTV in the population.
384 The sentinel SSC showed very good CSe_i and $Pfree_i$ values from the month of
385 March onwards till September October. Despite the fact that not all herds and
386 animals were sampled within that SSC, the very high levels of both HSe_i and GSe_i
387 explains the performance of this SSC in terms of early detection in comparison to
388 OutB.
389 WS has been carried out in Belgium since the first BTV episode of 2006.
390 Prevalence estimation was the primary aim of the WS and till a compulsory
391 vaccination campaign was implemented in 2008. Measuring the vaccination
392 coverage and efficiency, as well as the freedom of disease were the aims of the
393 WS carried out in 2009 and 2010. Because WS only occurs during the winter
394 season, this SSC might not be optimal for early detection. However, it must be
395 noticed that the average within herd sensitivities and herd sensitivities information

396 from these WS are of high value as they provide results of disease situation after a
397 whole year, thus it may be concluded that WS is useful for substantiating freedom
398 of disease after a whole year surveillance or/and for the seroprevalence estimate in
399 the country.
400 Export testing had only limited value in Belgium due to the small number of
401 samples taken in that SSC.
402 When taking a look at the monthly simulation of CSe_i and $PFree_i$, it can be noted
403 that for the months where data was collected, though not all risk groups are
404 sampled (Sheep not sampled) in the WS and Sentinel SSC, the CSe as high as
405 OutB SSC. The large amount of herds tested (but lower than in OutB SSC)
406 combined to the relative good EPD contributed to this high CSe. The Export
407 testing had a low CSe, the highest value was in April May. Despite the relatively
408 good EPD, very small number of animals and herds were sampled in that SSC
409 which contributed to this low value of CSe. Relying only on testing export to
410 provide confidence around the posterior probability of freedom is not sufficient.
411 Once again the OutB turned out to be efficient providing all the assumptions were
412 met.
413 The current surveillance systems prescribed by the consolidated regulation
414 1266/2007/EC [9] (amended by a number of different regulations, the latest
415 amendment being the regulation 789/2009/EC [10] aims at a surveillance system
416 at herd level and within a herd. But for a vector borne disease such as BTV it
417 might be better to aim the surveillance around municipality level, or risk group
418 level set on the vector biology characteristics. This study enabled to have a clear

419 insight on the different herd sensitivities in the different risk groups characterized
420 by risk factors influencing the epidemiology of the disease (Zone, Vector
421 Activity, and Species). The outcome of this study showed that targeting cattle
422 herds in risk zones and non-risk zones during the vector season activity provided
423 the best sensitivity. Furthermore the sensitivity analysis supports these results as
424 well. Due to the vector borne nature of this disease, the clustering effect according
425 to the vector distribution, must be considered, rather than a classical surveillance
426 system based on herds.
427 It is evident that the output of the present study is strongly dependent on the input
428 parameters and the assumptions, such as the RR_i, the TSe_i for the diagnostics test,
429 or the population effectively sampled (i.e. OutB SSC). However these
430 assumptions were limited as much as possible, using literature and empirical data
431 for the diagnostic test sensitivities, outbreak data for the relative risks. Fitting
432 distributions, taking in account the uncertainty and variability around the input
433 parameters, also enabled the most accurate representation of the real life situation.
434 In the future, a cost benefit analysis should be considered in other to better
435 estimate the efficiency of each surveillance system, not only in terms of
436 sensitivity but also in terms of field work, human resources, relative costs, and
437 ethical considerations.
438
439

5. Conclusion

Some recommendations can be made following the output of the present study, for the future BTV surveillance in Belgium;

-WS is useful to have an overall prevalence interpretation at the end of the year.

-Export testing on its own is not enough to guarantee freedom of disease nor to enable early detection.

-Sentinel program is very efficient to prove freedom of disease and as an early detection system, providing sufficient samples are taken, and the sampling frequency is high enough, a monthly or 4 monthly base would be wise.

-Clinical passive surveillance SSC is efficient too but submitted to a few constraints. This component is of limited value if disease awareness is low, such as, for instance, when animals show less clinical signs or if vaccination is applied. This emphases the need of having an ongoing vigilance system, amongst the farming sector, through information campaigns or routine health checkup system on farms.

As a main conclusion, this study has enabled to better quantify the sensitivity of the main surveillance SSC taking in account, for each SSC, the risk factors, the sampling probability, the expected prevalence and the diagnostic process sensitivity, based on passed outbreak data as well as field reality which provides further reliability to the results. Such methods showed to be a useful tool to meet the international standards when implementing disease surveillance in a country.

Competing Interest

The authors declare that they have no competing interests.

Authors' contributions

SW created the scenario model in the study, performed most of the statistical analysis in the study and drafted the manuscript.

EM prepared the data and contributed to the writing and revising of the manuscript.

CF provided statistical support and revised the manuscript.

KD provided feedback about the virological background and revised the manuscript.

JH provided feedback regarding the legal requirements and revised the manuscript.

KM participated in the design of the study and revised the manuscript.

YV participated in the design and coordination of the study and revised thoroughly the manuscript.

All authors read and approved the final manuscript.

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634 Figure 1 Scenario tree illustrating the successive events from infection to
635 detection for BTV in Belgium
636
637 Figure 2 Map allowing definition of BTV-8 risk zones in Belgium
638
639 Figure 3 Evolution in CSe for each month of the year (2007) for the different
640 surveillance SSCs
641

642 Figure 4 Probability of disease freedom per SSC and per month when
643 accumulating evidence of disease freedom over the months

644

645 Table 1 Relative risk distributions for each risk category node

Node	Relative Risk
Risk Zone	Pert Distr (1; 1; 2)
Non risk zone	Uni Distr (1; 1)
High vector activity	Pert Distr (1 ; 2; 3)
Non vector activity	Uni Distr (1; 1)
Cattle	Pert Distr (1; 3.6; 4.2)
Sheep	Uni Distr (1; 1)

646

647

Table 2 Representative herds population, and sampled herds within each SSC (WS, Sentinel, OutB, Export)

Risk Group	Population	WS	Sentinel	OutB (All)	OutB (2%)	Export
RZ/VAH/BV	14060	0	108	14060	281	55
RZ/VAH/OV	11184	0	0	11184	224	3
RZ/VAL/BV	14060	144	6	14060	281	21
RZ/VAL/OV	11184	0	0	11184	224	1
NRZ/VAH/BV	24745	0	131	24745	495	121
NRZ/VAH/OV	20593	0	0	20593	412	5
NRZ/VAL/BV	24745	200	21	24745	495	24
NRZ/VAL/OV	20593	0	0	20593	412	0

RZ/VAH/BV: Risk Zone Vector Activity High Bovine NRZ/VAH/BV: Non Risk Zone Vector Activity High Bovine

RZ/VAH/OV: Risk Zone Vector Activity High Ovine NRZ/VAH/OV: Non Risk Zone Vector Activity High Ovine

RZ/VAL/BV: Risk Zone Vector Activity Low Bovine NRZ/VAL/BV: Non Risk Zone Vector Activity Low Bovine

RZ/VAL/OV: Risk Zone Vector Activity Low Ovine NRZ/VAL/OV: Non Risk Zone Vector Activity Low Ovine

656 Table 3 Herd and Risk Group sensitivities (Medium value (Minimum-Maximum))

657 for each herd risk group in WS, Export and Sentinel SSC

Risk Group		Surveillance component				
		WS	Export	Sentinel	OutB All	OutB 2%
RZ/VAH/BV	HSe	0.00 (0.00-0.00)	0.10 (0.10-0.10)	0.74 (0.73-0.75)	0.55 (0.03-0.83)	0.55 (0.04-0.82)
	GSe	0.00 (0.00-0.00)	0.20 (0.14-0.29)	0.96 (0.89-0.99)	1.00 (0.99-1.00)	0.99 (0.36-1.00)
RZ/VAH/OV	HSe	0.00 (0.00-0.00)	0.01 (0.00-0.01)	0.00 (0.00-0.00)	0.47 (0.02-0.74)	0.48 (0.02-0.74)
	GSe	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.99 (0.93-1.00)	0.78 (0.04-0.99)
RZ/VAL/BV	HSe	0.99 (0.99-1.00)	0.04 (0.04-0.04)	0.07 (0.07-0.07)	0.55 (0.04-0.82)	0.55 (0.03-0.82)
	GSe	0.95 (0.83-0.99)	0.02 (0.01-0.03)	0.01 (0.01-0.01)	0.99 (0.99-1.00)	0.96 (0.17-0.99)
RZ/VAL/OV	HSe	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.47 (0.021-.74)	0.48 (0.02-0.74)
	GSe	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.99 (0.77-1.00)	0.56 (0.02-0.96)
NRZ/VAH/BV	HSe	0.00 (0.00-0.00)	0.21 (0.20-0.22)	0.81 (0.80-0.82)	0.74 (0.03-0.96)	0.74 (0.53-0.96)
	GSe	0.00 (0.00-0.00)	0.60 (0.44-0.69)	0.98 (0.91-0.99)	1.00 (1.00-1.00)	0.99 (0.58-1.00)
NRZ/VAH/OV	HSe	0.00 (0.00-0.00)	0.01 (0.01-0.01)	0.00 (0.00-0.00)	0.68 (0.04-0.92)	0.68 (0.04-0.93)
	GSe	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.99 (0.99-1.00)	0.97 (0.18-0.99)
NRZ/VAL/BV	HSe	1.00 (1.00-1.00)	0.04 (0.04-0.05)	0.22 (0.22-0.23)	0.74 (0.04-0.96)	0.74 (0.03-0.96)
	GSe	0.97 (0.89-1.00)	0.02 (0.01-0.03)	0.05 (0.08-0.13)	1.00 (0.99-1.00)	0.99 (0.20-1.00)

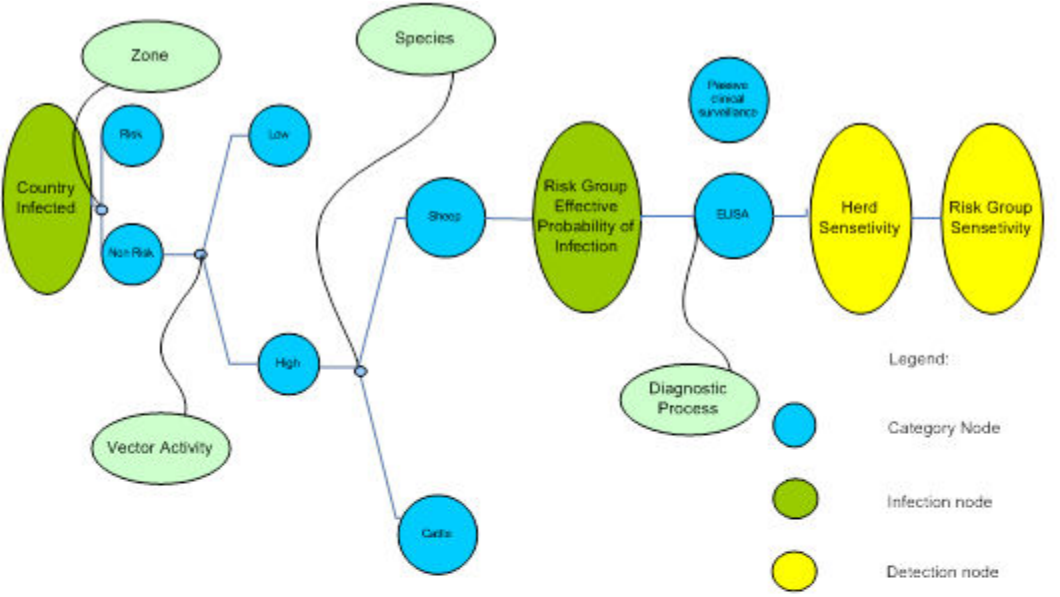
NRZ/VAL/OV	HSe	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.68 (0.04-0.93)	0.68 (0.04-0.93)
	GSe	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.99 (0.99-1.00)	0.89 (0.09-0.99)

RZ/VAH/BV: Risk Zone Vector Activity High Bovine NRZ/VAH/BV: Non Risk Zone Vector Activity High Bovine

RZ/VAH/OV: Risk Zone Vector Activity High Ovine NRZ/VAH/OV: Non Risk Zone Vector Activity High Ovine

RZ/VAL/BV: Risk Zone Vector Activity Low Bovine NRZ/VAL/BV: Non Risk Zone Vector Activity Low Bovine

RZ/VAL/OV: Risk Zone Vector Activity Low Ovine NRZ/VAL/OV: Non Risk Zone Vector Activity Low Ovine


Zone
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Risk Group Effective Probability of Infection
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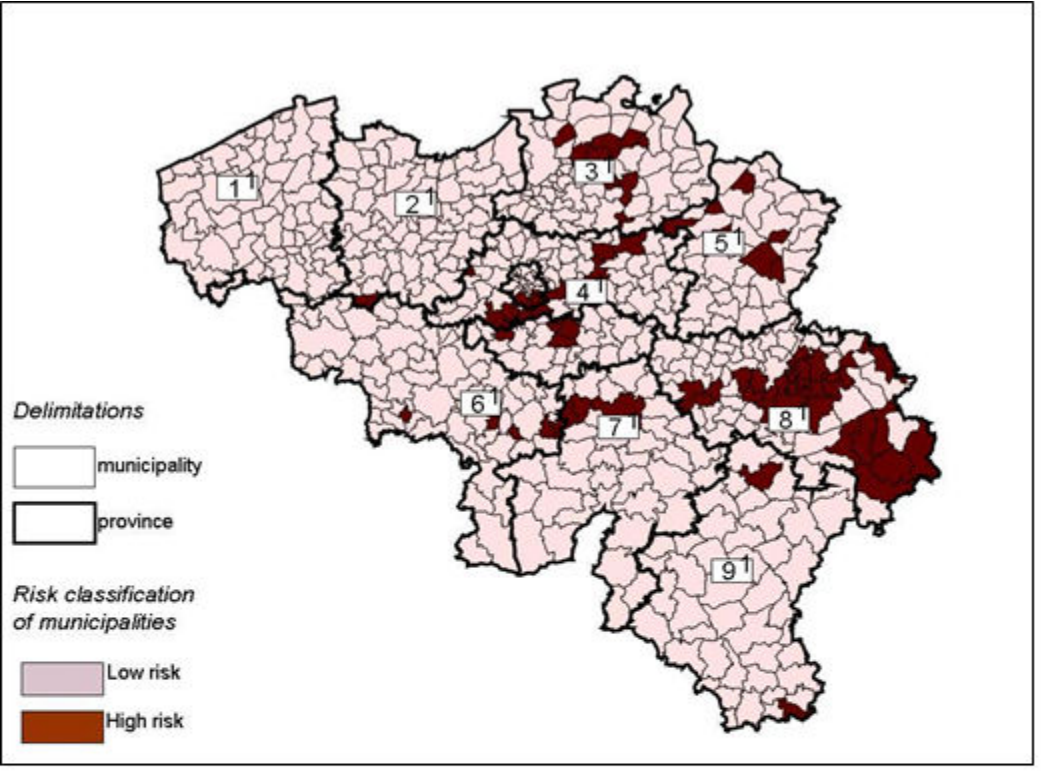
Vector Activity
Cattle
Legend:
Category Node
Infection node
Detection node

Figure 1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Delimitations
municipality
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Risk classification of municipalities
Low risk
High risk

Figure 2

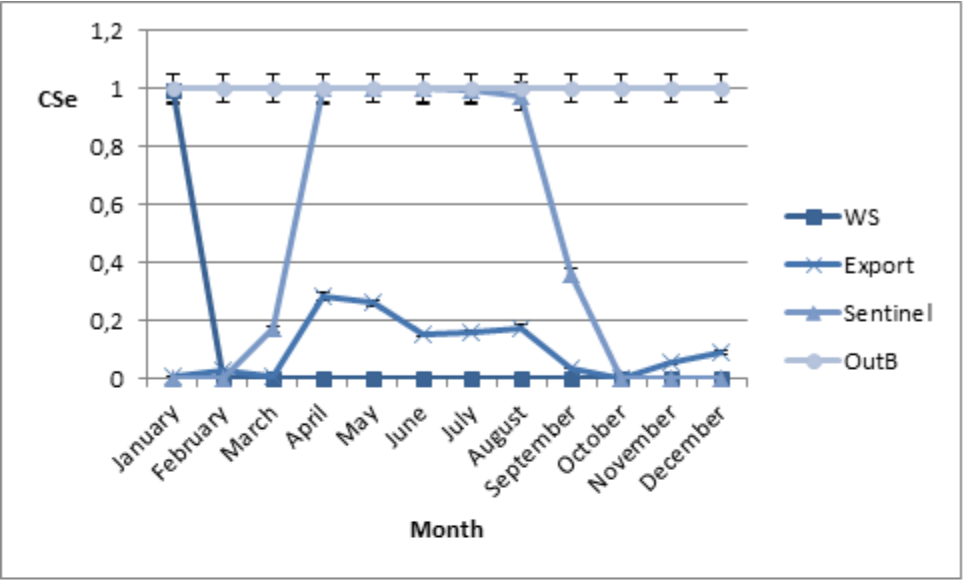
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Figure 3

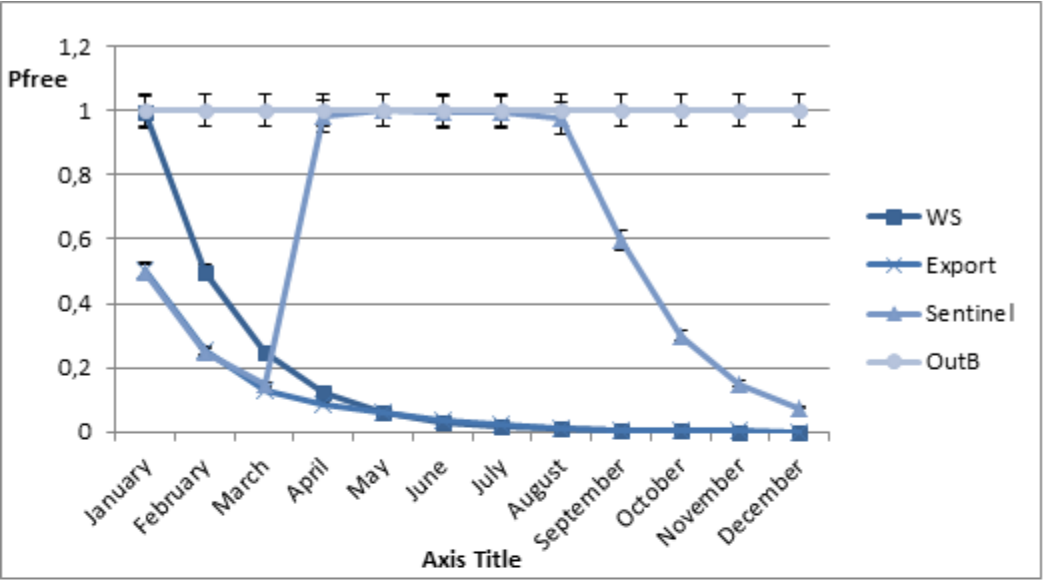
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Figure 4