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Economic evaluation of the surveillance and intervention programme for bluetongue virus serotype 8 in Switzerland

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ABSTRACT

Empirical analyses founded on sound economic principles are essential in advising policy makers on the efficiency of resource use for disease mitigation. Surveillance and intervention are resource-using activities directed at mitigation. Surveillance helps to offset negative disease effects by promoting successful intervention. Intervention is the process of implementing measures (e.g. vaccination or medication) to reduce or remove a hazard in a population. The scale and ratios in which the two are combined affect the efficiency of mitigation, its costs, benefits, and thus net effect on society's well-being. The Swiss national mitigation programme for bluetongue virus serotype 8 was used as case study to investigate the economic efficiency of mitigation. In 2008, Switzerland implemented a vaccination programme to avoid and reduce disease and infection in its ruminant population. To monitor the vaccination programme and the vector dynamics, a surveillance system consisting of serological and entomological surveillance was established. Retrospective analyses for the years 2008–2009 and prospective analyses for the years 2010–2012 were conducted to investigate if the mitigation programme was economically beneficial. In the retrospective analysis, the implemented programme (=comparative scenario) was compared to a hypothesised baseline scenario of voluntary vaccination and surveillance. In the prospective analysis, the comparative scenario assumed to continue was compared to two baseline scenarios: one of voluntary vaccination combined with surveillance and one of no vaccination combined with surveillance. For each scenario, monetary surveillance, intervention and disease costs were calculated. The comparison of baseline and comparative scenarios yielded estimates for the total benefit (=disease costs avoided), margin over intervention cost and the net value of the programme. For 2008–2009, in aggregate, the mean biannual total benefit was 17.46 m Swiss francs (CHF) (1CHF = 0.66€ at the time of analysis) and the mean net benefit after subtraction of the intervention and surveillance cost was 3.95 m CHF. For the three years 2010–2012, overall net costs were estimated at 12.93 m and 8.11 m CHF, respectively, for comparison of the implemented mitigation programme with the two baseline scenarios. It was concluded that the surveillance and intervention programme implemented in 2008–2009 was economically beneficial, while its continuation in the same form in 2010–2012 would produce net costs. These costs were due to the mean intervention cost remaining constant at a level of approximately 11 m CHF per year while the mean total benefit would be gradually reduced in 2010–2012 due to the reduced occurrence of disease in a fully vaccinated population.

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1. Introduction

People gain economic value, or benefits, from the consumption of goods or services created in animal production systems by the transformation of scarce resources into products. Not only is substantial value derived from consumption of products such as eggs, meat, wool, or leather, but also from animals kept as pets, used for sports, work, or research. Animal disease is an economic problem because it reduces the quantity of outputs available for people's consumption. The lost output therefore represents a decrease in people's potential economic well-being. To counter such negative disease effects, which are a type of economic cost, additional resources must be expended for disease mitigation. These represent another cost to society because, in the absence of disease, those resources could have been employed in some alternative productive use. Thus the objective is to minimise total costs, for which the criterion under diminishing returns to mitigation effort is that the last increment of mitigation expenditures is just covered by the value of the consequent reduction in losses.

Surveillance and intervention are resource-using activities that comprise disease mitigation. Surveillance helps to offset negative disease effects by promoting successful interventions. The scale and ratios in which the two elements of resources are combined affect the efficiency of mitigation, its costs, benefits, and thus net effect on society's well-being. For economic appraisal it is indispensable to investigate and understand the technical and economic relationships between surveillance, intervention and mitigation, which are reflected in prevalence or incidence reduction. Resources for surveillance and intervention should be combined at least cost and used for that level of avoidable output losses that maximises net benefits, the condition for optimal economic efficiency. If surveillance and intervention are economic substitutes, then using one of more enables reduced use of the other. Hence, an increase in surveillance resources could produce more and better information which in turn would allow more targeted and potentially less resource-intensive intervention.

The national mitigation programme for bluetongue virus serotype 8 (BTV-8) in Switzerland was used as a case study to explore the potential of empirical analyses to investigate the economic efficiency of disease mitigation. The virus is transmitted by *Culicoides* spp. biting midges and may cause severe clinical disease and mortality in farmed ruminants (Elbers et al., 2008), thereby contributing to disease costs. There are two sources of disease costs, namely losses and expenditures (McInerney et al., 1992). Losses comprise the negative impact of disease on output, while expenditures include the extra resources used to combat negative disease effects. Bluetongue virus serotype 8 causes output losses and expenditures to be made for activities directed at disease mitigation.

In 2006, BTV-8 was reported for the first time in the Netherlands with subsequent spread in north western Europe (Wilson and Mellor, 2008), reaching Switzerland in October 2007 (Hofmann et al., 2008). Shortly after the first outbreaks were detected, Switzerland declared the whole country as one 'restriction zone' to avoid trade restrictions at national level. As more cases were confirmed, the Swiss Federal Veterinary Office (FVO) implemented a BTV-8 intervention programme. In this specific case, the intervention programme was a compulsory vaccination programme at national level. In 2008, all cattle, sheep and goats over three months old were vaccinated. In 2009, all cattle and sheep over three months old were vaccinated while the vaccination of goats was voluntary.

The vaccination programme aimed to avoid and reduce disease and infection in the population, while serological surveillance activities aimed to check if the vaccination programme yielded the expected results. Serological surveillance in ruminants was performed aiming at a detection of 2% virus positive animals at regional level. Further, entomological surveillance was performed in 16 regions in accordance with EU Regulation 1266/2007 (http://eur-lex.europa.eu/) to monitor the dynamics of the vector. In line with the requirements of this Regulation, entomological surveillance in Switzerland was envisaged to be abandoned by the end of 2010.

To the authors' knowledge, no studies have yet been conducted that explicitly investigated the relationship between costs of surveillance and intervention activities to reduce BTV-8 incidence in an infected population and the monetary benefits resulting from disease mitigation. Gunn et al. (2008) developed an economic model to identify, measure and value disease costs for various scenarios of bluetongue (BT) introduction and spread in Scotland and to evaluate disease mitigation strategies. Baseline costs of surveillance and prevention were estimated to be 141 m £ over a 5-year time horizon and it was found that the benefits of avoiding disease incursion exceeded the costs of surveillance and prevention. Carrasco et al. (2010) developed an epidemiologic transmission model for BT in the United Kingdom and linked it to economic and info-gap analyses to identify a robust surveillance programme for early detection of the disease.

The aim of this project was an economic assessment of the BTV-8 surveillance and intervention programme in Switzerland, both retrospectively and prospectively. The objectives were (1) to assess if the implementation of the surveillance and intervention programme to contain the disease in 2008 and 2009 was economically efficient and (2) to evaluate if continuation of the implemented programme during 2010–2012 would be justified.

2. Methodology

2.1. General overview and scenarios

Retrospective economic analyses for the years 2008–2009 and prospective economic analyses for the years 2010–2012 were performed. For 2008–2009, the surveillance and intervention programme implemented (called the retrospective comparative scenario, RCS), was compared to a retrospective baseline scenario (RBS), a hypothesised alternative. For 2010–2012, the implemented surveillance and intervention scenario was assumed to continue, now called the prospective comparative scenario (PCS), and compared to two different prospective baseline scenarios 1 and 2 (PBS1 and PBS2). The details of the scenarios are provided in Table 1.

Table 1
Description of scenarios used for the retrospective and prospective economic analyses of bluetongue virus serotype 8 surveillance and intervention activities in Switzerland.

	2008 and 2009 retrospective analysis		2010–2012 prospective analysis		
	Baseline scenario	Comparative scenario	Baseline scenario 1	Baseline scenario 2	Comparative scenario
Serological surveillance					
Monthly seroconversion	2%	2%	20%	2%	2%
Confidence	99%	99%	95%	99%	99%
Entomological surveillance	Yes	Yes	In 2010 only	In 2010 only	In 2010 only
Vaccination coverage	35%	90%	0%	35%	90%

Voluntary vaccination was considered to be the most likely alternative to compulsory vaccination for the following reasons: (1) Since 2008, the FVO has had the legal power to allow and stipulate the specifications of BTV-8 vaccination in Switzerland; (2) an effective vaccine was available; and (3) neighbouring countries had already started vaccinating, which may have motivated Swiss farmers to follow suit.

The surveillance activities included nine main steps: (1) planning, (2) preparation, (3) supervision, (4) sampling, (5) laboratory testing, (6) data collection, transfer and administration, (7) data analysis and interpretation, (8) dissemination and communication of results, and (9) revision and adaptation of the running programmes. For each single step, a list was created with detailed activities specific to the serological and entomological part of the surveillance programme (Tables 2 and 3). For the intervention programme, detailed activities were listed as for surveillance, apart from steps (4) and (5) that were replaced by 'implementation of vaccination programme' and step (9) that was merged with step (1) (Table 4).

A stochastic spreadsheet model for the economic analyses was developed using @Risk software for Excel version 5.0 (Palisade Corporation, Newfield, NY, USA). All uncertain data values were integrated as distributions and the model was run with 20,000 iterations. The impact of uncertain input values on the outputs was assessed using the in-built sensitivity analysis tool, which performed multivariate stepwise regression for values sampled from the defined distributions to calculate beta regression coefficients. All monetary values were expressed in Swiss francs (CHF) (1CHF = 0.66€ at the time of analysis).

2.2. Epidemiologic model

In an independent project, a deterministic compartment model with susceptible, infected, recovered, vaccinated and protected holdings was developed to simulate the effect of different vaccination strategies on the BTV-8 disease dynamics in the Swiss cattle, sheep and goat population (Di Labio et al., 2009). The vaccination model was applied on single clusters of holdings that were assumed to form an epidemiologic unit for homogenous spread within an area with a radius of 25 km. The dynamics of the vector was implicitly modelled by the introduction of a temperature dependent infection rate which captured the temperature effect on the vector population dynamics and on infection dynamics overall. The model was built and run with the modelling software Vensim© Professional, Version 5.5c (Ventana Systems, Inc., Harvard, USA). A more detailed description of the epidemiologic model is provided in Appendix A.

For the simulation of the retrospective scenarios, the starting population was fully susceptible, while for the prospective scenarios the starting population was partly protected due to the compulsory vaccination campaign in 2008 and 2009. The epidemiologic model predicted the number of infected holdings in a zone with a 25 km radius and a starting population of 3100 susceptible holdings. The epidemiologic modelling output "number of BTV-8 infected holdings" was used to calculate the national number of infected holdings per year and scenario. First, the proportion of BTV-8 infected holdings of the 3100 susceptible holdings was calculated. Assuming homogenous mixing, the national number of infected holdings per scenario and year was calculated by multiplying this proportion by the total number of susceptible holdings (n = 53,290).

2.3. Study population

The study population included 53,290 holdings that kept cattle, sheep and/or goats as recorded in the 2008 national agricultural census (www.blw.admin.ch/themen/00006/00232/, data provided by FVO). Animal categories defined in the agricultural census were allocated to 13 specific categories according to species and age (e.g. dairy heifers). These categories were further allocated to animal groups, namely adult cattle, adult sheep, lambs, calves and goats. Next, the respective number of infected holdings per scenario was randomly selected from all holdings listed in the national agricultural census database. By summing up all animals per category the aggregate number of bovine, caprine and ovine animals in infected holdings was calculated. These two steps were repeated a 1000 times per scenario to produce a set of estimates characterising the total number of animals per category on infected holdings. The 1000 datasets per scenario were then exported into @Risk for Excel, where the integrated distribution fitting feature was used to automatically fit probability distributions to the simulated data. All distributions were either normal or lognormal (Appendix Table S1).

Table 2
Main surveillance steps and activities, cost categories (LB = labour, OE = operations and expenses), job position (FVO = Federal Veterinary Office) or price/unit, and number of working hours or input units used to calculate serological surveillance cost for bluetongue virus serotype 8 in Switzerland. CHF = Swiss francs[a], ELISA = enzyme-linked immunosorbent assay, PCR = polymerase chain reaction.

Surveillance step	Activity	Cost category	Job position or price/unit	No. of working hours or units for 2009–2012
(1) Planning	Sample size estimation	LB	FVO researcher	40
	Specification of surveillance activities	LB	FVO researcher	120
	Budget calculation	LB	FVO researcher	40
(2) Preparation	Development of sampling plan	LB	FVO researcher	40
	Preparation of forms	LB	FVO researcher	20
	Ordering sampling material	LB	FVO doctoral student	20
	Assembling sampling material	LB	FVO doctoral student	20
	Sending sampling material to cantons	OE	250 CHF (Lump sum)	1
(3) Supervision	Supervision of surveillance activities	LB	FVO researcher	20
(4) Sampling	Call-out fee	OE	0 CHF/visit[b]	–
	Blood sampling by veterinarian (incl. material)	OE	8.50 CHF/sample taken	2009: 2092 2010–2012: Pert(200,250,300)[c]
	Postage to send samples to laboratory	OE	25 CHF/holding	2009: 250 2010–2012: Pert(200,250,300)[c]
(5) Laboratory testing	ELISA testing (incl. data recording)	OE	16 CHF/sample	2009: 2092 2010–2012: Pert(2000,2100,2200)[c]
	PCR testing of ELISA positive samples (incl. sequencing)	OE	Uniform(150,250)[c] CHF/sample	2009: 182 2010–2012: Pert(2000,2100,2200)[c]·$Prop_{SP}$[d]
(6) Data collection, transfer and administration	Electronic collation of data	LB	FVO researcher	20
	Standardisation of data into electronic format	LB	FVO researcher	20
	Quality control of collected data	LB	FVO researcher	40
(7) Data analysis and interpretation	Descriptive statistics	LB	FVO researcher	20
	Exploratory data analysis	LB	FVO researcher	20
	Collation and interpretation of results	LB	FVO researcher	20
(8) Dissemination and communication of results	Creation/update of websites	LB	FVO researcher	10
	Writing of annual report	LB	FVO researcher	40
	Creation of layout of annual report	LB	FVO communication	10
	Reporting to the European Bluetongue net	LB	FVO researcher	10
	Translation	LB	FVO staff	20
(9) Revision and adaptation of running programme	Interim report with discussion	LB	FVO researcher	40

[a] 1CHF = 0.66€ at the time of analysis.
[b] Integrated into intervention costs, see text.
[c] 'Pert' denotes a pert distribution with minimum, most likely and maximum values in brackets, and 'Uniform' a uniform distribution with minimum and maximum values in brackets.
[d] $Prop_{SP}$ = proportion of seropositive animals, see text.

2.4. Estimation of costs and benefits

To evaluate the implemented programme, monetary costs of surveillance and intervention were compared with monetary benefits resulting from the comparison with alternative programmes envisaged. The total benefit was defined as the disease costs estimated to have been avoided as a result of the implemented programme as opposed to a hypothesised alternative, i.e. the difference in disease costs between the comparative scenario and the corresponding baseline scenario. The disease costs included production losses, expenditures for palliative treatment and export, and cantonal response costs in case of an outbreak. Consequently, the benefits of avoiding disease by implementing mitigation measures included both output losses and expenditures that would accrue if disease occurred. The margin over intervention cost (MI) was calculated as follows:

$$MI = DC_{BS} - DC_{CS} - (IC_{CS} - IC_{BS})$$

where *DC* stands for disease costs, *IC* for intervention cost, *BS* for baseline scenario, and *CS* for comparative scenario. Crucially, this margin represents the maximum expenditures potentially available for surveillance without the net benefits from mitigation overall becoming zero. Thus to maximise the net benefits from mitigation, surveillance must be conducted at minimum cost.

Table 3
Main surveillance steps and activities, cost categories (LB = labour, OE = operations and expenses), job position (FVO = Federal Veterinary Office) or price/unit, and number of working hours or input units used to calculate entomological surveillance cost for bluetongue virus serotype 8 in Switzerland. CHF = Swiss francs.[a]

Surveillance step	Activity	Cost category	Job position or price/unit	No. of working hours or units
(1) Planning	Specification of surveillance activities	LB	FVO researcher	10
	Budget calculation	LB	FVO researcher	10
(2) Preparation	Development of sampling plan	LB	FVO researcher	10
	Ordering sampling material (traps)	LB	FVO doctoral student	10
	Assembling sampling material (traps)	LB	FVO doctoral student	20
(3) Supervision	Supervision of surveillance activities	LB	FVO researcher	10
(4) Sampling	Holding visit (twice) and installation of traps and dismantling (incl. cleaning and storage)	LB	FVO doctoral student	40
	Collecting midges (weekly during 34 weeks)	LB	Agricultural employee	10
	Sending midges to laboratory	OE	5 CHF/sample	646
(5) Laboratory testing and; (6) data collection, transfer and administration	Identification of midges (incl. data recording)	OE	20,000 CHF (lump sum)	1
(7) Data analysis and interpretation	Descriptive statistics	LB	FVO researcher	10
	Collation and interpretation of results	LB	FVO researcher	20
(8) Dissemination and communication of results	Report writing for public, cantonal veterinary services, and European Bluetongue net	LB	FVO researcher	10
	Translation	LB	FVO staff	10
(9) Revision and adaptation of running project	Revision of sampling design	LB	FVO researcher	10

[a] 1CHF = 0.66€ at the time of analysis.

The overall net value (i.e. net benefit or net costs) of the programme was calculated as follows:

$$Net\ value = MI - (SC_{CS} - SC_{BS})$$

where *SC* stands for surveillance cost.

For the prospective scenarios, the future costs and benefits needed to be translated into present values by multiplying the costs or benefits by the discount factor $1/(1+r)^t$, where $r = 3.5\%$ is the selected discount rate and t the time in years.

Monetary values for production losses were estimated by multiplying the aggregate numbers in the different animal categories by lost physical production and price coefficients. The monetary costs for all surveillance and intervention activities comprised labour, operations and expenses. Each job position at the FVO (e.g. researcher, communication staff) was assigned a specific wage rate per productive hour that was calculated based on actual salary classes and an annual productive working time of 1781 h. The cantonal veterinary service (*CVS*) wage rates were obtained from the *CVS* Geneva (personal communication E. Grosclaude). The wage rate for agricultural employees was derived from monthly published agricultural statistics (SFU, 2009). The numbers of working hours per job position were indicated by the persons performing the described tasks or by their supervisors using whenever possible data from the official time recording system.

The input data for operations and expenses were either requested from the respective institutions or businesses that delivered the service (e.g. Institute of Virology and Immunoprophylaxis) or indicated by FVO staff involved in the surveillance and intervention programme. The calculation of the costs and benefits is explained in detail below. Whenever possible, Swiss specific data were used. Where data were missing or inconsistent, values from the scientific literature and expert opinion were used. A BT expert team was formed to support this process. It included a FVO researcher with experience in BTV-8 epidemiological modelling, a FVO researcher responsible for the planning, implementation, and assessment of the BTV-8 surveillance programme, and two FVO officials responsible for the planning and implementation of the BTV-8 vaccination programme.

2.4.1. *Surveillance cost*

From July 2007 to May 2008, 200 holdings with 5400 dairy cattle were surveyed monthly for anti-BTV antibodies using bulk milk samples and enzyme linked immunosorbent assay (ELISA) testing (Schwermer et al., 2008). The surveillance cost for the bulk milk surveillance in 2008 was integrated in the model as a lump sum of 50,000 CHF as listed in the FVO's financial budget. Because serological bulk milk testing does not provide conclusive results when vaccinated cows are present, in 2009 bulk milk surveillance

Table 4
Main intervention steps and activities, cost categories (LB = labour, OE = operations and expenses), job position (FVO = Federal Veterinary Office, CVS = cantonal veterinary service) or price/unit, and number of working hours or input units used to calculate intervention cost for bluetongue virus serotype 8 in Switzerland for the retrospective comparative scenario. CHF = Swiss francs.[a]

Intervention step	Activity	Cost category	Job position or price/unit	No of working hours or units	
				2008	2009
(1) Planning	Description of problem and literature research	LB	FVO researcher	89	89
	Epidemiological modelling work	LB	FVO post doctoral researcher	310	852
	CVS conference (working group discussions)	LB	FVO researcher, FVO and CVS head	736	368
	CVS conference travelling cost	OE	64 CHF/person	56	28
	Outline intervention strategy, detailed intervention activities, and expected outcomes	LB	FVO researcher	89	89
	Budget calculation	OE	9680 CHF for 2008 and 6776 CHF for 2009 (lump sums)	1	1
(2) Preparation	Coordination of activities with collaborators	LB	FVO researcher	178	178
	Formulation of vaccination lists	LB	FVO researcher	89	89
	Establishment and administration of electronic registration system for vaccinated animals	OE	450,000 CHF for 2008 and 250,000 CHF for 2009 (lump sums)	1	1
	Ordering of vaccines	LB	FVO researcher	17	17
	Distribution of vaccines to CVS	LB	FVO researcher	178	125
	Preparation of information letters and brochures	LB	FVO researcher	267	267
	Translation thereof	LB	FVO translator	142	142
(3) Supervision	Supervision of intervention activities	LB	FVO researcher	89	89
(4) Implementation of vaccination programme	Call-out fee	OE	Uniform(20,25) CHF/visit[b]	86,901[c]	65,122[c]
	Cost of vaccines	OE	1 CHF/dose	2,874,270[c]	1,730,120[c]
	Injection of vaccine (incl. material)	OE	4 CHF/injection	2,874,270[c]	1,730,120[c]
	Registration of vaccination	OE	2 CHF/holding	86,901[c]	65,122[c]
(5) Data collection, transfer, and administration	Quality control of collected data, database administration, maintenance and adaptations	LB	FVO researcher	726	588
(6) Data analysis and interpretation	Descriptive statistics	LB	FVO researcher	89	89
	Collation and interpretation of results	LB	FVO researcher	89	89
(7) Dissemination and communication of results	Bluetongue information movie for stakeholders	LB	FVO communication	82	33
	Bluetongue information movie: production and distribution cost	OE	50,360 for 2008 and 13,700 for 2009 (lump sums)	1	1
	Information leaflets for animal owners and veterinarians	LB	FVO communication	33	33
	Information leaflets for animal owners and veterinarians, production and distribution costs	OE	23,000 CHF for 2008 and 76,000 CHF for 2009 (lump sums)	1	1
	Media releases, blogs, journal articles, reports	LB	FVO communication	124	66
	Talks with farmers	LB	FVO communication	21	21
	Information desk	LB	FVO communication	17	8
	Internet: Creation and updating of websites	LB	FVO communication	66	41
	Letters to CVS and presentation at CVS conference	LB	FVO researcher	267	267
	Translations	LB	FVO staff	142	142
	Information events, provision of information by phone, written replies to farmers, veterinarians, jurists, politicians, general public	LB	FVO researcher	712	1139

[a] 1CHF = 0.66€ at the time of analysis.
[b] 'Uniform' denotes a uniform distribution with minimum and maximum values in brackets.
[c] The numbers of holdings visited and vaccines applied was calculated based on FVO and national census data, see text.

was replaced by blood sampling and ELISA testing of individual animals. For the entomological surveillance of the vector, 19 traps were installed in Switzerland and Lichtenstein and midges were collected and counted weekly during 34 weeks (Zaugg et al., 2008).

The total surveillance cost (SC) was calculated according to the following equation:

$$SC = \sum_{i}\sum_{j} LB_{i,j} + OE_{i,j}$$

where LB is the labour cost and OE the cost for operations and expenses in the context of serological i and entomological j surveillance. Tables 2 and 3 list all serological and entomological surveillance activities for the comparative scenarios for the years 2009–2012 including cost categories LB and OE, job position or price/unit and input data. For each surveillance activity labelled LB, the following equation was used:

$$LB = h_X \cdot w_Y$$

where h_X is the number of working hours spent per surveillance activity X and w_Y the wage rate per job position Y.

For each surveillance activity labelled OE, the following equation was used:

$$OE = U_X \cdot p_U$$

where U_X is the number of units per surveillance activity X and p_U the price per unit.

Polymerase chain reaction (PCR) was used to re-test and serotype all animals that were ELISA positive. In 2009, 8.7% of all samples were seropositive (Schwermer, 2009). The prospective proportion of seropositive samples was estimated to be a pert distribution with minimum value 0.08, most likely value 0.087 and maximum value 0.094.

In the comparative scenarios, the call-out fee was included in the intervention costs, because the vaccinating veterinarians took blood samples at the time of vaccination to exploit synergies. For the RBS and PBS2, the call-out fee in CHF for the serological surveillance was set as a uniform distribution with a minimum value of 20 CHF and a maximum value of 25 CHF, which reflected the call-out fee officially recommended by the FVO during the bluetongue campaign. All other inputs stayed the same. For the PBS1, serological surveillance activities were expected to comply with the minimal requirements stipulated in EU Regulation 1266/2007, which would reduce the total serological surveillance costs by a factor 10 (personal communication H. Schwermer, FVO).

2.4.2. Intervention cost

Table 4 lists all intervention activities including cost categories, job position or price/unit and input data for the RCS for the years 2008 and 2009. The cost calculations were performed analogously to those described for the surveillance cost.

In 2008, all cattle were vaccinated twice, while sheep and goats were only vaccinated once. In 2009, cattle that had not been vaccinated previously needed to be vaccinated twice, which reflected the proportion of young animals in the population (10%), as derived from the national agricultural census data provided by the FVO. All other animals of the bovine and ovine species needed to be only vaccinated once as stipulated in the Swiss ordinance regarding the vaccination against BT (SR 916.401.348.2, www.admin.ch/ch/d/as/index.html). For all holdings that kept cattle that needed to be vaccinated twice (50% of all holdings as derived from the national agricultural census), two farm visits were accounted for. The total number of holdings visited (N_{HV}) for vaccination in 2008 and 2009 was calculated as follows:

$$N_{HV2008} = VCOV(N_{HC} \cdot 2 + N_{HSG})$$

$$N_{HV2009} = VCOV(0.50 \cdot N_{HC} \cdot 2 + N_{HC} \cdot 0.50 + N_{HS})$$

where VCOV is the vaccination coverage, N_{HC} number of holdings with cattle and optionally sheep or goats (=43,267), N_{HSG} number of holdings with sheep and/or goats, but no cattle (=10,023), and N_{HS} number of holdings with sheep (=7457).

The total number of vaccines given (N_V) was calculated as follows:

$$N_V = N_S \cdot VCOV \cdot N_D$$

where N_S is the number of animals suitable for vaccination and N_D the respective number of vaccine doses applied per animal. In 2008, 1,389,108 cattle, 334,100 sheep and 81,316 goats were suitable for vaccination; in 2009, 1,449,134 cattle and 328,308 sheep were suitable for vaccination.

For the RBS and PBS2, the price per dose of vaccine and registration cost were assumed to be the same, but the call-out fee for the vaccination and the price of injecting the vaccine were changed to a regular call out fee (PCO_R) and injection price (PI_R), respectively (Table 5).

No data were available for the workload, operations and expenses for intervention activities in the RBS and prospective scenarios. Consequently, FVO staff members were asked to make qualitative estimates for these, and for lump sum expenditures in relation to the RCS. Then the qualitative estimates were transformed into quantitative values by applying the following weights to the observed RCS values: much less (0.4), less (0.7), the same (1), more (1.3), and much more (1.6). For example, the activity 'ordering vaccines' was considered as 'less' for RBS_{2008} relative to RCS_{2008}. Consequently, the input value for RBS_{2008} for this activity was estimated at 70% (coefficient [1 − 0.3]) of that for RCS_{2008}. The qualitative estimates are available from the corresponding author on request.

2.4.3. Monetary benefits

The monetary benefits were the difference in disease costs between the comparative scenario and the corresponding baseline scenario. Disease costs were the sum of production losses, export expenditures (E_X), expenditures for palliative treatment (E_{PT}), and cantonal response expenditures for suspect and confirmed cases (E_{CVS}). The production losses included losses due to mortality (L_M), abortion (L_A), prolonged calving interval (L_{PCI}), premature culling (L_{PMC}), reduced milk yield (L_{RMY}), wool reduction (L_{WR}), reduced weight gain (L_{RWG}), and export (L_X). Their estimation was based on Velthuis et al. (2010) who

Table 5
Input data used to estimate bluetongue virus serotype 8 (BTV-8) related disease costs in Switzerland. Input units in brackets (CHF = Swiss francs[a]).

Input	Notation	Value or distribution[b]	Description/source
Mortality, premature culling and rendering costs			
Mortality rate adult cattle (year^{-1})	$Mt_{\text{adult cattle}}$	Pert(0.0011,0.0013,0.0015)	Mean BTV-8 mortality rate for cattle from OIE WAHID[c] data for all European countries for the years 2007 and 2008 = most likely (ML) value, lower and upper limit: ±15%
Mortality rate calves (year^{-1})	Mt_{calves}	$Mt_{\text{adult cattle}} \times 3.5$	Mounaix et al. (2008): Calves found to have 3–4 times higher mortality than adult cattle
Mortality rate adult sheep (year^{-1})	$Mt_{\text{adult sheep}}$	Pert(0.03,0.035,0.04)	Mean BTV-8 mortality rate for sheep from OIE WAHID[c] data for all European countries for the years 2007 and 2008 = ML value, lower and upper limit: ±15%
Mortality rate lambs (year^{-1})	Mt_{lambs}	$Mt_{\text{adult sheep}}/3$	Mounaix et al. (2008): Lambs found to have three times lower mortality than adult sheep
Rendering costs adult cattle (CHF)	$RC_{\text{adult cattle}}$	Uniform(210,315)	Estimate derived from price list of waste disposal company 'TMF Bazenheid'[d]
Rendering costs calves (CHF)	RC_{calves}	Uniform(50,100)	Ditto
Rendering costs adult sheep or lambs (CHF)	$RC_{\text{adult sheep}} = RC_{\text{lambs}}$	Uniform(25,50)	Ditto
Proportion of morbid adult cattle culled prematurely	$PropPMC_{\text{adult cattle}}$	Pert(0.026,0.03,0.035)	Mean value from Velthuis et al. (2010) for the years 2006 and 2007 = most likely value, lower and upper limit: ±15%
Proportion of morbid adult sheep culled prematurely	$PropPMC_{\text{adult sheep}}$	Pert(0.013,0.015,0.017)	Ditto
Morbidity rates			
Morbidity rate adult cattle (year^{-1})	$Mb_{\text{adult cattle}}$	Pert(0.019,0.023,0.027)	Mean BTV-8 morbidity rate for cattle from OIE WAHID[c] data for all European countries for the years 2007 and 2008 = upper value; average Elbers et al. (2008) and Conraths et al. (2009) = ML value; ML value minus difference between ML and upper value = lower value
Morbidity rate calves (year^{-1})	Mb_{calves}	$Mb_{\text{adult cattle}}/3$	Mounaix et al. (2008): Calves found to have three times smaller morbidity than adult cattle
Morbidity rate adult sheep (year^{-1})	$Mb_{\text{adult sheep}}$	Pert(0.059,0.060,0.061)	Mean BTV-8 morbidity rate for sheep from OIE WAHID[c] data for all European countries for the years 2007 and 2008 = upper value; average Conraths et al. (2009) for the years 2006 and 2007 = ML value; ML value minus difference between ML and upper value = lower value
Morbidity rate lambs (year^{-1})	Mb_{lambs}	$Mb_{\text{adult sheep}}/6$	Mounaix et al. (2008): Lambs found to have six times smaller morbidity than adult sheep
Reproduction			
Proportion of morbid adult cattle with abortion	$PropA_{\text{adult cattle}}$	Pert(0.035,0.041,0.047)	Mean value from Velthuis et al. (2010) for the years 2006 and 2007 = most likely value, lower and upper limit: ±15%
Proportion of morbid adult sheep with abortion	$PropA_{\text{adult sheep}}$	Pert(0.022,0.026,0.03)	Ditto
Proportion of morbid dairy cows for commercial milk production with prolonged calving interval	$PropPCI_{\text{dairy cows for commercial milk production}}$	Pert(0.38,0.45,0.52)	Ditto

Table 5 (*Continued*)

Input	Notation	Value or distribution[b]	Description/source
Costs per abortion dairy cows for commercial milk production or dairy cow for non-commercial milk production (CHF)	$CA_{\text{dairy cows for commercial milk production}} = CA_{\text{dairy cows for non-commercial milk production}}$	Normal(882.12, 504.97)	Häsler et al. (2006)
Costs per abortion suckler cow (CHF)	$CA_{\text{suckler cow}}$	Normal(794,454)	Häsler et al. (2006)
Costs per abortion ewe or dairy ewe (CHF)	$CA_{\text{ewe}} = CA_{\text{dairy ewe}}$	253	=Value of lamb lost · average number of lambs per ewe[e]
No. of days postponed gestation	d	Pert(21,42,63)	Expert estimate: 1, 2 or 3 cycles of 21 days each, most likely 2 cycles
Costs per day of prolonged calving interval in dairy cows for commercial milk production (CHF)	$CPCI_{\text{dairy cows for commercial milk production}}$	Pert(5,6,7)	Stocker (2008) and Swissgenetics (www.swissgenetics.ch)
Milk loss			
Relative reduction in milk yield in morbid dairy cows for commercial milk production or dairy cows for non-commercial milk production (year^{-1})	$RMY_{\text{dairy cows for commercial milk production}} = RMY_{\text{dairy cows for non-commercial mik production}}$	Pert(0.0005,0.0248, 0.05)	Expert estimate based on Gunn et al. (2008), Heimberg (2008), Mounaix et al. (2008), Velthuis et al. (2010)
Weight loss			
Proportion of morbid adult cattle showing weight loss	$PropWL_{\text{adult cattle}}$	Pert(0.077,0.09,0.108)	9% value from Gunn et al. (2008) = most likely value, lower and upper limit: ±15%
Expenditures compensatory growth per animal (CHF)	ECG	Pert(8,8.5,9)	Expert estimate based on Velthuis et al. (2010)
Veterinary treatment			
Proportion of morbid animals receiving veterinary treatment	$PropRVT$	Pert(0.6,0.7,0.8)	Expert estimate based on information collected from Swiss veterinary practitioners
Regular call-out fee veterinarian (CHF)	PCO_R	Uniform(30,35)	Ditto
Regular price for injection by veterinarian (incl. material) (CHF)	PI_R	Pert(5.5,6,6.5)	Ditto
Regular price of blood sample taken by a veterinarian (incl. material) (CHF)	PST_R	Uniform(16,20)	Ditto
Price veterinary treatment adult cattle (CHF)	$PVT_{\text{adult cattle}}$	Uniform(200,300)	Expert estimate based on information collected from Swiss veterinary practitioners. Includes holding visit, material used, veterinary medicines, administrative and labour costs
Price veterinary treatment calves (CHF)	PVT_{calves}	Uniform(150,200)	Ditto
Price veterinary treatment adult sheep (CHF)	$PVT_{\text{adult sheep}}$	Uniform(100,150)	Ditto
Price veterinary treatment lambs (CHF)	PVT_{lambs}	Uniform(50,100)	Ditto
Export and cantonal response related inputs			
Proportion of confirmed cases per total number of infected holdings	$PropCC$	Uniform(0.0075,0.048)	Expert estimate based on the proportion of confirmed cases per total number of infected holdings derived from IVI[f] data (0.75% in 2008 and 4.8% in 2009)
Duration of movement ban for confirmed cases (d)	t_{BCC}	75	Swiss legislation
Duration of movement ban for suspect cases (d)	t_{BSC}	5	Ditto

Table 5 (*Continued*)

Input	Notation	Value or distribution[b]	Description/source
Export loss per animal not exported (CHF)	L_{NCX}	Pert(0,12350,22711)	Expert estimate based on an independent study conducted by P. Bosshard (unpublished data) to investigate the impact of a reduction of live cattle exports on domestic market prices. Assuming that a decrease in export of live cattle of 50–100% would cause a price reduction on the domestic cattle market of 10–15%, he estimated the mean economic loss for the years 2010–2012 per animal not exported at 22,711 CHF. This value was taken as the upper limit
Proportion of export cattle tested	*PropT*	0.86	Estimate based on IVI[f] data from 2008
Proportion of export cattle vaccinated	*PropV*	0.14	Ditto
Price for laboratory testing for export (CHF)	*PTX*	55	Derived from IVI[f] data
Price polymerase chain reaction testing (CHF)	*PPCR*	Uniform(100,150)	Ditto
Price of insecticide treatment per holding (CHF)	*PIT*	Uniform(90,120)	Federal Veterinary Office
No. of working hours to issue movement ban provision	H_{MBP}	Pert(1.5,2,2.5)	CVS Geneva
No. of working hours for epidemiological investigation	H_{EI}	Uniform(3,5)	CVS Geneva
No. of working hours to lift movement ban	H_{LMB}	Uniform(1,2)	CVS Geneva

[a] 1CHF = 0.66€ at the time of analysis.
[b] 'Pert' denotes a pert distribution with minimum, most likely and maximum values in brackets, 'Uniform' a uniform distribution with minimum and maximum values in brackets, and 'Normal' a normal distribution with mean and standard deviation in brackets.
[c] OIE = World Organisation for Animal Health, WAHID = World Animal Health Information Database (www.oie.int).
[d] http://www.tmf.ch Price for collection of slaughter waste: 210 CHF/ton for deliveries between 0 and 4999 kg.
[e] Mean lamb value derived from data from Swiss Farmer's Union (www.sbv-usp.ch) and mean number of lambs per ewe (=1.545) calculated from the annual reports of the Swiss Sheep Breeders Association (www.caprovis.ch).
[f] IVI = Institute of Virology and Immunoprophylaxis (www.ivi.admin.ch).

calculated the financial costs of the BTV-8 epidemic in the Netherlands. Because Switzerland declared itself as a restriction zone at an early stage of the epidemic, no losses accrued from movement bans in different zones within the country. Upon consultation with the expert team, it was determined that the BT incursion in Switzerland as well as vaccination did not have an effect on the consumption of beef and dairy products. Table 5 lists all input data related to the calculation of disease costs apart from number of animals per category, animal values and production data, which can be found in Appendix Tables S1 and S2. The production losses were calculated as follows:

$$L_M = \sum_{x \in X1} \sum_{y \in Y1} N_x \cdot Mt_y \cdot (MV_x + RC_y)$$

where $X1$ stands for the affected animal categories (dairy cows for commercial milk production, dairy heifers, dairy calves, dairy cows for non-commercial milk production, suckler cows, beef cattle, beef calves, breeding bulls, ewes, lambs, dairy ewes and rams), $Y1$ the respective animal groups, N the number of animals on infected farms, Mt the mortality rate, MV the market value of the animals, and RC the rendering costs.

$$L_A = \sum_{x \in X2} \sum_{y \in Y2} N_x \cdot Mb_y \cdot PropA_y \cdot CA_x$$

where $X2$ stands for cattle and sheep categories suffering abortion, $Y2$ the respective animal groups, Mb the morbidity rate, $PropA$ the proportion of morbid animals that have an abortion, and CA for costs per abortion.

$$L_{PCI} = N_{DC} \cdot Mb_{AC} \cdot PropPCI_{DC} \cdot d \cdot CPCI_{DC}$$

where DC stands for dairy cows for commercial milk production, Mb_{AC} the morbidity rate in adult cattle (AC), $PropPCI_{DC}$ the proportion of morbid dairy cows for commercial milk production that have a prolonged calving interval, d the number of days of postponed gestation, and $CPCI_{DC}$ the costs per day of a prolonged calving interval in dairy cows for commercial milk production.

$$L_{PMC} = \sum_{x \in X3} \sum_{y \in Y3} N_x \cdot Mb_y \cdot PropPMC_y \cdot (MV_x - SV_x)$$

where $X3$ stands for the animal categories prematurely culled (dairy cows for commercial milk production, dairy heifers, dairy cows for non-commercial milk production, suckler cows, breeding bulls, ewes, and dairy ewes), *Y*3 for the respective animal groups, *PropPMC* for the proportion of morbid animals that are culled prematurely, and *SV* for slaughter value.

$$L_{RMY} = N_{DC} \cdot Mb_{DC} \cdot RMY_{DC} \cdot MY_{DC} \cdot PM + N_{NCC} \cdot Mb_{NCC} \cdot RMY_{NCC} \cdot MY_{NCC} \cdot PMR$$

where *RMY* stands for the relative reduction in milk yield in morbid cows, *MY* for milk yield, *PM* for the production price per kg milk, *NCC* for dairy cows for non-commercial milk production, and *PMR* for the price per kg milk replacer.

$$L_{WR} = (N_{EW} + N_{DE}) \cdot Mb_{AS} \cdot WY \cdot PW$$

where *EW* stands for ewes, *DE* for dairy ewes, Mb_{AS} the morbidity rate of adult sheep, *WY* the wool yield per sheep, and *PW* the price per kg wool. It is assumed that the wool from all morbid animals cannot be used, as they render fragile wool (Gunn et al., 2008).

$$L_{RWG} = N_{AC} \cdot Mb_{AC} \cdot PropWL_{AC} \cdot ECG$$

where *PropWL* stands for the proportion of morbid cattle showing weight loss and *ECG* the expenditures for compensatory growth per affected animal.

Export losses accrued from the number of animals that were not exported due to the disease. The number of live cattle exported was the following (the number in brackets indicate the change compared to the previous year): 2006: 4230; 2007: 4453 (+5.43%); 2008: 4469 (+0.4%); 2009: 5831 (+30.5%). The export value of Swiss cattle in 2008 was 5% higher than in 2007, but then decreased by 18% in 2009. On that basis, it was concluded that the number of export cattle in the RCS and PCS was not perceptibly affected by BT disease and related mitigation measures.

For the baseline scenarios, the number of cattle destined for export that could not be exported (N_{NCX}) was estimated as follows. Assuming that there would be two suspect cases per confirmed case, the number of confirmed cases (N_{CC}) and suspect cases (N_{SC}) in each scenario was calculated as follows:

$$N_{CC} = N_{IH} \cdot PropCC$$

$$N_{SC} = N_{CC} \cdot 2$$

where N_{IH} is the number of infected holdings and *PropCC* the proportion of confirmed cases per total number of infected holdings.

Then, the total number of movement ban days (N_{BD}) for the whole of Switzerland per year and scenario was calculated:

$$N_{BD} = N_{CC} \cdot t_{BCC} + N_{SC} \cdot t_{BSC}$$

where t_{BCC} and t_{BSC} are the duration of movement bans in days for confirmed and suspect cases, respectively. Dividing N_{BD} by 365 produced the number of holdings that were banned from export (N_{BH}) for the duration of a whole year. This figure was taken to calculate the proportion of banned holdings per year per total holdings with cattle (*PropBH*), which was then used to estimate N_{NCX} and L_X:

$$PropBH = N_{BH}/N_{HC}$$

$$N_{NCX} = PropBH \cdot N_{DCX}$$

$$L_X = N_{NCX} \cdot L_{NCX}$$

where N_{DCX} is the number of cattle destined for export and L_{NCX} the export loss per animal not exported.

Export expenditures accrued from the sum of expenditures for vaccinating (E_{XV}) or blood sampling and testing (E_{XT}) of export cattle that were not already vaccinated. For all scenarios, the number of export cattle to be vaccinated or tested (N_{CXVT}) was calculated by multiplying the number of cattle destined for export by (1 − VCOV). The E_{XV} and E_{XT} were calculated as follows:

$$E_{XV} = N_{CXVT} \cdot PropV \cdot N_D \cdot (PCO_R + PV + PI_R)$$

$$E_{XT} = N_{CXVT} \cdot PropT \cdot (PCO_R + PST_R + PTX)$$

where *PropV* and *PropT* are the proportion of N_{CXVT} vaccinated and tested, respectively, *PV* is the price per vaccine dose as in the section intervention cost, PST_R the regular price of a blood sample taken by a veterinarian, and *PTX* the price for laboratory testing for export.

The E_{PT} were calculated as follows:

$$E_{PT} = \sum_{y \in Y4} N_Y \cdot Mb_y \cdot PropRVT \cdot PVT_y$$

where *Y*4 stands for adult cattle, adult sheep, calves or lambs, *PropRVT* the proportion of morbid animals receiving veterinary treatment, and *PVT* the price of veterinary treatment.

Cantonal response expenditures for suspect and confirmed cases accrued from laboratory testing, epidemiological investigations, and measures to control midges. In case of a clinically suspect case, the *CVS* implements an animal movement ban on the holding, and orders the blood sampling of suspect animals (maximum five per holding) and an epidemiological investigation. The samples from suspect animals are tested for all serotypes using PCR. Sick animals receive palliative treatment, unless their condition requires welfare culling, and are treated with insecticides. If the holding is virus positive, all non-vaccinated animals (N_{NV}) have to be blood sampled and tested. Non-vaccinated animals are all animals on non-vaccinated holdings or young animals on vaccinated holdings. Once the holding fulfils the requirements for termination of an outbreak as stipulated in the Swiss Animal Health Ordinance (SR 916.401, www.admin.ch/ch/d/as/index.html), the *CVS* lifts the movement ban. The expenditures of the *CVS* for a suspect case (ESC_{CVS}) were calculated as follows:

$$ESC_{CVS} = N_{SC}[PCO_R + 5 \cdot PST_R + 5 \cdot PPCR + PIT + (H_{MBP} + H_{EI} + H_{LMB}) \cdot w_{CVS}]$$

where *PPCR* is the price of PCR testing for suspect and confirmed holdings, *PIT* the price of the insecticide treatment per holding, H_{MBP} the number of working hours to issue the movement ban provision, H_{EI} the number of working hours for the epidemiological investigation, H_{LMB} the number of working hours to lift the movement ban, and w_{CVS} the wage rate per hour of the *CVS* personnel.

The additional expenditures of the *CVS* for a confirmed case (ECC_{CVS}) were calculated as follows:

$$ECC_{CVS} = N_{CC}[PCO_R + N_{NV} \cdot (PST_R + PELISA + PropSP \cdot PPCR)]$$

where *PELISA* is the price of ELISA testing and *PropSP* the proportion of seropositive samples as in the section surveillance cost.

3. Results

3.1. Surveillance cost

Table 6 lists the entomological and serological surveillance cost for all scenarios. The mean undiscounted entomological surveillance cost was 35,265 CHF. The mean undiscounted serological surveillance cost was 15,594 CHF for the PBS1 and between 155,591–161,550 CHF for the other scenarios. For all scenarios, serological surveillance cost mainly accrued from the costs of laboratory testing (43–45%), planning of the surveillance programme (14%) and sampling (15–18%). Sensitivity analyses showed that the price for PCR testing in the serological surveillance programme had the strongest positive impact on the total surveillance cost for all prospective scenarios with regression coefficients ≥0.93. The other regression coefficients for the prospective scenarios were 0.28 for the number of animals sampled, 0.20 for the proportion of seropositive samples, and <0.20 for the number of holdings visited and the call-out fee.

3.2. Intervention cost

Table 7 lists the detailed intervention cost for all scenarios. The mean totals of intervention cost for the RCS were 17.52 and 11.09 m CHF for 2008 and 2009, respectively. The mean totals of intervention cost for the RBS were 9.22 and 5.87 m CHF for 2008 and 2009, respectively. The intervention cost for the retrospective scenarios mainly accrued from implementation costs (91–94%) and to a much lesser extent from planning (1–2%), preparation (3%), and dissemination and communication (1–4%). The mean total discounted intervention cost was highest for the PCS with 9.88–10.60 m CHF. The intervention cost for the PBS2 was about half the cost for the PCS. The PBS1 yielded the lowest intervention cost of 0.33–0.35 m CHF. The intervention cost for the PCS and PBS2 accrued mainly from implementation costs (92–94%) and to a lesser extent from preparation (2–3%), dissemination and communication (2–4%), and planning (1%). The intervention cost for PBS1 stemmed mainly from dissemination and communication efforts (52%), planning (30%), and preparation work (17%).

3.3. Disease costs

Table 8 lists the detailed disease costs for all scenarios. The mean total disease costs for the RCS were 5.62 m CHF in 2008 and 0.86 m CHF in 2009. The mean total disease costs for the RBS were 18.48 m CHF in 2008 and 5.45 m CHF in 2009. For the RCS in 2008 and 2009, disease costs mainly accrued from the cantonal response measures (55%), mortality (20% and 19%, respectively), and veterinary treatment expenditures (11%). For the RBS in 2008 and 2009, the disease costs mainly accrued from losses due to mortality (38% and 35%, respectively), cantonal response measures (26% and 25%, respectively) and palliative treatment expenditures (21% and 20%, respectively).

The mean total discounted disease costs for the years 2010–2012 were 1.23–3.14 m CHF for PCS, 7.14–9.95 m CHF for PBS1, and 3.97–5.82 m CHF for PBS2. For the PCS in 2010–2012, the total disease costs mainly accrued from losses due to the cantonal response measures (56–59%), mortality (20–21%), and palliative treatment expenditures (11%). For the PBS1 and PBS2, the total disease costs mainly accrued from losses due to mortality (35%), cantonal response measures (25–27%), and palliative treatment expenditures (20%). In all scenarios, losses due to premature culling, reduced wool production, reduced weight gain and export contributed least to the total disease costs.

Sensitivity analysis produced very similar results for the retrospective and prospective scenarios. For all scenarios, the proportion of confirmed cases per total number of infected holdings had the strongest positive impact on total disease costs (regression coefficient ≥0.93). The relative reduction in milk yield in morbid cows, morbidity in adult cattle, the price of veterinary treatment for adult cattle and mortality in adult cattle showed regression coefficients between 0.10 and 0.17 for all baseline scenarios. The number of working hours for the epidemiological investigation showed a regression coefficient of 0.11 for all comparative scenarios. All other input parameters had regression coefficients <0.1.

3.4. Total benefit, margin over intervention cost and net benefit/costs

The total benefit, difference in intervention cost, margin over intervention cost, difference in surveillance cost and net benefit and/or net costs resulting from the retrospective and prospective comparison of the baseline and comparative scenarios are illustrated in Figs. 1 and 2 and Appendix Table S3. For the retrospective analysis (Fig. 1), the mean total benefit was 12.86 m CHF in 2008 4.60 m CHF in 2009 and, in aggregate, 17.46 m CHF for the two years together. The mean margin over intervention cost was 4.56 m CHF in 2008, −0.62 m CHF in 2009 and, in aggregate, 3.94 m CHF for the two years together. These figures also represent the mean net value, because the calculated difference in surveillance cost was near zero.

The mean discounted total benefit resulting from the comparison between the PCS and PBS1 (Fig. 2A) was 8.75 m CHF in 2010, 4.26 m CHF in 2011, 4.13 m CHF in 2012 and, in aggregate, 17.15 m CHF for the three years together. The mean difference in discounted intervention cost was larger

Table 6
Entomological (entom.) and serological bluetongue virus serotype 8 surveillance cost (SC) calculated for Switzerland for the years 2008–2012 for the retrospective baseline scenario (RBS), retrospective comparative scenario (RCS), prospective baseline scenario 1 (PBS1), prospective baseline scenario 2 (PBS2), and prospective comparative scenario (PCS) [in 1000 CHF].[a]

		Entom. SC	Serological SC									
		2008–2010	2009		2010[b]			2011[b]			2012[b]		
		Any scenario	RBS	RCS	PBS1	PBS2	PCS	PBS1	PBS2	PCS	PBS1	PBS2	PCS
(1) Planning		2.20	22.00	22.00	2.13	21.26	21.26	2.05	20.54	20.54	1.98	19.84	19.84
(2) Preparation		1.90	8.43	8.43	0.81	8.14	8.14	0.79	7.87	7.87	0.76	7.60	7.60
(3) Supervision		0.90	2.20	2.20	0.21	2.13	2.13	0.21	2.05	2.05	0.20	1.98	1.98
(4) Sampling	Mean	3.90	29.66	24.03	2.33	28.72	23.29	2.25	27.75	22.50	2.17	26.81	21.74
	5th percentile		29.09		2.24	27.12	22.39	2.16	26.20	21.63	2.09	25.31	20.90
	95th percentile		30.22		2.42	30.36	24.19	2.34	29.34	23.38	2.26	28.34	22.59
(5) Laboratory testing	Mean	20.00	69.87	69.87	6.78	67.77	67.77	6.55	65.48	65.48	6.33	63.26	63.26
	5th percentile		61.68	61.68	5.95	59.48	59.48	5.75	57.46	57.46	5.55	55.52	55.52
	95th percentile		78.06	78.06	7.63	76.31	76.31	7.37	73.73	73.73	7.12	71.23	71.23
(6) Data collection, transfer and administration		–	8.80	8.80	0.85	8.50	8.50	0.82	8.21	8.21	0.79	7.94	7.94
(7) Analysis and interpretation of data		3.3	6.60	6.60	0.64	6.38	6.38	0.62	6.16	6.16	0.60	5.95	5.95
(8) Dissemination and communication of results		2.2	9.26	9.26	0.89	8.94	8.94	0.86	8.64	8.64	0.84	8.35	8.35
(9) Improvement and adaptation of project		1.1	4.40	4.40	0.43	4.25	4.25	0.41	4.11	4.11	0.40	3.97	3.97
Total	Mean	35.27	161.22	155.59	15.07	156.09	150.65	14.56	150.81	145.56	14.06	145.71	140.64
	5th percentile		153.02	147.40	14.21	147.49	142.13	13.73	142.50	137.33	13.27	137.68	132.68
	95th percentile		169.42	163.78	15.94	164.99	159.41	15.40	159.41	154.02	14.88	154.02	148.81

[a] 1CHF = 0.66 € at the time of analysis.
[b] Prospective values are discounted.

Table 7
Bluetongue virus serotype 8 intervention cost calculated for Switzerland for the years 2008–2012 for the retrospective baseline scenario (RBS), retrospective comparative scenario (RCS), prospective baseline scenario 1 (PBS1), prospective baseline scenario 2 (PBS2), and prospective comparative scenario (PCS) [in million CHF].[a]

Intervention step		2008		2009		2010[b]			2011[b]			2012[b]		
		RBS	RCS	RBS	RCS	PBS1	PBS2	PCS	PBS1	PBS2	PCS	PBS1	PBS2	PCS
(1) Planning		0.11	0.14	0.11	0.13	0.11	0.07	0.09	0.10	0.07	0.09	0.10	0.07	0.09
(2) Preparation		0.25	0.54	0.17	0.34	0.06	0.14	0.28	0.06	0.14	0.26	0.05	0.13	0.25
(3) Supervision		0.004	0.01	0.004	0.01	0.004	0.004	0.01	0.004	0.004	0.01	0.004	0.004	0.01
(4) Implementation	Mean	8.65	16.50	5.33	10.25	0	5.15	9.90	0	4.98	9.56	0	4.81	9.24
	5th percentile	8.30	16.30	5.11	10.10		4.94	9.76		4.77	9.43		4.61	9.11
	95th percentile	9.01	16.70	5.55	10.39		5.36	10.04		5.18	9.70		5.00	9.37
(5) Data collection, transfer and administration		0	0.08	0	0.07	0	0	0.06	0	0	0.06	0	0	0.06
(6) Data analysis and interpretation		0	0.02	0	0.02	0	0	0.02	0	0	0.02	0	0	0.02
(7) Dissemination and communication		0.20	0.23	0.26	0.28	0.18	0.21	0.24	0.18	0.20	0.23	0.17	0.19	0.22
Total	Mean	9.22	17.52	5.87	11.09	0.35	5.58	10.60	0.34	5.39	10.23	0.33	5.20	9.88
	5th percentile	8.86	17.33	5.65	10.94		5.37	10.45		5.18	10.10		5.01	9.75
	95th percentile	9.58	17.72	6.09	11.23		5.79	10.74		5.59	10.37		5.40	10.01

[a] 1CHF = 0.66€ at the time of analysis.
[b] Prospective values are discounted.

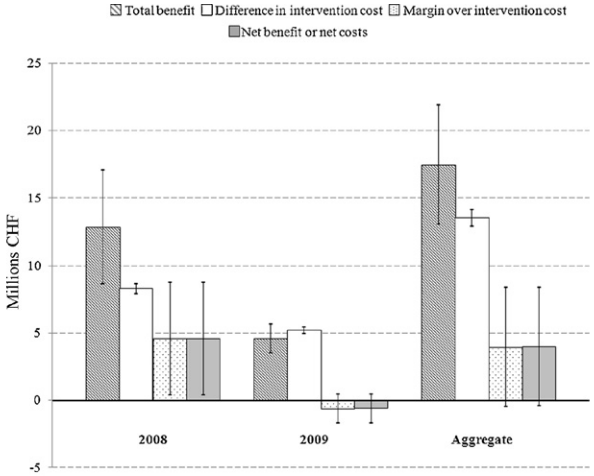

Fig. 1. Total benefit, difference in intervention cost, margin over intervention cost, and net benefit or net costs resulting from the comparison of the retrospective baseline scenario and retrospective comparative scenario.

than the mean total benefit which resulted in a negative mean margin over intervention cost for all years. The mean net value after subtraction of the difference in surveillance cost was −1.62 m CHF in 2010, −5.76 m CHF in 2011, −5.55 m CHF in 2012 and, in aggregate, −12.93 m CHF for the three years together.

The mean discounted total benefit resulting from the comparison between the PCS and PBS2 (Fig. 2B) was 4.58 m CHF in 2010, 0.89 m CHF in 2011, 0.93 m CHF in 2012 and, in aggregate, 6.41 m CHF for the three years together. The mean difference in discounted intervention cost was larger than the mean total benefit which resulted in a negative mean margin over intervention cost for all years. The mean net value after subtraction of the difference in surveillance cost was −0.43 m CHF in 2010, −3.94 m CHF in 2011, −3.74 m CHF in 2012 and, in aggregate, −8.11 m CHF for the three years together.

4. Discussion

The aim of this study was to make an economic evaluation of the BTV-8 surveillance and intervention programme in Switzerland both retrospectively (2008–2009) and prospectively (2010–2012). The retrospective analyses demonstrated that the surveillance and intervention programme to contain the disease implemented in 2008 and 2009 was economically beneficial with a mean net benefit of 3.95 m CHF. Yet the estimates for 2009 already signal changes that are more apparent from the prospective analyses. These show that the continuation of the surveillance and intervention programme in the same form would produce mean net costs of 8.11 m CHF for the period 2010–2012 when compared to the most likely alternative scenario. This loss is due to intervention cost remaining constant at a level of approximately 11 m CHF per year while the total benefit in a fully vaccinated population, i.e. the avoidable disease costs, are expected to be comparatively small (1–5 m CHF between 2010 and 2012). Because the intervention was so costly relative to the

Table 8
Bluetongue virus serotype 8 disease costs calculated for Switzerland for the retrospective baseline scenario (RBS), retrospective comparative scenario (RCS), prospective baseline scenario 1 (PBS1), prospective baseline scenario 2 (PBS2), and prospective comparative scenario (PCS) [in 1000 CHF].[a]

Disease costs		2008		2009		2010[b]			2011[b]			2012[b]		
		RBS	RCS	RBS	RCS	PBS1	PBS2	PCS	PBS1	PBS2	PCS	PBS1	PBS2	PCS
Losses due to														
Mortality	Mean	7017.36	1121.13	1925.03	162.65	3543.12	2103.52	243.78	2587.49	1427.07	643.41	2505.66	1406.65	621.65
	5th percentile	6529.17	1037.20	1784.15	145.42	3295.17	1952.33	220.71	2403.10	1323.03	592.28	2327.66	1303.37	572.36
	95th percentile	7501.25	1206.36	2065.46	181.60	3792.00	2256.01	267.94	2773.15	1533.18	695.47	2683.74	1509.78	671.96
Abortion	Mean	385.74	61.61	108.96	9.18	199.16	118.23	13.67	145.44	80.25	36.18	140.86	79.08	34.96
	5th percentile	109.65	17.44	29.91	2.50	55.52	32.93	3.85	40.33	22.29	10.12	39.23	22.09	9.74
	95th percentile	668.67	106.73	189.77	16.06	345.76	205.45	23.79	252.68	139.86	62.96	244.89	137.48	60.89
Prolonged calving interval	Mean	833.50	133.11	238.97	20.11	433.13	257.13	29.69	316.45	174.63	78.70	306.38	172.04	76.04
	5th percentile	550.19	87.82	157.56	13.17	286.31	169.68	19.49	209.00	115.30	51.86	202.01	113.37	50.04
	95th percentile	1150.38	183.80	329.86	27.94	597.35	354.79	41.20	436.20	241.15	108.56	422.48	237.16	105.08
Premature culling	Mean	251.73	40.22	65.87	5.55	121.52	72.16	8.34	88.75	48.97	22.05	85.94	48.26	21.30
	5th percentile	221.32	35.32	57.91	4.82	106.99	63.52	7.27	78.11	43.09	19.36	75.59	42.47	18.72
	95th percentile	283.72	45.40	74.29	6.33	136.91	81.30	9.48	100.03	55.25	24.90	96.82	54.37	24.05
Reduced milk yield	Mean	979.45	155.42	236.17	19.89	473.07	280.87	32.44	345.63	190.70	85.98	334.49	187.89	83.07
	5th percentile	377.03	59.69	91.13	7.63	180.57	107.11	12.27	132.48	72.90	32.72	127.87	71.57	31.66
	95th percentile	1603.01	254.66	386.67	32.76	782.83	465.44	53.93	570.40	315.43	142.10	551.67	310.60	137.58
Wool reduction	Mean	14.18	2.26	2.45	0.21	4.43	2.63	0.31	3.24	1.78	0.81	3.13	1.76	0.78
	5th percentile	13.23	2.03	2.24	0.16	4.11	2.41	0.25	2.98	1.62	0.70	2.89	1.59	0.68
	95th percentile	15.15	2.51	2.67	0.26	4.77	2.86	0.37	3.50	1.96	0.91	3.38	1.93	0.88
Reduced weight gain	Mean	11.21	1.79	3.21	0.27	5.82	3.46	0.40	4.25	2.35	1.06	4.12	2.31	1.02
	5th percentile	9.69	1.55	2.77	0.23	5.03	2.98	0.34	3.67	2.03	0.91	3.56	2.00	0.88
	95th percentile	12.81	2.05	3.68	0.31	6.65	3.95	0.46	4.86	2.69	1.21	4.72	2.65	1.17
Export	Mean	73.57	0.00	27.45	0.00	40.42	24.03	0.00	29.57	16.26	0.00	28.72	16.10	0.00
	5th percentile	5.42	0.00	2.00	0.00	3.09	1.77	0.00	2.23	1.20	0.00	2.16	1.19	0.00
	95th percentile	210.08	0.00	79.16	0.00	116.43	69.51	0.00	84.69	47.22	0.00	83.02	46.09	0.00
Expenditures for														
Palliative treatment	Mean	3797.41	606.80	1088.67	91.86	1972.93	1171.32	135.55	1441.03	794.84	358.26	1395.31	783.42	346.15
	5th percentile	3143.10	501.50	899.15	75.04	1631.96	967.97	111.46	1191.91	656.59	295.63	1154.26	647.53	285.84
	95th percentile	4516.89	722.59	1295.92	110.53	2347.20	1394.12	162.10	1712.67	946.49	426.90	1659.97	931.94	412.35
Export	Mean	282.01	385.45	368.90	78.69	445.91	290.07	76.03	431.03	280.35	73.46	416.45	270.87	70.97
	5th percentile	272.80	373.59	356.88	70.81	431.38	280.61	68.43	417.01	271.21	66.08	402.88	262.04	63.84
	95th percentile	291.18	397.29	380.86	86.73	460.43	299.52	83.85	445.05	289.45	80.98	429.93	279.66	78.20
Cantonal response	Mean	4835.47	3112.77	1387.12	469.47	2747.21	1492.20	694.47	2007.46	1012.72	1836.88	1942.65	998.03	1775.79
	5th percentile	1658.06	1059.83	474.19	161.52	943.00	508.89	238.76	688.32	347.07	627.71	664.07	340.82	604.45
	95th percentile	8055.82	5225.82	2308.28	786.42	4575.16	2488.44	1160.81	3346.72	1689.24	3082.67	3234.66	1665.92	2970.01
Total	Mean	18,484.23	5620.56	5452.77	857.88	9946.32	5815.93	1234.68	7370.79	4030.52	3136.77	7135.00	3966.60	3031.74
	5th percentile	15,009.87	3564.46	4462.45	548.18	8027.80	4738.52	777.11	5959.98	3298.33	1926.22	5773.75	3252.89	1860.61
	95th percentile	22,026.25	7744.21	6470.71	1178.77	11,894.62	6907.52	1704.39	8799.91	4780.31	4387.15	8510.90	4698.91	4239.13

[a] 1CHF = 0.66€ at the time of analysis.
[b] Prospective values are discounted.

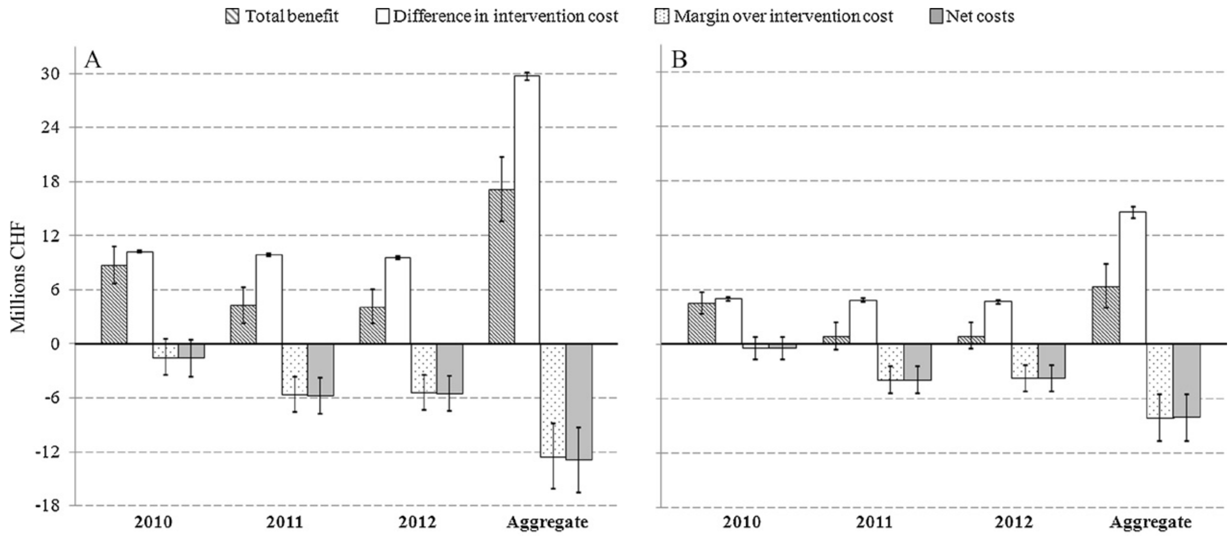

Fig. 2. Total benefit, difference in intervention cost, margin over intervention cost, and net costs resulting from the comparison of (A) the prospective baseline scenario 1 and prospective comparative scenario, and (B) the prospective baseline scenario 2 and prospective comparative scenario.

total benefit for all years except 2008, the overall outcome for BTV-8 mitigation was a net cost even before surveillance was taken into account. Overall, surveillance cost was only a fraction of the intervention cost. Moreover, the surveillance approaches differed little between the scenarios, which highlighted their secondary role. Hypothesising that surveillance and intervention are economic substitutes, using more of one should lead to a reduced use of the other. Hence, an increase in surveillance resources could produce more and better information which in turn would allow more targeted and potentially less resource-intensive intervention. A criterion for economic optimisation is that resources for surveillance and intervention are combined in such a way that their aggregate cost is minimised for any given level of benefits. Moreover, to identify the best of all such possible economic optima the relationship between variable levels of benefit and their associated levels of surveillance and intervention, optimally combined, should be investigated.

The surveillance information gained was mainly used to evaluate the success of the vaccination programme and to adapt the policy if evidence showed unsatisfactory results. Such measures have not been deemed necessary as the vaccination programme yielded the expected results. Also, the surveillance information needs to comply with EU Regulation 1266/2007 that stipulates the requirements for BT surveillance in the EU. In case of a non-vaccination strategy, surveillance could be reduced to the minimum laid down in the Regulation. In such a case, the only economic criterion for compulsory surveillance would be how to satisfy the requirements using the cheapest approach.

Importantly, the analysis was conducted to inform decision-making regarding the BTV-8 mitigation programme in Switzerland only for the years 2010–2012, as required by national policy makers. For the longer term, under a no vaccination policy, it is to be expected that the proportion of susceptible holdings will progressively increase due to newborn animals and vaccinated animals that will lose the immunity, which will cause an increase in disease costs. On the evidence of the policy implemented, shown in the prospective analysis to produce a net cost, there is a case for investigating a range of combinations of surveillance and intervention scenarios potentially to identify combinations yielding a net benefit, thus making such programmes economically justifiable. One potential approach, for example, could be to increase surveillance activities and focus intervention efforts on high risk populations only.

In 2010, the FVO decided to change its strategy and offered farmers the possibility to apply for an exemption from compulsory vaccination for cattle and sheep. In total, 14% of farmers decided to abandon the national vaccination programme (Anonymous, 2010a). The FVO decided to discontinue the national vaccination programme in 2011 (Anonymous, 2010b).

Owing to time restrictions, the present analyses only considered measurable costs and benefits. Additional benefits or costs may have stemmed from animal welfare impact, expertise gained in setting up a registration system for vaccination purposes in ruminants, impact on national and international reputation, consumer and industry confidence and trust. Such benefits and costs have a perceived value attached to them and attempts could be made to measure them using approaches such as contingent valuation (Drummond, 2005).

The analyses demonstrated that the largest part of the disease costs in the comparative scenarios accrued from the cantonal response measures for suspect and confirmed cases and to a lesser extent from veterinary treatment expenditures and mortality. This reflects the thorough outbreak control measures for BTV-8 that are stipulated in technical guidelines and the Swiss Animal Health Ordinance (SR 916.401.348.2). The losses due to mortality were the only production losses in all scenarios that contributed ≥20% to the total disease costs (maximally

38%). All other production losses contributed ≤5% to the total disease costs. Sensitivity analyses demonstrated that the proportion of confirmed cases and thus the amount of required cantonal response measures had by far the largest impact on the total disease costs in the comparative scenarios. The observation that outbreak control measures can contribute considerably to disease costs was also made by Velthuis et al. (2010) who reported that 55% of the BT related costs in 2006 in the Netherlands stemmed from the compulsory indoor housing of ruminants around infected holdings and 43% from transport restrictions and diagnostic costs. After abolition of the compulsory indoor regulation, the largest part of the costs was caused by production losses and treatment costs and only 6% by transport restrictions.

The output of a model depends strongly on the quality of the input data used. One major limitation of the present model was the lack of reliable data to estimate total disease costs. A range of assumptions was therefore made regarding coefficients of production losses and the impact of the surveillance and intervention programme on exports. Further, the epidemiologic modelling output had not been specifically designed to underpin economic analyses and was therefore not fully compatible. The first major limitation was that the epidemiologic model was designed only for an area with a 25 km radius and a susceptible population of 3100 holdings (Di Labio et al., 2009). The number of infected holdings in one such area then needed to be extrapolated to the national population proportionately, as there was no information available regarding spatial spread. A spatial explicit epidemiologic model on national level would deliver a more precise estimate of the actual number of infected holdings in the whole population. The second major limitation was that the epidemiologic model classified holdings as infected when there was at least one infected animal on the farm. Therefore, it did not provide any information about the number of infected animals on the farm nor the morbidity rate. The expert team suggested that the morbidity rate may vary depending on the infection pressure in a region, i.e. the morbidity rate would have been higher for the RBS and PBS. Due to lack of data to support this hypothesis, the same morbidity rate was used for all infected holdings, which may underestimate the total benefit. However, as the same assumptions were used for all scenarios, the relative conclusions drawn from comparison are still expected to be valid.

Epidemiologic and economic analyses are complementary in support of the decision-making process. Without epidemiologic models providing information about the disease dynamics in the population, this type of economic analysis would not have been possible. On the other hand, by definition epidemiologic models are not constructed to take into account the economic implications of resource allocation decisions (Howe, 1988). Ideally, epidemiologic and economic analyses should be planned together from the start. Only then can the respective models on which empirical work is based be made fully compatible with the objective of providing decision-makers with the comprehensive technical and economic information they require.

5. Conclusion

We conducted an economic assessment of surveillance and intervention activities directed at reducing BTV-8 prevalence in the Swiss ruminant population. By investigating the technical and economic relationships between surveillance, intervention and mitigation, it provided important information to guide policy makers in their decision-making. The results showed that the implementation of the mitigation programme was beneficial overall for the years 2008–2009, but produced net costs in future years. Further, the study highlighted the secondary role of surveillance in the mitigation process, thereby indicating that alternative combinations of surveillance and intervention should be considered potentially to produce a net benefit. The approach presented provides a structure that helps analyse and understand the use of mitigation resources and informs decisions about their allocation.

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Appendix A. Description of the epidemiologic model used to simulate bluetongue virus serotype 8 in the Swiss cattle, goat and sheep population

Three altitude strata were defined to take into account specific environmental temperatures and population structures (<800, 800–1499 and 1500–2000 m above sea level, respectively). Assuming that BTV-8 homogeneously spreads in an area with a radius of 25 km, the sizes of the starting populations at risk to be infected were calculated based on the Swiss mean density for cattle, sheep and goat holdings per altitude stratum. The number of holdings at risk to be infected at the start of the simulation period were 2000, 700 and 400 holdings for the three altitude strata, respectively.

The population of holdings was divided into five exclusive compartments: Susceptible (S), infected and infectious (I), recovered (R), vaccinated (V), and protected (P) (Appendix Fig. S1). The total population at any point of time was given by $N = S + I + R + V + P$. The model was run with daily time steps over the selected time periods. Simulations started on January 1st, and the annual (repeated) vaccination was implemented in February. On April 20th of each year a new infection was simulated to be introduced into the population, which was otherwise assumed to be constant.

Differential equations using the transmission parameters temperature-dependent infection rate $\beta(T)$, loss of natural (ω_r) and of vaccine-induced immunity (ω_p), vaccination rate (ν), development of vaccine-induced immunity (ρ), and recovery rate (λ) were used to describe the flows between compartments over time as follows:

$$\frac{dS}{dt} = \omega_r R + \omega_p P - \beta(T)SI - \upsilon S$$

$$\frac{dI}{dt} = \beta(T)SI + \beta(T)VI - \lambda I$$

$$\frac{dR}{dt} = \lambda I - \omega_r R - \upsilon R$$

$$\frac{dV}{dt} = \upsilon S - \beta(T)VI - \rho V$$

$$\frac{dP}{dt} = \upsilon T + \rho V - \omega_p P$$

Transition rates were constant apart from the flow from S to I, which was simulated using $\beta(T)$ which captured the temperature effect on the population dynamics of the vector and consequently on the whole infection dynamics. The model parameters $\beta(T)$ and λ were estimated based on observations of the incidence rates in cattle and sheep herds in BTV-8 outbreaks officially notified in Germany. To estimate $\beta(T)$ a model proposed by Hilbert and Logan (1983) to describe the effect of temperature on biological processes was used. For the simulation of different vaccination strategies in Switzerland, daily mean Swiss temperatures were used in combination with $\beta(T)$ estimates derived from the German outbreak data. For each day of the year, the mean of the daily mean temperature of all weather stations in the respective altitude stratum was taken and the mean value for each day over the last 10 years calculated.

The parameter values ω_r, ω_p, ν, and ρ were derived from scientific literature and expert opinion. The development as well as the loss of vaccine-induced immunity was modelled as a Weibull distribution. It was assumed that cattle and sheep would be protected 35 (double shot vaccination scheme) and 21 days (single shot) after the first vaccination, respectively, and that the duration of the national vaccination campaign was nine weeks. Thus, a holding would be vaccinated and protected 40–100 days (on average 70 days) after the start of the vaccination campaign. A herd was considered infected if at least one animal/herd was infected. With a herd size of 40 animals, the threshold value for I was 0.025. Infected animals were assumed to gain lifelong immunity. Because of the perennial replacement of animals, an immune or vaccine-protected holding was assumed to become susceptible again once 2/3 of the animals had been replaced.

An algorithm was used to derive the annual number of BTV-8 infected holdings from the daily outcomes of the simulations. The annual number of BTV-8 infected holdings per vaccination scenario for the years 2008–2012 was collated in a spreadsheet for inclusion in the economic analyses.

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.prevetmed.2011.09.013.

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