ORIGINAL ARTICLE

Description of Extended Pre-Harvest Pig *Salmonella* Surveillance-and-Control Programme and its Estimated Effect on Food Safety Related to Pork

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Impacts

- For large slaughterhouses, post-harvest interventions might be cost-effective to achieve a low *Salmonella* prevalence in pork. However, for small-to-medium sized slaughterhouses, pre-harvest measures might be more feasible.
- We describe an example of a *Salmonella* surveillance-and-control programme using data from the Danish island of Bornholm.
- Our analysis shows that it is possible to obtain a low prevalence of *Salmonella* in pork produced within the programme.

Keywords:
Salmonella; surveillance; pigs; simulation; meat-juice; carcass swab; pork

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Summary

Salmonella in pork can be combated during pre- or post-harvest. For large slaughterhouses, post-harvest measures like decontamination might be cost-effective while this is less likely with small-to-medium sized slaughterhouses. In this study, pre-harvest measures might be more relevant. We describe an extended surveillance-and-control programme for *Salmonella* in finisher pigs, which, to establish equivalence to the Swedish control programme, is intended for implementation on the Danish island, Bornholm. The effect of the programme on food safety was estimated by analysing *Salmonella* data from pig carcasses originating from herds that would have qualified for the programme during 2006–2008. Food safety was interpreted as prevalence of *Salmonella* on carcasses as well as the estimated number of human cases of salmonellosis related to pork produced within the programme. Data from the Danish *Salmonella* programme were obtained from Bornholm. We used a simulation model developed to estimate the number of human cases based on the prevalence of *Salmonella* on carcass swabs. Herds are only accepted in the programme if they have one or less seropositive sample within the previous 6 months. In this way, the *Salmonella* load is kept to a minimum. The programme is not yet in operation and pigs that qualify for the programme are currently mixed at slaughter with those that do not qualify. Therefore, we had to assess the impact on the carcass prevalence indirectly. The prevalence of *Salmonella* in carcass swabs among qualifying herds was 0.46% for the 3 years as a whole, with 2006 as the year with highest prevalence. According to the simulation the expected number of human cases relating to pork produced within the programme was below 10. When the programme is in operation, an extra effect of separating pigs within the programme from those outside is expected to lower the prevalence of *Salmonella* even further.

Introduction

Denmark exports around 85% of its pork production, which is why it is relevant to focus on the requirements listed by the importing countries, where Finland and Sweden play a role. Both countries have a recognized unique position with regard to *Salmonella* within the European Union (EU). This has been approved by the EU and enables the two countries to require additional guarantees when importing fresh meat to ensure a low risk of *Salmonella* in imported fresh meat. The official control requires that a large number of samples are taken from every batch of meat prior to export, and positive batches are rejected. For example, of a batch of 200 units, 50 must be sampled (Commission Regulation 1688/2005; Anonymous, 2005).

In accordance with Article 8 of Regulation 853/2004, fresh meat of bovine and porcine animals intended for Finland and Sweden must be tested for Salmonella (Anonymous, 2004). However, according to sub-paragraph (d) of Article 8, these microbiological tests need not be carried out for fresh meat from an establishment subject to a control programme recognized by the EU as equivalent to that approved for Finland and Sweden (Anonymous, 2005).

In Denmark, a serological *Salmonella* surveillance programme for finisher pigs has been in place since 1995. Accordingly, monthly meat-juice samples are taken in connection with slaughter. The samples are examined for *Salmonella* antibodies by use of the Danish Mix-ELISA (Nielsen et al., 1998). The cut-off for individual meat-juice samples is OD% 20 (Alban et al., 2002). The herds are assigned to one of three herd-levels based on the proportion of *Salmonella*-positive samples found in the previous 3 months (Alban et al., 2002). Herds allocated to level 2 or 3 are subjected to a penalty fee, which motivates farmers to seek advice from veterinarians to reduce the within-herd prevalence of *Salmonella*.

However, within the last couple of years, it has proved difficult to lower the prevalence of *Salmonella* in Danish market-age pigs further. The recently conducted EU baseline study of *Salmonella* in finisher pigs showed that – measured by use of lymph nodes – Danish finisher pigs had a prevalence of *Salmonella* of 7.7% which was a little lower than the EU average (10.3%). When measured as carcass prevalence, Danish pork had a prevalence of 3.3% which is lower than the EU average of 8.3%. In comparison, Sweden and Finland showed prevalences of 1.3% and 0.0%. This indicate that the Danish control programme is not able to ensure a *Salmonella* prevalence in pigs – and thus a food safety level – which is equivalent to that in Sweden or Finland (http://www.efsa.europa.eu/EFSA/efsa_locale-1178620753812_1178713190037.htm).

Salmonella in pork can be combated during pre- or post-harvest. Recently, it has been shown that at least for large slaughterhouses, post-harvest measures like hot-water decontamination might be cost-effective and will most likely have a significant impact on food safety as described by Alban and Sørensen (2009) and Barfod et al. (2009). Even though equivalence to Sweden and Finland in terms of food safety most likely can be achieved by this intervention, the focus in the currently running negotiations is equivalence of control programmes at the pre-harvest level and their ability to produce a low prevalent output from the slaughterhouses.

The concept of regionality opens for establishing equivalence for well-defined regions within countries. On the island of Bornholm, the prevalence of *Salmonella* in finishers and in fresh pig meat has consistently been lower than in the rest of Denmark for several years. This conclusion is based on the routine surveillance data from serological analysis of meat-juice and bacteriological examination of carcass swabs. Thus, pig production on Bornholm is already in a situation where equivalence to Sweden and Finland is close to be achieved at the pre-harvest level. The question is, therefore, whether it is possible to define robust surveillance and control programme covering fresh pig meat from the slaughterhouse on Bornholm, which can be accepted by EU as equivalent and will enable the slaughter plant on Bornholm to be exempt from carrying out microbiological testing of pork meat prior to export to Sweden and Finland.

Therefore, for Bornholm a surveillance-and-control programme, known as SALCONMEAT, has been designed on top of the existing Danish programme. Only herds that fulfil the requirements are included in the programme. The programme covers feed, housing, replacement of stock as well as requirements for sow herds, finisher herds, and the slaughterhouse on Bornholm.

The purpose of the present work was to describe the programme and to assess its effect on food safety. By analysing historical data from Bornholm from the period 2006 to 2008, it has been possible to identify the herds that theoretically fulfilled the requirements of the programme as well as the number of herds that did not meet the criteria. First, we unravelled the proportion of *Salmonella*-positive carcasses among pigs originating from herds that qualified for the SALCONMEAT programme. Hereby, we were able to estimate the effect of the SALCONMEAT programme in terms of the output of *Salmonella* positive carcasses from the slaughterhouse. By applying a new risk model developed by Barfod et al. (2009), we were also able to study the food safety implications of the SALCONMEAT programme by simulating the number of human cases related to the pork produced within the programme. We make our evaluation based on data from the current pre-harvest surveillance (meat-juice results used to identify positive herds) and slaughterhouse monitoring (carcass swab sampling). Hence, we are interested in seeing how low a prevalence of *Salmonella* you can reach by use of a system like the Danish where you only allow one seropositive reactor per herd.

Materials and Methods

Description of the production premises on Bornholm and the SALCONMEAT *Salmonella* control programme

Bornholm is an island located in the Baltic Sea, east of the rest of Denmark and south of Sweden. A total of 45 000 inhabitants live on Bornholm, which is connected to Denmark, Sweden and Poland by four ferry services. There is currently only one feed company located on Bornholm. In 2008, there were 203 pig herds producing approximately 408 000 finishers annually. The most common size is a production of 1000–2000 finishers per herd per year.

The current Danish *Salmonella* surveillance-and-control programme applies to the slaughterhouse on Bornholm as it does to finisher herds and abattoirs in the rest of the country. This includes requirements for the feed factory, serological monitoring of nucleus and multiplier herds as well as finisher herds (Nielsen et al., 2001). In the Danish *Salmonella* programme, a large number of pen-faecal samples in herds in level 2 and level 3 are collected and tested microbiologically (Alban et al., 2002). The distribution of *Salmonella* serotypes in the pig production is monitored this way and it is documented that more than 99% of the isolates carry an antigenic structure which is covered by the Danish Mix ELISA used in the Danish serological surveillance system (Baptista et al., 2009).

To qualify for the SALCONMEAT programme, extra requirements must be met by producers, including the feed suppliers. Serological monitoring of the finisher herds is conducted using a sample size large enough to detect a prevalence of at least 5% (95% confidence level). Samples are dispatched daily and results are available 2 days later and before the next delivery of finishers from the herd. Only herds which have a maximum of one seropositive sample within the previous 6 months – after the last delivery – are included in the programme. These herds are allowed to deliver animals in the following week. Herds with one seropositive sample within the previous 6 months are carefully observed week by week, because they have a higher probability of having an additional seropositive sample which will result in the herd having to leave the programme. Herds with two or more seropositive samples are excluded from the programme and are informed about this as soon as the test-results are received at the slaughterhouse. A sow herd and a finisher herd are most often contractually connected.

Nucleus and multiplier herds are monitored with an increased intensity by use of both serology and bacteriology. A maximum of one positive serological reactor is allowed while all bacteriological tests must be negative. The sow herds are monitored indirectly through finishing herds that they supply with stock.

If *Salmonella* is found in a sow pen-faecal sample, both the sow herd and the finisher herd are excluded from the programme. If a positive sample is found in a finisher herd, the sow herd supplying piglets is inspected through trace-back and trace-forward (the other finisher herds that have received pigs from the sow herd).

Herds that have one seropositive sample are listed monthly and observed carefully week by week. It should be noted that since January 2009, a total of three herds did not fulfil the criterion, and six herds were under observation.

The programme is not yet in operation because of the extra costs of running it. However, the existing serological data allows us to investigate how many of the slaughter pig herds on Bornholm that would have been excluded from the program in January 2009 if SALCONMEAT had been in operation (Appendix 1).

Data sources

By use of data from the Danish serological surveillance programme covering a 3-year period from January 2006 to December 2008, we were able to divide the herds into those fulfilling the requirements of the SALCONMEAT programme and those that did not. This assignment of herds was dynamic because the *Salmonella* status of the herds changed from month to month.

In Danish pig slaughterhouses, a *Salmonella* monitoring programme is in place and includes daily swabbing of 300 cm^2 of five carcasses. Three areas of 100 cm^2 are swabbed by using the same gauze tampon. The method is recognized by the US Food Safety and Inspection Service (FSIS, 1996). The only difference between the method recommended by FSIS and the Danish method is that five carcasses are sampled in the Danish programme instead of one required by FSIS. The swab samples from five carcasses are analysed as one pooled sample. The single sample prevalence was calculated from the pooled sample prevalence, by using a conversion factor of three (Sørensen et al., 2007) instead of five, hereby taking loss of sensitivity related to pooling into account. The herds of origin of the five carcasses represented in the pooled swab samples are registered.

The data were divided into three groups: according to the herd origin of each of the five samples in the pooled sample.

1 All five samples originated from herds that all qualified for the SALCONMEAT programme.
2 Lack of serological samples from at least one herd, hence its status with regards to the SALCONMEAT programme was unknown.
3 At least one of five samples originated from a herd that did not qualify for the SALCONMEAT programme.

Data analysis

For calculating the chi-square value, the VassarStats web site for statistical computation was accessed and here Fisher Exact Probability Test for 2×2 contingency tables was used (please see http://faculty.vassar.edu/lowry/VassarStats.html).

A simulation model developed by Barfod et al. (2008) was used to estimate the number of human cases of salmonellosis to be expected from pork (fresh pig meat) produced within the SALCONMEAT programme. The model provides an opportunity to estimate the number of human cases to be expected from a pig population with certain *Salmonella* carcass prevalence at slaughter. Thus, the model was used to estimate the number of human cases to be expected with/and without SALCONMEAT in place.

The model is based, among others, on the parameters included in Table 1. In a year, the Danish population consisting of around five million inhabitants consumes a little more than two million carcasses. A serving size of 200 g was used. As pork is not eaten raw, the model holds the assumption that the number of human cases is proportionate to the number of bacteria present in the raw meat. To adjust for this assumption, the model contains a reduction factor that deals among others with the effect of preparing food including heat-treatment. This factor is analogous to the so-called a-factor in the Danish *Salmonella*-attribution model (Hald et al., 2004) and anchors the model output to the observed number of human cases in 2006 in Denmark. The reporting rate was set to around 5%. That implies that it is assumed that only about 5% of the true *Salmonella* cases are reported; presumably the mildest cases are not.

A stochastic simulation model was constructed in @Risk (Palisade Corporation, Middlesex, UK) using Monte Carlo simulation (Latin hypercube sampling). The model simulates whether a serving is contaminated with *Salmonella* or not, based on quantitative input data from 2005 to 2006 from five Danish abattoirs. In short, carcass swab samples of 2800 cm^2 and faecal samples were obtained from around 2000 pig carcasses and tested quantitively for *Escherichia coli* and *Salmonella* (unpublished data, S. Aabo). These data provided the basis for modelling the quantitative number of *Salmonella* bacteria on the carcass by simulation based on a combination of a faecal carcass contamination model (Barfod et al., 2008;.) and the concentration of *Salmonella* bacteria, in the faeces (*Salmonella*/g faeces). In short, the faecal contamination was modelled by sampling from the lognormal distribution of *E. coli* in swabs and in faeces and the number of *Salmonella*/carcass was achieved by sampling from the binomial distribution for *Salmonella* prevalence followed by using the RiskDiscrete function on faecal *Salmonella* concentration data. From the simulated distribution describing the number of *Salmonella* per carcass, a distribution of the number of *Salmonella* bacteria for *Salmonella*-positive serving was modelled. Next, for the positive servings, it was subsequently assessed whether a given quantitative number of *Salmonella* bacteria in a serving would result in disease. This was performed by use of a β-poisson dose–response model, as recommended by FAO/WHO (2002):

Table 1. Parameters used in simulation model[a] assessing the number of human cases related to *Salmonella* in pork, Denmark, 2008

Parameter	Value	Origin of information
No. pork carcasses for national consumption	2 170 800	Danmarks Statistik/Danish Agricultural & Food Council
Carcass weight	75 kg	DMA
Size of serving	0.2 kg	Authors opinion
Servings per carcass	375	Calculated
No. servings	814 050 000	Calculated
Population	5 427 000	Danmarks Statistik
Yearly consumption of pork	30 kg/person	Eurostat (corrected)
Reduction factor (RF)	0.0142	Estimated RF = Observed_incidence/incidence_predicted_without_factor
Reporting rate	0.0539 RiskNormal(0.05; 0.005)	Chalker and Blaser, 1988

[a]Simulation model developed by Barfod et al. (2008).

Probability of illness (P_{ill})

$$= 1 - (1 + Dose/\beta)^{-\alpha} \quad \text{(Equation 1)}$$
$$\text{where } \alpha, \beta = 0.1324, 51.45$$

It should be noted from Fig. 1 that with a dose of *Salmonella* of approximately 10^4, around 50% of exposures would lead to sickness. It should also be noted that for very low doses of *Salmonella* (<10) the probability of becoming ill becomes almost insignificant.

To evaluate the effect of the SALCONMEAT programme, the national surveillance prevalence of 1.0% *Salmonella* positive carcasses was used as reference point in the risk model. By entering the Bornholmean surveillance prevalences of 0.5% and 0.2%, the number of cases, which could be expected if Bornholm delivered all pork meat to the Danish marked in 2006 could be modelled.

Results

The number of herds that would have qualified for the SALCONMEAT programme varied over the previous 3 years (Fig. 2). Initially, approximately 170 herds qualified. The number of qualified herds declined to 120 during the first half of 2007 and increased during the second half of 2007 to 140. By the end of 2008, approximately 130 herds had qualified. The latter decline is probably a result of herds stopping production. The number of herds outside the programme has varied between 10 and 50. Figure 2 shows the monthly number of herds inside and outside the programme, despite that, as described in Materials and Methods, a weekly status is assigned to each herd.

The fluctuations in the number of herds qualifying for the programme is also reflected in the total number of positive meat-juice samples found in herds that qualified/did not qualify for the programme (Fig. 2). A maximum was observed in January 2007 when 33 positive samples were found among the herds outside the programme and 15 samples among the herds inside the programme. Since then, the total number of positive meat-juice samples has declined substantially. In all 3 years, the total number of positive meat-juice samples in the herds within the programme is much lower than the number of positive samples in the herds outside the programme – despite the fact that the number of herds within the programme is much higher than the number of those outside the programme.

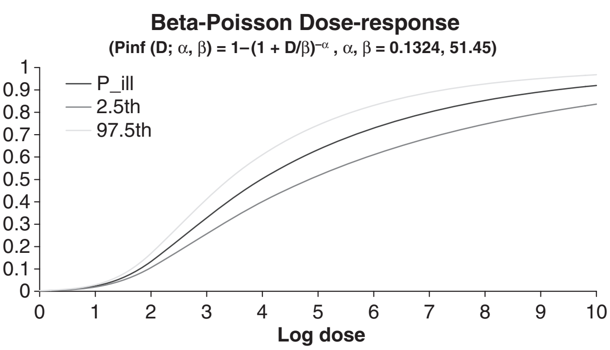

Fig. 1. Graphical description of dose–response model for *Salmonella* recommended by FAO/WHO (2002) and used in a modelling of the number of human cases related to pork produced according to the SALCONMEAT programme, 2009, Denmark.

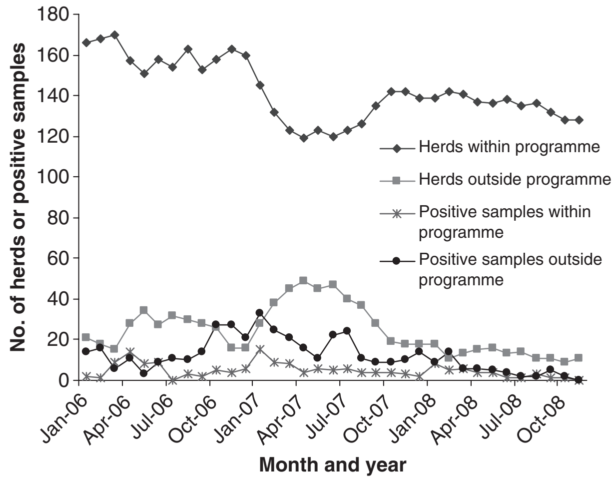

Fig. 2. The number of finisher herds and the total number of meat-juice samples positive for antibodies against *Salmonella* divided according to whether the herd would have qualified for the SALCONMEAT programme for *Salmonella* during 2006–2008, Bornholm.

For *Salmonella*, there is an association between herd serology and bacteriology measured on, for example, the carcass; however, there is also a variation between the slaughterhouses in their ability to deal with *Salmonella* (Sørensen et al., 2004). It is, therefore, important to look at *Salmonella* data from the slaughterhouse monitoring programme, specifically from Bornholm (Table 2). On the basis of the herd origin of the carcass swab samples, the data were divided according to whether the herd would have been within or outside the programme at the time the samples were taken. Only pools where all five carcass samples came from herds that qualified for the programme were used for the estimation of the effect of the programme.

Table 2 shows that the prevalence of *Salmonella*-positive carcasses varied slightly during 2006–2008. Among the herds that would have qualified for the programme, a carcass prevalence of 0.91%, 0% and 0.45% was obtained for 3 years, respectively. When the data for 3 years are combined, a carcass prevalence of 0.46% was obtained for

Table 2. Prevalence of *Salmonella* in 3550 carcass swab samples divided according to whether the finisher pig herd qualified for the SALCONMEAT programme or not, by year, 2006–2008, Bornholm

	Prevalence of *Salmonella* in given year					
	2006		2007		2008	
	Pools of 5	Carcass[a]	Pools of 5	Carcass[a]	Pools of 5	Carcass[a]
	Pos/total	(%)	Pos/total	(%)	Pos/total	(%)
Within programme	3/110	0.91	0/108	0	2/148	0.45%
Outside programme or lack[b] of samples taken	2/132	0.51	6/124	1.61%	2/88	0.76%

[a]A conversion factor of 3 was used to convert the prevalence of *Salmonella* measured in a pool of samples to the prevalence on the individual carcass sample (Sørensen et al., 2007).

[b]A specific number of meat-juice samples are required from each herd before it can be allocated to the programme.

the herds within the programme and 0.97% for the herds outside the programme ($P = 0.19$). If only data from 2007 and 2008 are used, then a prevalence of 0.26% was obtained within the programme compared with 1.26% for the herds outside the programme ($P = 0.049$).

According to the simulation, a total of 107 human cases (90% CI 0–366) were attributable to pork in Denmark in 2006 (Table 3). If we assume that all pork consumed in Denmark originate from SALCONMEAT alone, we set the individual carcass *Salmonella* prevalence to 0.5 or 0.2%, which resembled the findings of 2006–2008 or 2007–2008, respectively. For these scenarios, the model predicted 52 and 21 human cases, respectively.

The initial results presented in scenario 2a and 2b in Table 3 assume that all pork consumed in Denmark originates from SALCONMEAT. However, to estimate the number of human cases caused specifically by pork from SALCONMEAT, an adjustment to the actual production of pork within the programme was needed. On Bornholm, 406 000 finishers are slaughtered annually, and of these, 393 000 carcasses are expected to be produced within the SALCONMEAT programme. In Denmark, around 2.2 million carcasses are consumed annually. Hence, production within the SALCONMEAT programme is 393 000/2 170 800 = 18% of the national production.

Table 3 presents the estimated number of human cases of salmonellosis related to the production of pork within the SALCONMEAT programme. It is observed that the number is nine or four – depending upon whether data from 2006to 2008 or 2007 to 2008 were used.

As model control, we used the national carcass prevalence of *Salmonella* in 2006 which was 1.0%. In that year, 101 human cases were ascribed to Danish pork according to a mathematical model that compared the number of human cases caused by different *Salmonella* sero- and phage types with the distribution of the *Salmonella* types isolated from the various animal-food types (Anonymous, 2006). Consequently, if a prevalence of 0.5% is assumed for pork from SALCONMEAT and, as a maximum, production constitutes 18% of what is consumed in Denmark, then around $101 \times (0.005/0.01) \times 0.18 = 10$ human cases can be expected. Similarly, when a carcass prevalence of 0.2% is assumed, the number of human cases is expected to be around four.

Table 3. Simulated[a] number of human cases of *Salmonella* in Denmark ascribed to pork assuming three different prevalence levels of *Salmonella* and origin of production, 2008

Scenario	Origin of pork	Prevalence[b] in pork based on carcass swabs (%)	Average no. human cases of *Salmonella* (90% CI): Assuming all pork in Denmark is of specific origin	Adjusting for production capacity in area of origin
1	Entire Denmark	1.0	107 (0–366)	107 (0–366)
2a	Only SALCONMEAT	0.5	52 (0–298)	9
2b	Only SALCONMEAT	0.2	21 (0–92)	4

[a]Based on simulation model developed by Barfod et al. (2008).

[b]Prevalence calculated as the individual carcass prevalence.

Discussion

The programme may commence once it has been approved by the EU as equivalent to the programme in Sweden and Finland. However, the effect of the programme can be estimated by examining the data from the herds which would have qualified for the programme.

For a given programme to be successful, it needs to be able to correctly allocate herds into those which qualify and those which do not qualify for the programme. And this not only applies at the beginning of the programme. Herds that at some stage no longer qualify for the programme should be removed from the programme immediately. Hereafter, the herds can receive advice on risk-mitigating action with respect to *Salmonella*. Once the action taken leads to observable results that qualify the herds, then they can re-enter the programme.

In the SALCONMEAT programme, the criterion for entering and leaving the programme is clearly stated. It is noted that the number of herds within the programme has varied between 2006 and 2008. In the first half of 2007, however, a larger number of herds left the programme because of the detection of *Salmonella*-positive meat-juice samples. Half a year later, the herds re-entered the programme (Fig. 2).

With regard to sow herds, the requirement for re-entering is that no positive pen-faecal samples are found within the previous 6 months. For the finisher herds, a maximum of one seropositive meat-juice sample within the previous 6 months is required. This implies that herds that do not qualify for the programme often remain excluded for 3–6 months before the requirement is met.

As soon as more than one seropositive sample is found, the herd can no longer participate in the programme. In this study, we have presented the data as if the assignment of herds took place on a monthly basis because the data are stored as monthly records. A cut-off of OD% 20 is used in the Danish programme, despite that the correlation between serology and bacteriology is slightly higher at cut-off OD% 11 (Alban et al., 2002). The reason is that a level 0 is used in the Danish programme for herds with continuous negative samples. It has been considered that would be detrimental for level 0 if cut-off of OD% 11 was chosen, because this would increase the proportion of false-positive results (Alban et al., 2002). However, it would be of interest to study what the effect of lowering the cut-off in the SALCONMEAT programme would be on the ability to produce pork with a low prevalence of *Salmonella*.

To promote reassignment of herds outside the programme, the herd owners receive advice from the responsible slaughterhouse consultant in relation to (i) reducing the risk of introducing *Salmonella* into the herd and (ii) reducing the spread of *Salmonella* within the herd if introduced. The advice on *Salmonella* introduction deals with rules that any person, including visitors, must abide by when entering the herd as well as rules for bringing animals and feed into the herd. The advice regarding mitigating internal spread concerns segregating the herd into smaller units. The aim was to ensure that each unit consists of a more or less uniform group of pigs (based on weight of pigs or function of sows) with a specified hygiene level. The unit with weaned piglets should have the highest hygiene level. Any passage from 1 unit to the next should be carried out most carefully. Furthermore, care should be taken to ensure that the other slaughter pig units (young and older) maintain their hygiene level. Information about cleaning procedures is crucial for the maintenance of a high level of hygiene. And it is recommended that washing, disinfection and liming are carried out.

Usually, herd owners are motivated to implement the advice given. To take into account the variation in how pig production is conducted, the advice given is based on risk factors present in the individual herd. Some known risk factors play a minor role for the herds in the SALCONMEAT programme, for example, feed and trade, both because of local tradition and because requirements are already a part of the programme. Experience shows that protection against infections like *Salmonella* is not always taken sufficiently seriously in all herds at all times. However, in most cases, it is possible to obtain visible results after an advisory visit to the herd, resulting in a risk-mitigating effect on *Salmonella*.

Based on data from the slaughterhouse monitoring, the SALCONMEAT programme seem to have an effect because the prevalence of *Salmonella*-positive carcasses is lower among the herds that would have qualified for the programme (0.46%) than among the remaining herds (0.97%). However, this is not statistical significant when evaluating the 3 years ($P = 0.19$), but significant when evaluating the latest 2 years ($P = 0.049$) (Table 2). Because of export of pork to the US, the Danish slaughterhouse monitoring is made in accordance with the US authorities, FSIS. If the area to swab was increased from the current 300 cm^2 to, for example, 1400 cm^2, then the sensitivity would increase.

One of the main points of difference between the SALCONMEAT programme and the Danish Surveillance-and-Control programme for *Salmonella* in finisher herds is that *Salmonella*-positive herds are removed from the SALCONMEAT programme and transported and slaughtered on separate days. The aim of this work was to see how well such a system would perform. The strategy in the programme is somewhat equivalent to the Swedish sanctions against *Salmonella*-positive herds.

The programme is not currently in operation because of the high costs involved. Consequently, the evaluation of the expected effect in respect of *Salmonella* was based on historic data. Once the programme is in operation, pigs from herds outside the programme will be slaughtered separately from pigs from herds within the programme. This reduces cross-contamination between carcasses harbouring *Salmonella* and carcasses not harbouring *Salmonella*. In general, logistic slaughter has a limited effect among herds with lower levels of *Salmonella* (Alban et al., 2007). However, recent results show that if the number of seropositive pigs slaughtered in a day can be kept below around 50, then roughly a halving of the prevalence can be expected (Dahl, 2009). The study showed that for slaughterhouses where more than 50 seropositive pigs per day were introduced, approximately half the positive carcasses could be attributed to cross-contamination. The other half were positive because of *Salmonella* from the sampled pig itself. Reducing the number of seropositive pigs below the threshold of 50 seropositive pigs per day is feasible in the SALCONMEAT programme because:

1 the slaughterhouse only slaughters between 1700 and 2100 pigs a day;
2 the herds in the programme are only allowed to have a maximum of one positive sample within the previous 6 months.

This implies that there are very few *Salmonella*-positive pigs slaughtered on the days when the programme is in action. Only recently infected herds that have not yet been identified as infected might be slaughtered together with the non-infected herds. The impact will be that the prevalence of *Salmonella* will be lower than seen today; and most likely less than 0.2% measured as the individual carcass prevalence.

The simulation model applied is both flexible and robust and is designed to contrast the effect of different levels of slaughter hygiene and concentration of enteric pathogens. According to the simulation, a total of 107 human cases could be ascribed to Danish pork in 2006. This is very close to the 101 cases reported as the official number ascribed to pork in that year (Anonymous, 2006). Although the majority of simulations give estimates of human illness close to the observed annual incidences, occasional sampling of extreme values from the input distributions can cause prediction of a high number of human cases, corresponding to outbreaks naturally occurring. Consequently, the output distributions are not normally distributed but skewed towards the right (observable from the 90% CIs in Table 3).

The prevalence of *Salmonella* in pork produced within the SALCONMEAT programme is low. It might have been higher if the area swabbed was increased to 1400 cm^2. However, the simulation model that was used is based on the current monitoring where 300 cm^2 is swabbed. The estimated number of human cases relating to the pork produced within the SALCONMEAT programme is very low; <10. This is a result of (i) a low prevalence of *Salmonella* on the carcasses and (ii) a limited amount of pork produced within the programme. It is questionable whether such a small number will show up in the national statistics of the importing country. It is up to a risk manager to decide whether the limited number of expected human cases relating to the pork produced under the SALCONMEAT programme is considered a low or a negligible risk. It might be speculated that if the exposure of a population to *Salmonella* is very low, then the immunity is low as well. However, the difference in salmonellosis notification rate (human cases per 100 000 inhabitants) between the two countries is not that large: 45.6 for Sweden and 67.0 for Denmark (please see http://www.efsa.europa.eu/en/scdocs/doc/1496.pdf).

EU countries with very low prevalence of *Salmonella* in pork (Sweden and Finland – and with them also Norway which is not a member of EU) are currently allowed to require testing of meat prior to export (Anonymous, 2005). However, an outbreak of *Salmonella* Typhimurium U288 occurred in Norway and Sweden during November and December 2008, which was caused by Danish pork that had tested negative in export tests (Bruun et al., 2009). This emphasizes that food safety is not an outcome of testing but an outcome of management. Testing will only verify the quality of a management programme with a certain probability.

In a few of years, EU will set targets for the accepted level of *Salmonella* in the pork production. It is unknown at present whether the targets will be set at pre- or post-harvest level – or both. For small-to-medium sized slaughterhouses, post-harvest measures like hot-water decontamination might not be cost-effective and pre-harvest measures, therefore, might be the solution. The principles behind a surveillance-and-control programme like SALCONMEAT might, thus, be a feasible option if the targets are set at a low prevalence. Our results show that for a medium-sized slaughterhouse, it is possible to keep the prevalence of *Salmonella* in pork very low by setting strict pre-harvest requirements based among others on a serological testing programme.

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Appendix 1

Graphical presentation of serological surveillance results from finisher herds that were assigned to be outside the SALCONMEAT programme in January 2009 or which were under observation because of the finding of one seropositive sample within the previous 6 months, Bornholm 2009

	No. seropositive samples found in herd in month in year 2008											
Herd no.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Herd could not participate in the SALCONMEAT programme in January 2009 because of >1 seropositive sample within the previous 6 months												
1	1	3	1		1			**1**	**1**	**1**		**2**
2									**1**			**1**
3		1			1	1			**1**	**1**		
Herd was under observation in January 2009 because of one seropositive sample within the previous 6 months												
4												**1**
5												**1**
6										**1**		
7	1	2	1	2	2				**1**			
8									**1**			
9		2		1			**1**	**1**	**1**			

The vertical line is used to indicate that only the most recent 6 months' results are used in the assignment of a herd in January 2009. Figures in bold show the samples which formed part of the herd assignment in January 2009.