Intestinal parasites in swine in the Nordic countries: multilevel modelling of *Ascaris suum* infections in relation to production factors

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SUMMARY

In Denmark, Finland, Iceland, Norway and Sweden, 413 sow herds were randomly selected for sampling. Faeces from pigs of 7 age groups/categories were examined for helminth eggs (11233 individual samples), and an accompanying questionnaire was completed at each visit. In total, 1138 pigs on 230 farms were found to be positive for *Ascaris suum*. Considerable differences in the occurrence of *A. suum* could be observed directly for several of 20 independent variables at the herd or category level. However, given that univariate analyses may be severely affected by confounding of covariates resulting in spurious inference, additional multivariate analyses were undertaken. An ordinary logistic regression on *Ascaris* positive/negative farms showed that Denmark had the highest frequency of infected herds, while Iceland and Finland had the lowest frequencies and that herds using 'late weaning' and 'Class 2' drugs (pyrantel, levamisole) were most often infected. Because many herds were found to be totally negative for *A. suum*, mixed hierarchical logistic-normal regression models (both the penalized quasi-likelihood and the Markov Chain Monte Carlo methods) were developed for both a full (all herds) and a reduced (the 230 infected herds) data set using either a cut-off of >0 eggs per gram (epg) or >200 epg to counter for false-positive egg counts. Estimates for identical models, but where the animal level variance was constrained to the binomial assumption, were also calculated. Significant covariates were robust to model development with 'Age group', 'Country', 'Weaning age', 'Water system' and simple interactions between the latter two and 'Age group' being significantly associated with the occurrence of *A. suum*, while all variables concerning anthelmintic drug, anthelmintic strategy, floor type, bedding, dung removal, washing and disinfection were not. These findings are discussed in the light of the complex relationship between *A. suum* and its pig host.

Key words: *Ascaris suum*, multilevel modelling, herd factors, pigs, Nordic countries.

INTRODUCTION

The large round worm of pigs, *Ascaris suum*, is transmitted via eggs that embryonate in the environment, and therefore the level of infection will depend to a large degree on environmental and management factors (reviewed by Nansen & Roepstorff, 1999). Simple univariate analyses of such relationships are common in the literature. However, they ignore 2 important facts; (1) that many herd factors are themselves associated and (2) that most, if not all, such datasets have a hierarchical structure, i.e. with at least 2 levels (pigs and herds). When multivariate analytical techniques which properly account for the clustering of level 1 observations (i.e. pigs) within the level 2 units (i.e. farms) are employed (known as multilevel analyses), many of the former univariate statistical differences tend to disappear (Goldstein, 1995). As pointed out by Nansen & Roepstorff (1999), in the case of *A. suum*, the transmission rate and the rate of development of

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Table 1. Numbers of sow herds and pigs sampled in relation to pig category

	Weaners*	Small fatteners†	Large fatteners‡	Gilts§	Dry sows‖	Lact. sows	Boars	Total
Number of sow herds	381	295	332	344	408	402	330	413
Number of pigs sampled	1798	1420	1722	1203	2501	1963	626	11233
Mean number of pigs sampled per herd ± S.D.	4·7 ± 1·4	4·8 ± 2·4	5·2 ± 2·5	3·5 ± 1·7	6·1 ± 2·6	4·8 ± 2·3	1·9 ± 1·3	27·2 ± 9·9¶

* Weaners, approx. 25 kg body weight, i.e. 8–12 weeks old (if the farmer routinely dewormed the weaners when they weighed approx. 25 kg, only untreated pigs were sampled).
† Small fatteners, approx. 45 kg body weight, i.e. 14–18 weeks old.
‡ Large fatteners, approx. 90 kg body weight, i.e. 24–28 weeks old.
§ Gilts, i.e. young sows pregnant for the first time, normally 9–11 months old (if the gilts were routinely dewormed pre-farrowing, only untreated gilts were sampled).
‖ Dry sows as close to farrowing as possible (if sows were routinely dewormed pre-farrowing, only untreated sows were sampled).
¶ The total mean number of pigs sampled per herd is not equal to the sum of pigs sampled in the various age categories, as all pig categories were not sampled in all herds.

post-exposure immunity are likely to have distinct and non-linear influences on the appearance of age–prevalence curves, and in the case of multivariate linear approximations to non-linear systems of infection dynamics these effects may therefore best be appreciated by examining not only herd risk factors but also their interactions with age. In the framework of a joint Nordic project on intestinal parasites in pigs, a cross-sectional survey was carried out covering all 5 countries. The study design and the national and age-specific prevalence rates have been reported elsewhere (Roepstorff *et al*. 1998), while the present paper reports the results of multilevel analyses of the relationship between management factors and *A. suum* prevalence as determined by faecal egg counts.

MATERIALS AND METHODS

Herd and animal selection and parasitological analyses

The protocol of this cross-sectional study and the parasitological analyses have been described in detail elsewhere (Roepstorff *et al*. 1998). In total, 413 sow herds were selected randomly in Denmark (DK), Finland (FIN), Iceland (I), Norway (N), and Sweden (S) after stratification on herd size. If possible, faecal samples were collected from 5 animals in each of 7 categories of swine from each herd (Table 1), and processed by different modifications of the McMaster technique in use in each of the 5 countries. These methods were compared three times during the survey study (Christensson *et al*. 1991), showing that each laboratory had a relative efficacy (compared to the other laboratories) that was reproducible for both high and low egg counts and was consistent over the 3 year period of sampling. The egg counts were therefore made directly comparable by correcting the reported values of *A. suum* epg (eggs per gram faeces) for the different efficiencies. This resulted in a variable effective lower detection limit by country, as follows: 13·4 epg (DK, I), 19·5 epg (FIN), 20·6 epg (southern S), 24·2 epg (northern S) and 40·2 epg (N).

Data collection

Selected herds had all been visited once by participating co-workers who were trained to complete the comprehensive questionnaire and to collect the appropriate samples. The questionnaire comprised a combination of open-form numeric questions (e.g. number of sows, weaning age in weeks, number of farrowings, etc.) and closed-form questions, where co-workers had to place tick marks within a series of pre-designed boxes (e.g. choose which of 6 possible anthelmintic strategies for a specific group of pigs best described the farm practice). Questions were answered during the visit either by direct observation or by interviewing the farmer. The questions may roughly be divided into 3 levels. First, those at the herd level which dealt with physical composition or management practice, e.g. country, date, herd size, herd type, weaning age, etc. Second, those which were specific for the various categories or groups of swine, e.g. anthelmintic strategy and choice of drug, and housing system and hygienic measures in the various sections of the herds. Finally, some observations such as number of farrowings, date for last deworming, breed, and general body condition were made at the individual pig level. In total, 27 questions were directed at the herd level, 24 questions at the group level (i.e. answered for each of weaners, fatteners, gilts, dry sows, lactating sows and boars), and 3–5 questions were answered for each sampled animal. Care was taken to avoid missing values. However, some questions could obviously not always be answered, for example when no pigs of a specific age group were present (e.g. no fatteners, no boars)

Table 2. Herd variables and their categories

(The first 8 variables (country–boars) were all variables at the herd level, while the 2 last variables (anth. strategy and anth. class) were recorded at the age category level.)

Variable	Categories
Country	Denmark, Finland, Iceland, Norway and Sweden.
Season	Jan.–March, April–June, July–Sept. and Oct.–Dec.
Herd type	*Sows only*: specialized sow herds selling all or the large majority of the weaned pigs, and therefore with few or no fatteners.
	Sows+fatteners: sow herds that raise all or the large majority of their growing pigs to slaughter.
SPF	*SPF herds*: specific pathogen-free herds have eliminated ectoparasites and several microorganisms and have no contact to conventional herds, limited access for visitors, etc. The herds are not declared free of helminth infections. Some of the SPF herds in the present study had been reinfected with microorganisms (especially *Mycoplasma*) but were still classified as SPF here, as the reinfection did not cause changes of importance for helminths. The SPF system only occurred in Denmark.
	Conventional herds: all herds that were not SPF herds. Some of the large conventional herds had similar protection against infectious diseases as the SPF herds, but without being classified as such.
Herd size	*Numbers of sows*: numbers of sows and gilts present in the herds at the visit. The exact numbers were recorded and the variable was tested as either a continuous or a discrete variable.
Weaning age	*Age in weeks*: when the piglets were weaned. Normal weaning age is 5–6 weeks. The exact weaning age was recorded, but the variable was categorized as early or late weaning in the modelling.
Buying sows	*No buying*: the herds raised all their gilts themselves and did not buy any gilts/sows.
	Buying: the herds bought some or all gilts/sows from other herds.
Boars	*Artificial insemination*: no boars or only few boars that merely contact stimulated the newly recruited young sows.
	Boars: most often located in more traditional pens than the sows, e.g. with solid floor and straw.
Anthelmintic strategy	*No routine*: no or only sporadic treatment (less than once a year) was carried out in most groups of pigs, i.e. a maximum of one group was treated regularly.
	Targeted treatment: the time for treatment was in most groups of pigs related to the age of the growing pigs (typically at weaning or before/after the move to the fattening unit) or to the reproductive cycle of the gilts/sows (typically prefarrowing).
	Non-targeted treatment: the dominating strategy was to treat all pigs in a category simultaneously every 3–6th month.
Anthelmintic class	*No routine*: no or only sporadic treatment.
	Class 1: benzimidazoles or probenzimidazoles. Fenbendazole was the dominating drug.
	Class 2: imidazothioles and levamisoles. Pyrantel citrate and levamisoles were dominating.
	Class 3: ivermectin (dominating) and piperazine. The few organophosphorous drugs used were placed in this class.

or when the farmer was unable to remember individual details of the sampled animals.

Data were validated through internal checking and verbal verification. Since treatment against sarcoptic mange was routinely conducted using ivermectin, on farms which reported no 'deworming', treatment for mange was regarded as concomitant anthelmintic treatment.

Reduction in the number of independent variables

In total, more than 150 independent variables which had a theoretical and biologically plausible association with *A. suum* infections were recorded for each herd and animal. However, some covariates were omitted on the basis that the responses were considered unreliable, while multi-collinearity was observed among many of the remainder. A preliminary analysis of frequencies and co-distributions of the independent covariates allowed for a reduction in their number and collinearity. Where appropriate, each set of variables measured at the group level was transformed to a single farm-level covariate indicating the predominant management practice and ensuring that each level of the newly created variable contained sufficient numbers. This process was employed in the transformation of 12 group-specific variables. Eight variables initially recorded at the herd level (1–8) and the 12 re-parameterized 'group' variables (9–20) are presented in Tables 2 and 3, while the numbers of herds in each category are given in Tables 4 and 5.

For some variables recorded for individual animals, missing values tended to predominate. Given the potential to introduce severe bias through any imputation method, these variables were excluded. Similarly, where animal-level covariates simply reflected herd management practice or were otherwise insufficiently heterogeneous, they were also excluded.

Table 3. Herd variables and their categories

(All variables were recorded at the age category level.)

Variable	Categories
Outdoor runs	*Always indoor*: no pigs in the herds had any access to outdoor facilities. *Some outdoor*: at least some pig categories had access to outdoor facilities, but often only during the summer months.
Tethered sows	*Permanently tethered*: both gilts, dry sows and lactating sows were permanently tethered or fixed, i.e. located in narrow iron cages that prevent them from turning around. These sows were only loose when visiting the boars. *Partly tethered*: gilts, dry sows and lactating sows were sometimes loose and sometimes fixed/tethered (often tethered dry sows and loose in the farrowing pens). *Permanently loose*: gilts, dry sows and lactating sows were always loose (singly or in groups).
Management	*Groupwise*: weaners, fatteners, dry sows or lactating sows had groupwise management, i.e. parts or whole house sections were emptied/filled simultaneously. *Continuous*: no groups of pigs in the herds had any groupwise management.
Partitions	*Always metal*: partitions between pens in all sections of the herds were always either metal alone or metal in combination with wood. *Mixed*: the various sections of the herds had combinations of 'Always metal' and 'Never metal'. *Never metal*: no metal (except for nails, etc.) in the partitions of any sections of the herds
Feeding system	*Wet feeding*: the majority of the pig categories ($\geqslant 4$) had wet feeding, i.e. a fluent mixture of fodder and whey was automatically transported to the troughs in a pipe system. *Dry in troughs*: dry feeding in troughs (manual or automatic) in the majority of the pig categories ($\geqslant 3$) and a maximum of one group had floor feeding. *Floor feeding*: dry feeding in which the fodder was spread out on the floor (manually or automatically) to at least 2 categories of pigs.
Water supply	*Troughs*: water always given directly in troughs or drinking nipples were located above the troughs. *Lying area*: water most frequently supplied by drinking nipples in the lying area, when not given in troughs. *Dung area*: the drinking nipples most frequently (or at least just as frequently) placed in the dung area as in the lying area, when not given in troughs.
Floor, cleaning	*Slatted floor*: partly or totally slatted floors in the pens of the majority of the pig categories. *Solid floor with daily cleaning*: solid floor in the pens of the majority of the pig categories and dung was always removed daily. A minority of the pens had slatted or partly slatted floors. *Solid floor without daily cleaning*: at least one section of the herd had solid floor without daily cleaning, either due to poor hygiene, permanent beds or outdoor soil runs.
Bedding	*No bedding*: no straw or wood shavings in the majority of the sections ($\leqslant 2$ sections with bedding). *Wood shavings*: wood shavings the dominating bedding material. *Straw*: straw the dominating bedding material.
Washing	*No washing*: no washing in any sections. Washing with a frequency of less than once per year was not regarded as washing. *± Washing*: washing in some but not all sections. Washing was carried out manually or by means of cold or hot high pressure. *Always washing*: washing in all sections.
Disinfection	*No disinfection*: no disinfection in any sections. Disinfection with a frequency of less than once per year was not regarded as disinfection. *± Disinfection*: disinfection in some but not all sections. *Always disinfection*: disinfection in all sections.

Statistical analyses

The design of this observational study, where animals were sampled from within farms, which themselves were sampled within country, created a hierarchical data structure. While the farm was the actual unit of selection (a census was performed of all countries), the unit of assessment and hence the logical unit of analysis (to avoid the potential for ecological fallacy), is in fact the individual animal. However, animals within the same farm are expected to be more alike than animals from different farms, that is, we anticipate significant correlation in observations of animals housed together on the same farm. This is particularly true in the case of infectious diseases and transmissible infections. Further, this argument may be extended to clustering of like responses by farm within country. Thus, the use of statistical methods which make the assumption that individual animal observations are independent, could result in spurious statistical inference. However, in addition to the interest in factors associated with the prevalence of *A. suum* infection (i.e. with the probability of an animal testing positive; animal = unit of interest), there remains a clear additional need to consider what factors may be associated with

Table 4. Occurrence of *Ascaris suum* in 413 Nordic sow herds in relation to herd variables

(The values are means of percentages of egg-positive samples (>200 epg) of the various age groups in the herds (to be continued in Table 5).)

Variable and category*	No. of herds	Weaners	Small fatteners	Large fatteners	Gilts	Dry sows	Lact. Sows	Boars
Country								
Denmark	51	1·5	12·3	15·3	16·9	7·3	7·6	5·8
Finland	111	0·2	1·1	1·9	3·0	1·5	0·8	1·0
Iceland	20	8·2	4·7	4·8	1·5	0·0	1·1	0·0
Norway	82	0·9	5·2	12·7	14·6	10·0	8·3	10·5
Sweden	149	0·3	3·5	19·7	11·0	4·5	2·4	2·1
Season								
Jan.–March	29	0·7	5·0	12·1	8·3	3·3	2·1	2·3
April–June	156	0·6	3·5	12·5	12·7	7·4	4·4	4·7
July–Sept.	199	0·4	4·8	12·5	8·7	3·8	3·5	2·6
Oct.–Dec.	29	4·7	1·7	18·6	5·6	0·4	2·3	0·0
Herd type								
Sows only	119	0·2	1·2	8·1	7·1	4·0	3·1	3·7
Sows + Fatt.	294	1·1	4·7	14·0	11·1	5·2	3·9	2·9
SPF								
SPF herds	19	0·0	0·0	3·6	15·4	11·1	7·1	11·1
Conventional	394	0·9	4·3	13·3	9·7	4·6	3·5	2·7
Herd size								
1–29 sows	158	1·5	6·6	11·5	11·3	4·5	4·5	4·0
30–99 sows	202	0·7	3·3	13·2	8·4	4·9	3·3	1·7
⩾100 sows	53	0·0	1·7	16·0	12·3	5·8	3·0	6·5
Weaning age								
3–5 weeks	180	0·1	0·8	8·4	7·2	4·8	2·0	3·4
6–10 weeks	233	1·4	6·5	16·3	12·3	4·9	5·0	2·9
Buying sows								
No buying	230	1·3	5·1	11·8	9·9	4·7	4·2	4·7
Buying	183	0·4	3·0	14·5	10·1	5·1	3·0	1·4
Boars								
Art. inseminat.	61	0·8	5·3	10·8	12·9	8·3	7·4	15·4†
Boars	352	0·9	4·0	13·3	9·5	4·3	3·0	2·6
Anth. strategy								
No routine	213	1·1	4·8	12·4	10·6	6·0	4·6	3·8
Targeted	87	0·5	3·4	18·4	12·1	3·2	3·0	2·7
Non-targeted	113	0·7	3·5	9·4	7·3	4·2	2·5	2·4
Anth. class								
No routine	213	1·1	4·8	12·4	10·6	6·0	4·6	3·8
Class 1 (BZ)	38	0·0	3·6	17·9	12·3	6·6	3·2	4·2
Class 2	59	1·6	4·5	9·1	5·7	3·9	3·4	0·0
Class 3	103	0·2	3·0	14·4	10·2	2·6	2·0	3·3
All herds	413	0·9	4·1	13·0	10·0	4·9	3·7	3·1

* See Tables 2 and 3 for further explanation.
† 13 herds primarily using AI had few boars, which were sampled.

the probability of a farm being 'positive' (farm = unit of interest), while simultaneously controlling for the potential effect of country of origin. Hence, an analysis to identify risk factors associated with infection (binary outcome = positive/negative) was conducted for both farms and animals.

'*Positive farm*' *risk factors*

Farms were classified as 'positive' if a single positive animal was recorded on the farm. Although the potential for false-positive low eggs counts has been documented (Boes, Nansen & Stephenson, 1997), by definition such false positives can only occur in the presence of truly infected animals. Thus, the use of a single positive faecal result (with minimum cut-off and hence maximum sensitivity) to classify farms was considered to be a highly specific 'test'. Assessment of potential risk factors for presence of *A. suum* infection on a farm was undertaken by means of ordinary logistic regression using the SAS® Release 6.14 software package. To account for the potential of clustering of responses by country, 4 dummy variables contrasting each country to Denmark were included in each model. Initial screening of appropriate (i.e. farm-level or above) covariates was by means of a stepwise selection process (SAS PROC LOGISTIC enter and remove limits of 0·05).

Table 5. Occurrence of *Ascaris suum* in 413 Nordic sow herds in relation to herd variables (continued from Table 4)

Variable and category*	No. of herds	Weaners	Small fatteners	Large fatteners	Gilts	Dry sows	Lact. Sows	Boars
Outdoor runs								
Always indoor	331	0·9	4·8	13·6	10·9	5·2	4·0	4·0
Some outdoor	82	0·5	1·6	11·0	6·3	3·5	2·5	0·0
Tethered sows								
Perm. tethered	70	1·0	3·4	12·2	11·5	8·7	6·5	5·0
Partly tethered	197	0·6	4·3	13·9	12·7	5·6	4·2	4·9
Perm. loose	146	1·2	4·2	12·3	5·3	2·1	1·7	0·0
Management								
Groupwise	38	0·5	0·7	12·2	9·7	4·8	3·2	2·3
Continuous	375	0·9	4·5	13·1	10·0	4·9	3·7	3·2
Partitions								
Always metal	224	0·6	4·5	13·9	10·4	4·3	3·6	3·7
Mixed	135	0·9	4·0	13·0	7·1	5·6	2·4	2·2
Never metal	54	1·8	2·5	9·4	15·8	5·8	7·5	3·2
Feeding system								
Wet feeding	15	0·0	0·0	5·2	0·0	3·2	4·4	0·0
Dry in troughs	382	0·8	4·3	13·6	10·5	5·1	3·8	3·4
Floor feeding	16	4·3	6·2	8·9	6·9	0·0	0·0	0·0
Water supply								
Troughs	157	1·7	7·0	17·1	13·4	6·9	6·1	4·7
Lying area	102	0·6	3·0	7·8	6·0	2·0	1·2	1·7
Dung area	154	0·3	2·3	12·5	9·2	4·8	3·0	2·8
Floor, cleaning								
Slatted floor	69	0·3	3·3	17·0	13·0	6·7	3·2	5·8
Solid, daily cl.	299	0·7	3·8	12·1	8·6	4·5	3·8	2·5
Solid, no daily	45	2·6	8·8	13·1	15·0	4·8	3·3	2·9
Bedding								
No bedding	36	0·6	3·1	10·5	8·1	7·2	1·3	4·0
Wood shavings	150	1·7	3·8	12·2	10·4	5·9	5·5	4·0
Straw	227	0·4	4·5	13·9	10·0	3·8	2·9	2·6
Washing								
No washing	74	1·0	5·9	18·4	15·4	5·4	4·7	2·5
± Washing	128	1·4	3·5	12·1	7·3	5·0	1·7	2·2
Always washing	221	0·4	3·9	11·6	10·0	4·6	4·5	4·1
Disinfection								
No disinfection	255	0·7	5·0	14·7	11·4	6·0	4·2	4·0
± Disinfection	90	1·8	1·2	9·3	6·2	3·7	2·7	2·6
Always disinf.	68	0·0	4·6	11·2	10·3	2·2	2·9	0·9
All herds	413	0·9	4·1	13·0	10·0	4·9	3·7	3·1

* See Tables 2 and 3 for further explanation.

Multivariate models of animal-level risk

Ordinary logistic regression was also employed to conduct a preliminary screening of potential risk factors for the presence of *A. suum* infection in individual swine using stepwise and forward selection procedures (SAS PROC LOGISTIC enter and remove limits of 0·05, respectively). Pigs were initially regarded as infected if they possessed any *A. suum* eggs in their faeces (epg >0). Although these models completely fail to account for the potential for clustering at the farm level, the resulting spuriously small parameter standard error estimates considerably increase the probability of individual variables remaining significant, thus ensuring that the process of elimination of covariates is effectively conservative. Those variables that were not statistically significant in any of these model combinations were excluded from subsequent analyses.

Variables which remained significant were further assessed by inclusion in generalized linear mixed (fixed and random effect) hierarchical (farm and animal level) statistical models, whereby total observed variation could be apportioned to that occurring between farms versus between animals within farms. A single random effect parameter was included to account for farm clustering (i.e. farm effect). Farm-level errors were assumed to be independent and normally distributed with mean 0, while, although animal-level errors were assumed to follow the binomial distribution, the potential for over- or under-dispersion was first accounted for by the inclusion of an unconstrained extra-binomial variance parameter in the estimation of the animal-

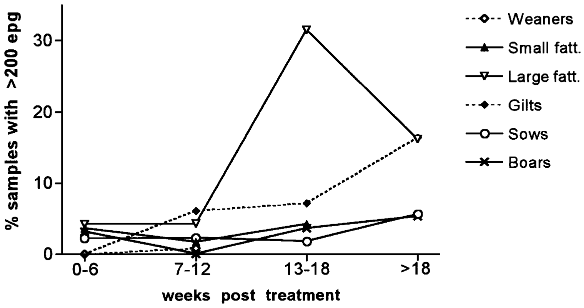

Fig. 1. Percentage of pigs with >200 epg in relation to the time-interval between sampling and the last anthelmintic treatment, according to the farmers. Only herds with routine targeted or non-targeted treatment are included, but not all groups of pigs were regularly treated. Totally, 3696 pigs were sampled in these herds. The curves for weaners and small fatteners stop at 7–12 and 13–18 weeks, respectively, due to the maximum age of these groups of pigs.

level variance. When significant underdispersion occurred, the model was repeated with the animal level variance constrained to the binomial assumption. A logistic link function was chosen so that the models may be described as logistic-normal. For all models, a restricted iterative generalized least squares (RIGLS) algorithm was used to obtain penalized quasi-likelihood (PQL) second order approximation estimates. However, the estimates obtained from this procedure were also compared to those generated by a Bayesian estimation approach utilizing Metropolis–Hastings sampling (scale factor for proposal variances = 5·8) in a Markov Chain Monte Carlo (MCMC) process which employed a 500 iteration burn-in and monitoring for a further 20 000 iterations.

Mixed models were generated for the full data set (i.e. containing all observations) and then subsequently for a reduced data set where observations from farms on which all animals tested negative were removed. All age group and country of origin covariates were included in each model. Significance testing of dummy variables as fixed effects was performed by means of the joint χ^2 (Wald) test statistic, with significance level set at 5 %. For fixed effect variables which remained significant to overall model fit, interaction terms with age-group covariates were created and similarly assessed. The variables included in the most parsimonious models above were reassessed when an elevated cut-off limit of 200 epg was used to re-parameterize the outcome variable. This cut-off level was chosen to reduce the influence of different efficiencies of the laboratory methods and to reduce the number of false-positive results at the level of the individual pig. For each model, plots of standardized residuals at farm and animal levels were examined to assess model fit and distributional assumptions. Multilevel statistical modelling was performed using MLwiN (version 1, Multilevel Models Project, Institute of Education, University of London).

RESULTS

In total, 11 233 individual samples collected from 413 farms were analysed. *Ascaris suum* eggs were observed in 1138 cases drawn from a total of 230 farms, giving an overall prevalence in sampled animals of 10·1 %, and a prevalence of 'positive' farms of 55·7 %. However, when a cut-off level of >200 epg was applied to reduce the individual false-positive rate, the total number of positive pigs fell marginally to 1074 (9·6 %) while the number of farms from which these animals were drawn declined more dramatically to 192 (46·5 %). That is, suspicious false-positive pigs were the only positive animals present on 38 (now 'false-negative') farms.

The raw calculations of percentages of positive pigs by age category in relation to the independent variables are presented in Tables 4 and 5. For several of the independent variables considerable differences in the distribution of the occurrence of *A. suum* could be observed directly. However, in recognition of the danger of confounding of covariates and spurious inference, no statistical analyses were performed on these univariate relationships.

The relationship between the anthelmintic treatment/sampling interval and the mean percentage of samples with epg >200 are displayed for each age group in Fig. 1. This covariate was not offered to the model building process due to extensive missing values. Moreover, the information obtained from the farmers regarding the time since last treatment was not completely accurate; most groups of pigs were excreting eggs within 6 weeks post-treatment, while another analysis showed that only 4 sows and no pigs of the other categories excreted eggs within the first 4 weeks after treatment. Only in the case of large fatteners and gilts did there seem to be a clear increase in the percentage of positive samples with time. When similar plots were generated for mean epg or percentage of samples with non-zero epg this overall trend was preserved, although the curves were more variable.

Farm models

Results of the stepwise selection process on ± infected herds are shown in Table 6. In addition to country of origin, only 2 other variables were individually significant in the most parsimonious full model. Farms which practised 'late weaning' were approximately twice as likely to be positive for *A. suum* ($P = 0·003$) than those which weaned piglets early, while herds which used 'Class 2 drugs' (pyrantel, levamisole, etc.) were also observed to be more than twice as likely to harbour *A. suum* ($P = 0·03$) than other herds, including those which

Table 6. Simple logistic regression model on ±*Ascaris suum* infections in herds

(A herd was regarded as *A. suum* positive if 1 animal had >0 epg.)

Variables and categories	Odds ratio	Confidence intervals	*P*-value
Country			
Denmark	1	—	—
Finland	0·04	0·01–0·09	0·0001
Iceland	0·08	0·02–0·27	0·0001
Norway	0·39	0·16–0·97	0·0381
Sweden	0·41	0·18–0·96	0·0368
Weaning age			
3–5 weeks	1	—	—
6–9 weeks	2·07	1·20–3·35	0·0025
Anthelmintic class			
No routine/Class 1/Class 3	1	—	—
Class 2	2·25	1·06–4·77	0·0314

Table 7. Mixed hierarchical logistic-normal regression model on complete data set (11 233 animals on 413 farms) ±*Ascaris suum* infections in pigs

(A pig was regarded as *A. suum* positive if faecal sample had >0 epg.)

Estimation method…	PQL–2nd order			MCMC–M-H sampling	
Fixed effects	Odds ratio	95% CI	*P*-value	Odds ratio	95% CI
Age group					
Gilts	1			1	
Weaners	0·034	0·016–0·073	$P<0.001$	0·031	0·011–0·073
Small fatteners	0·15	0·090–0·25		0·15	0·087–0·26
Large fatteners	1·76	1·41–2·20		1·74	1·36–2·21
Dry sow	0·28	0·22–0·38		0·29	0·21–0·39
Lactating sow	0·18	0·14–0·24		0·18	0·13–0·25
Boar	0·2	0·12–0·34		0·2	0·11–0·35
Country					
Denmark	1			1	
Finland	0·033	0·014–0·077	$P<0.001$	0·031	0·015–0·070
Iceland	0·16	0·046–0·57		0·16	0·047–0·48
Norway	0·47	0·22–0·98		0·47	0·25–1·05
Sweden	0·44	0·23–0·87		0·46	0·27–0·86
Weaning age					
3–5 weeks	1			1	
6–9 weeks	1·99	1·23–3·20	$P<0.001$	2·05	1·24–3·74
*Weaners	10·14	4·52–22·73		11·66	4·82–34·95
*Small fatteners	11·46	6·67–19·69		11·97	6·79–21·39
Water supply					
Troughs/lying area	1			1	
Dung area	0·51	0·32–0·83	$P=0.003$	0·52	0·33–0·80
*Dry sows	0·92	0·64–1·33		0·94	0·64–1·42
*Boars	1·15	0·60–2·21		1·17	0·59–2·36
Random effects	σ^2	S.E.		σ^2	S.E.
Farm-level variance	3·19	0·326		3·186	0·401
Extra-binomial variance	0·807	0·011		0·807	—

did not practise routine deworming (although the statistical significance of this association was weaker). Denmark was the reference country so that, when controlling for the effect of weaning age and use of Class 2 drugs, all other countries were associated with significantly lower mean *A. suum* herd infection prevalence than Denmark. In a model where positive farm status was based on the presence of a single positive animal using a cut-off value of 100 epg, Norway and Sweden became individually non-significant, and 'Class 2 drugs' was replaced by 'permanently loose sows' (correlated with low *A.*

Table 8. Mixed hierarchical logistic-normal regression model on reduced data set of positive-only farms (6232 animals on 230 farms) ± *Ascaris suum* infections in pigs

(A pig was regarded as *A. suum* positive if faecal sample had >0 epg.)

Estimation method…	PQL–2nd order			MCMC–M-H sampling	
Fixed effects	Odds ratio	95% CI	*P*-value	Odds ratio	95% CI
Age group					
Gilts	1			1	
Weaners	0·037	0·016–0·085	$P<0{\cdot}001$	0·036	0·017–0·075
Small fatteners	0·15	0·067–0·35		0·15	0·085–0·15
Large fatteners	1·75	1·38–2·23		1·75	1·38–2·21
Dry sow	0·30	0·22–0·40		0·3	0·22–0·4
Lactating sow	0·19	0·14–0·26		0·19	0·14–0·25
Boar	0·22	0·12–0·37		0·21	0·12–0·36
Country					
Denmark	1			1	
Finland	0·42	0·22–0·80	$P=0{\cdot}033$	0·44	0·23–0·82
Iceland	1·95	0·74–5·16		2·02	0·75–5·23
Norway	0·80	0·49–1·31		0·81	0·52–1·28
Sweden	0·75	0·49–1·17		0·77	0·51–1·19
Weaning age					
3–5 weeks	1			1	
6–9 weeks	1·23	0·88–1·71	$P<0{\cdot}001$	1·18	0·85–1·67
*Weaners	6·28	2·61–15·08		6·17	2·89–13·79
*Small fatteners	7·10	3·95–12·76		7·01	3·95–12·82
Water supply					
Troughs/lying area	1			1	
Dung area	0·53	0·38–0·74	$P<0{\cdot}001$	0·53	0·38–0·73
*Dry sows	0·94	0·63–1·39		0·93	0·63–1·37
*Boars	1·17	0·58–2·36		1·17	0·58–2·35
Random effects	σ^2	S.E.		σ^2	S.E.
Farm-level variance	0·934	0·124		0·971	0·136
Extra-binomial variance	1·007	0·018		1·007	—

suum infection level) when the cut-off was increased to 200 epg. However, in all models, the covariate concerned with age at weaning was the most individually significant to overall model fit, indicating that its association, with farm infection status was robust to the level of individual animal cut-off.

Hierarchical multivariate models

The results of mixed hierarchical logistic-normal regression models on full and reduced data sets are presented as Odds ratios for epg >0 in Tables 7 and 8, respectively, and on the full data set for epg >200 in Table 9.

Cut-off = resolution of test. Where a 'positive' outcome was defined as epg >0, and where the animal level variance estimate was unconstrained, the most parsimonious models for both the full (Table 7) and reduced (Table 8) data sets, contained only covariates recording 'age at weaning' and location of 'water supply', along with appropriate age group interaction terms. In the full model (Table 7), animals on farms which practised weaning between 6 and 9 weeks *post-partum* were approximately twice as likely to test positive for *A. suum*, regardless of age group, than animals on farms where weaning was 'early' (3–5 weeks *post-partum*). In addition to this, there were strong and highly significant interaction terms between weaning age and age category such that, on farms which practised 'late' weaning, weaners and small fatteners were more than 10 times as likely to test positive than these same age groups on 'early weaning' farms. However, interaction terms between weaning age and the other age groups were not significant.

With respect to covariates associated with the location of the water supply, animals on farms which placed the drinking nipples in the dunging area were approximately one-half as likely to test positive than animals on farms where the water was supplied in troughs or in the lying area. Again, while the overall effect is independent of age class, significant age group interaction terms demonstrated that this association was not true for the older age groups, specifically for dry sows and boars, where no difference in prevalence existed between the two water systems.

All parameter estimates were consistent between the two estimation methods; penalized quasi-likelihood (PQL) and the Markov Chain Monte Carlo

Table 9. Mixed hierarchical logistic-normal regression model on complete data set (11 233 animals on 413 farms) ± *Ascaris suum* infections in pigs

(A pig was regarded as *A. suum* positive if faecal sample had > 200 epg.)

Estimation method…	PQL–2nd order			MCMC–M-H sampling	
Fixed effects	Odds ratio	95% CI	*P*-value	Odds ratio	95% CI
Age group					
Gilts	1			1	
Weaners	0·0084	0·0016–0·045	$P<0.001$	0·0075	0·00051–0·036
Small fatteners	0·071	0·033–0·15		0·07	0·025–0·17
Large fatteners	1·35	1·08–1·67		1·34	1·04–1·74
Dry sow	0·32	0·24–0·42		0·33	0·23–0·45
Lactating sow	0·25	0·19–0·32		0·25	0·18–0·35
Boar	0·19	0·11–0·32		0·19	0·092–0·38
Country					
Denmark	1			1	
Finland	0·038	0·015–0·095	$P<0.001$	0·047	0·024–0·094
Iceland	0·18	0·048–0·68		0·22	0·070–0·61
Norway	0·73	0·34–1·56		0·72	0·38–1·27
Sweden	0·48	0·25–0·98		0·47	0·29–0·80
Weaning age					
3–5 weeks	1			1	
6–9 weeks	1·89	1·16–3·10	$P<0.001$	1·83	1·17–2·82
*Weaners	17·36	3·13–96·26		19·87	3·82–291·78
*Small fatteners	10·55	4·70–24·94		10·72	4·18–31·12
Water supply					
Troughs/lying area	1			1	
Dung area	0·59	0·36–0·97	$P = 0.11$	0·58	0·38–0·89
*Dry sows	0·81	0·55–1·20		0·82	0·50–1·32
*Boars	0·73	0·33–1·62		0·72	0·27–1·93
Random effects	σ^2	S.E.		σ^2	S.E.
Farm-level variance	3·098	0·34		2·36	0·346
Extra-binomial variance	0·588	0·008		0·588	—

(MCMC) process (Tables 7–9). Further, although there was notable underdispersion at the animal level (extra-binomial variance parameter = 0·807, Table 7), constraining the animal level variance to the binomial assumption had minimal effect on fixed parameter estimates. Nevertheless, plots of standardized residuals at both farm and animal level clearly showed that the distributional assumptions were not being adequately met. Specifically, the preponderance of 'negative' farms (on which no animals tested positive), resulted in the distribution of the negative residuals being severely truncated. This is further reflected in the reduction in farm level variance from 3·190 (Table 7) to 0·934 (Table 8) for the full and reduced models, respectively.

Remembering that observations from entirely negative farms were removed to form a reduced data set, the corresponding model assessed the association between the probability of an individual animal testing positive *given* that at least 1 animal on the farm tested positive (Table 8). While the reduction in farm-level variance (and the concomitant elimination of animal-level underdispersion: extra-binomial variance = 1·007) is not therefore surprising, it is notable that the associations with country of origin were reduced in both magnitude and significance, while those with weaning age and water system were maintained. That is, country of origin appeared to be most associated with the prevalence of positive farms rather than the prevalence of positive animals within farms. Iceland was the exception where, although not individually significant, the effect of elimination of negative farms was to reverse the direction of the parameter estimate (Odds ratio 0·16–1·95), suggesting that, as compared to Denmark, more farms in Iceland had no *A. suum*, but the prevalence on infected farms was higher. Similarly, the effect of 'late weaning' was reduced so that there was no longer significant interaction for age groups other than weaners and small fatteners. Thus, weaning age was associated with whether *A. suum* was present on a farm *and* whether weaners and small fatteners tested positive on farms where *A. suum* was present. Based on plots of standardized residuals, although the overall fit of the reduced model was improved from the full model, the distribution remained skewed towards farms of very low prevalence. Nevertheless, the model parameter estimates were nearly identical for each estimation method. Given the extra-binomial variance of the reduced model is nearly equivalent to 1·0, constraining it to this value (model not shown) has virtually no effect on model estimates.

Cut-off >200 epg. Increasing the individual animal cut-off to >200 epg had 2 distinct effects. First, underdispersion at the animal level was markedly increased in the full data set (Table 9; extra-binomial variance = 0·588) as the distribution was further skewed towards a greater number of 'negative' farms. This was again reflected by the reduction in farm-level variance from 3·098 in the model on the full data set (Table 9) to 0·447 in a model on the reduced data set (not shown) while animal level variance became much less underdispersed. Second, covariates associated with water supply and age group interaction terms were non-significant in the full model ($P = 0·11$, Table 9) but returned to significance ($P = 0·011$) in the reduced model (not shown). That is, location of water supply appeared to be most associated with the prevalence of positive animals within farms rather than the prevalence of positive farms. These and other trends in magnitude and significance of country of origin and weaning age covariates between full and reduced models were preserved regardless of estimation method and whether the animal level variance is constrained to the binomial assumption.

DISCUSSION

The relationships between the single herd factors and the occurrence of *A. suum* indicated that the prevalences may depend on several of the registered herd variables. Similar univariate relationships have been presented previously (Pattison, Thomas & Smith, 1980; Alfredsen, 1983; Möller, 1983; Biehl, 1984; Morris *et al.* 1984; Kennedy *et al.* 1988; Mercy, Chaneet & Emms, 1989). However, in general, herd factors covary and both significant and non-significant correlations may be invalid due to confounding of covariates and spurious inference.

Two previous attempts to perform multivariate analyses of the relationship between *A. suum* infections and herd factors have been undertaken, both using stepwise logistic regression where the dependent variable was the proportion of infected animals (belonging to a single specified age group) in the herds. In 66 representative Danish herds, Roepstorff & Jorsal (1990) found that the SPF system, early weaning and frequent cleaning were significantly correlated with low *A. suum* prevalences in fatteners, while the SPF system and routine anthelmintic treatment were associated with low prevalences in sows. Also in Denmark, Dangolla *et al.* (1996*a*) found that sows in selected large sow herds were significantly more infected with *A. suum* when herd size increased and the sows had bedding, while anthelmintic treatment was non-significant. However, *A. suum* normally exhibits a distinct age-related prevalence curve with a maximum in growing pigs (e.g. Boch, 1956; Boch & Neubrand, 1962; Jacobs & Dunn, 1969; Roepstorff & Jorsal, 1989). The exact appearance of this curve may be influenced by host–parasite interactions such as acquired resistance (see Urban, Alizadeh & Romanowski, 1988; Eriksen *et al.* 1992*a*) and the transmission rate (Nansen & Roepstorff, 1999). Consequently, analyses of single age groups may prove to be somewhat misleading.

In the current analyses, all models revealed a highly significant age–prevalence relationship with the prevalence increasing from weaners to large fatteners, whereupon the prevalence declined marginally in gilts and more dramatically in sows and boars. The appearance of this age-related prevalence curve may be explained by a gradual accumulation of infection combined with a move of weaners to more contaminated fattening pens, thereby causing an increase in prevalence in susceptible young pigs. However, pigs acquire immunity as a response to exposure (see above), resulting in a gradual reduction in prevalence with age. Thus, interactions between pig age and other herd factors were to be expected, as an increase in *A. suum* transmission will theoretically result in earlier development of immunity, shifting the maximum of the age-related prevalence curve to the younger age groups, while a very low transmission rate may be expected to result in susceptible populations of sows and boars (see Eriksen *et al.* 1992*a*). The latter may actually be the explanation of the unusual univariate relationship between pig age and 'SPF system', in which the first infections were delayed until late in the fattening period, and the breeding animals had unusually high prevalence rates. Generally, where variables influenced infection prevalence and interacted with age, the influence is greatest on young animals, suggesting that prevalence in older individuals is determined less by environment and more by host–parasite factors.

'Country' was also significantly correlated with *A. suum*. Iceland and especially Finland had very low prevalence rates in the full models, while swine from Denmark were the most heavily infected. Figures on *A. suum* prevalences in the 5 countries have been presented elsewhere (Roepstorff *et al.* 1998). Interestingly, the reduced models resulted in less marked differences between the countries and with Iceland now showing the highest prevalence rates. One explanation is that in the full data set the low prevalences in Iceland and to a lesser extent Finland may be caused by totally *A. suum* negative herds, while the few infected Icelandic herds had high infection rates. In Iceland and the northern regions of the other countries, the swine population is characterized by very low density with few, relatively isolated farms (Roepstorff *et al.* 1998) such that the possibility of inter-herd transmission may be very small. If the generally low prevalences in Finland

and Iceland, and to a lesser extent Norway and Sweden, can be attributed to poorer between-herd transmission, this may explain why Oksanen & Tuovinen (1991) did not find any differences in the indoor environment of Finnish herds, selected for either high or low liver condemnation rates due to migrating *A. suum* larvae. In contrast, many years of experience with Danish swine herds have only resulted in the discovery of a single herd without *A. suum* infections (Roepstorff, 1997). Thus, poor between-herd transmission may not be a limiting factor for *A. suum* in Denmark.

Weaning age was also significantly correlated with *A. suum* prevalences such that the two youngest age categories demonstrated significantly higher prevalence of infection in herds with late weaning. A similar relationship was also found for fatteners by Roepstorff & Jorsal (1989, 1990), but not for sows (Roepstorff & Jorsal, 1990; Dangolla *et al.* 1996*a*). This relationship is difficult to explain, as Nilsson (1982) found that *A. suum* primarily was transmitted amongst young pigs, while the impact of sows as the source of infection for piglets was negligible. The latter fact has recently been fully confirmed in modern Danish herds, in which even high outputs of *A. suum* eggs from lactating sows did not result in transmission to piglets (Roepstorff, 1997). The general high infection level in herds with late weaning is likely to result in strong immunity of the sows, and a transfer of immune factors to the piglets (Kelley & Nayak, 1965; Roepstorff, 1998), resulting in a modified and perhaps even a reduced piglet response to infection (Boes *et al.* 1999). An alternative explanation may be that late weaning is strongly correlated with a whole series of housing and management factors (as found here and by Roepstorff & Jorsal, 1990), which in combination result in favourable conditions for development of *A. suum* eggs.

Finally, the location of the water supply in the pens was also significantly associated with the occurrence of *A. suum*. A low relative humidity may cause the eggs to die before reaching infectivity (Wharton, 1979), while water spillage, resulting in a highly humid microenvironment, has been shown to facilitate embryonation (Nilsson, 1982), creating highly infective hot spots. Because most eggs are deposited in the dung area, it might be anticipated that a localization of drinking nipples there would increase the risk. In fact the opposite relationship was observed. The reason for this may be that eggs in the dung area are adversely affected by pig urine, which has been shown to inhibit development of *A. suum* eggs (Nilsson, 1982), while the few eggs that are inevitably spread in the lying area may take advantage of water spillage from troughs or drinking nipples placed there without being affected by urine. The interaction between 'water supply' and 'age group' may, as mentioned above, merely reflect that an inexpedient location of the water supply may have the greatest influence on the youngest and most susceptible pigs.

The present mixed hierarchical logistic–normal regression models on occurrence of *A. suum* in Nordic pigs of various age groups seem to be robust as almost identical estimates were obtained by the Markov Chain Monte Carlo process and the penalized quasi-likelihood second order approximation, and when using different epg cut-offs, while models calculated on the full (all herds) and the reduced (only *A. suum*-positive herds) dataset were different with regard to some of the estimates, indicating a different age-related prevalence curve in some of the tested variable categories.

Only 4 herd variables and a few interactions were significant in the full and the reduced models, namely 'age group', 'country', 'weaning age' and 'water supply', while all the other 20 herd factors tested were non-significant. Although the herd factors that are significantly correlated with *A. suum* prevalences are very interesting, it is also worth noting, which factors are not significantly correlated. Most noticeable are 'anthelmintic strategy' and 'anthelmintic drug', neither of which was even marginally significant in any model (except for a spurious relationship between infected herds and 'Class 2 drugs'). A similar lack of association has been observed for sows (Dangolla *et al.* 1996*a*) and fatteners (Roepstorff & Jorsal, 1990), while the latter authors found lower prevalence rates in routinely dewormed sows. There could be several reasons for this lack of association. One could be widespread anthelmintic resistance (AR). However, AR has never been documented with regard to *A. suum*, despite a comprehensive survey which revealed resistant *Oesophagostomum* spp. (Dangolla, 1994). According to AR-risk factors listed by Jackson (1993), *A. suum* is not a likely candidate for rapid development of AR. Samples with low numbers of eggs, caused by coprophagia of egg-containing faeces, have been shown to be very common, especially in housed pigs (Boes *et al.* 1997), and as many as 50% of egg-positive group-penned pigs have been shown to have low egg excretion (<200 epg) suggesting they are likely to be false positive (Roepstorff, 1998). As *A. suum* eggs may be present in the environment for a considerable time after anthelmintic treatment, false-positive samples may also help to explain the lack of association between the coproprevalence of *A. suum* and anthelmintic use. However, in the present models none of the anthelmintic covariates was significant when the cut-off was elevated to 200 epg, suggesting that the lack of association between anthelmintics and *A. suum* prevalences was real. Another possibility is that use of anthelmintics itself is a proxy measure of suitability for *A. suum* infection on a farm, indicating a realization by the farmer of a potential or past helminth problem. If such relationship exists it is not necessarily surprising that anthelmintic use does not predict low prevalence as its initiation is, in fact, dependent on prevalence. However, in Denmark only a limited number of farmers has any idea of the helminth infection level of their herd and even if they do know (normally due to findings of large ascarids in faeces or white spots in the livers), their choice of treatment strategy does not always reflect this knowledge (A. Roepstorff, personal observation). Furthermore, treatment strategy for sows has not been found to be associated with recorded management risk factors (Dangolla *et al*. 1996*b*). Our data suggest that a relationship exists between prevalence and the time-interval between last deworming and sampling for the 2 most heavily infected age groups, large fatteners and gilts, but not for the other groups of pigs. Other factors, particularly the use of bedding material, slatted floors, and access to outdoor runs, may at least theoretically influence the development and survival of *A. suum* eggs in the examined herds. Yet none of these factors was significantly associated with *A. suum* in any model. In comparison, *Oesophagostomum* sp. seems to be more dependent on management factors than *A. suum* (Roepstorff & Nilsson, 1991; Dangolla *et al*. 1996*a*). This may partly be explained by the fact that the pre-infective free-living stages of *Oesophagostomum dentatum* are very susceptible to unfavourable environmental factors, especially dessication (Rose & Small, 1980), while *A. suum* eggs may tolerate low humidity for a few weeks before they die (Wharton, 1979). However, even *A. suum* eggs may face such unfavourable conditions in modern stables that they do not reach infectivity except in particular areas ('hot spots') of the pens (Nilsson, 1982), while in intensive units for growing pigs transmission may not succeed at all (the SPF herds in Table 4; Roepstorff, 1997). Therefore, the lack of significant association between the occurrence of *A. suum* and several management factors, including use of anthelmintics, could indicate that the impact of these factors in practice may be negligible when acquired host immunity interferes with the relationship. That is, an increased transmission rate due to inexpedient herd factors results in strong acquired resistance and low prevalence, and the opposite, a very low transmission rate may result in more susceptible adult pigs (Eriksen *et al*. 1992*a*), which may more easily become egg excreters when exposed to low numbers of infective eggs (the SPF-herds in Table 4; Roepstorff, 1997). The aforementioned associations between *Oesophagostomum* and herd factors may, in contrast, be due to the lower immunogenicity of this helminth (see Nansen & Roepstorff, 1999).

It has been shown that *A. suum* eggs may remain infective in the environment for many months. Consequently, the infection rate to pigs at any point in time is a function of the management practices over the preceding months or year(s). This represents the limitation of cross-sectional studies to determine risk factors to infection. As with all infectious diseases, the incidence of infection is a function of both current and past prevalence and management. Furthermore, a consequence of a lack of correlation between transmission/dose rate and the resulting burdens of adult egg-excreting worms (Eriksen *et al*. 1992*b*; Roepstorff *et al*. 1997), or even an inverse relationship (Jørgensen *et al*. 1975) may be that herd factors may influence transmission without being significantly associated with the prevalence of egg excreters – on the assumption that the herd factors do not prevent transmission totally.

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