Potential role of noncommercial swine populations in the epidemiology and control of porcine reproductive and respiratory syndrome virus

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Objective—To assess the role of noncommercial pigs in the epidemiology of porcine reproductive and respiratory syndrome (PRRS) virus.

Design—Seroepidemiologic study and survey study.

Animals—661 pigs from which blood samples were collected at slaughter and 32 pigs from which blood samples were collected longitudinally.

Procedures—Spatial databases of commercial farms and 4-H participation were evaluated by use of commercial geographic information systems software. Information on disease knowledge and management methods of 4-H participants was obtained by mail survey and personal interview. Serum samples for antibody testing by PRRS ELISA were obtained from pigs at slaughter or at county fairs and on farms.

Results—Participation in 4-H swine programs was geographically associated with commercial swine production in Minnesota, and 39% of 4-H participants reared pigs at locations with commercial pigs. High seroprevalence at fairs (49%; range, 29% to 76%) and seroconversion after fairs indicated that PRRS virus exposure was common in pigs shown by 4-H participants and that transmission could occur at fairs.

Conclusions and Clinical Relevance—The small swine population shown by 4-H members (estimated 12,000 pigs) relative to the population of commercial swine in Minnesota (estimated 6.5 million pigs) suggested the former overall was likely of minor importance to PRRS virus epidemiology at present. However, the relative frailty of knowledge of biosecurity practices, evidence that PRRS virus exposure was frequent, common intentions to show pigs at multiple events, and often close interactions with commercial herds suggested that the 4-H community should be involved in regional efforts to control PRRS. (*J Am Vet Med Assoc* 2012;240:876–882)

A reproductive syndrome of unknown etiology described in the United States in 1989 was the first documented clinical PRRS virus infection of swine.[1] The causative arterivirus is now endemic in most swine-producing countries, and with an estimated cost of $560 million annually, PRRS is the most economically important disease affecting the US swine industry.[2] In inflation-adjusted terms, this estimate greatly exceeds the estimated annual economic burdens of both hog cholera ($364 million in 2004 dollars) and pseudorabies ($36 million in 2004 dollars) viruses before national programs were undertaken to control those diseases.[2] Like other RNA viruses, PRRS virus has marked genetic heterogeneity that is reflected in variability in virulence, clinical manifestations, and epidemiological attributes. Variants of the PRRS virus in Chile appear to have relatively low virulence, whereas highly virulent variants have been implicated in widespread and severe disease outbreaks in China.[3,4] The propensity of PRRS to cause reproductive disease is strain dependent, and variants of the virus also differ with respect to their potential for aerosol transmission.[5,6]

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Abbreviations

CI	Confidence interval
FFA	Future Farmers of America
LISA	Local indicator of spatial autocorrelation
MBAH	Minnesota Board of Animal Health
MPCA	Minnesota Pollution Control Agency
NASS	National Agricultural Statistics Service
PRRS	Porcine reproductive and respiratory syndrome

The foremost obstacle to PRRS control is the ability of the virus to spread among neighboring farms despite strict biosecurity measures. Elimination of PRRS from individual herds has been regularly achieved by use of a variety of approaches,[7–9] but these efforts are frequently undermined by reintroduction of virus via routes which, in most cases, are either unknown or speculative. In addition to obvious routes of introduction in pigs or semen, experimental studies have confirmed a variety of potential routes for PRRS virus transmission among herds, including people, fomites, transport vehicles, insects, and aerosols.[10–13] Coordinated efforts to control PRRS in France had qualified success,[14] and a government-led eradication program in Chile appears to have been successful.[15] Likewise, an emergency government program immediately following the initial de-

tection of PRRS in Sweden resulted in elimination of the virus.[16] However, in each of these countries, a low proportion of herds was infected when these programs were initiated. The American Association of Swine Veterinarians has stated a long-term goal of PRRS elimination in the United States.[17] However, in regions with a high herd prevalence of PRRS infection, considerable obstacles need to be overcome before any coordinated control program will be practical.[2]

Effective regional control of animal disease requires an understanding of all reservoirs of infection and of mechanisms and risks of pathogen transmission. The PRRS virus, like other arteriviruses,[18] is highly host specific, and it is unlikely that nonporcine species could be reservoirs of the virus. Consequently, when developing regional control strategies for PRRS, attention may be focused entirely on populations of Suidae. Although commercial swine herds (ie, herds kept with the primary objective of income generation from pork production) constitute most of the US swine population, many other swine populations exist. These include feral or wild pigs, pet pigs, hobby farm pigs, and pigs reared in youth education programs (eg, FFA and 4-H). Feral or wild pig populations are important reservoirs of infectious diseases, including brucellosis and pseudorabies,[19,20] and are also potentially important reservoirs for PRRS virus.[21] Although widespread in much of the United States, feral pigs as yet are not known to have become established in Minnesota. Youth education programs that include rearing and showing of pigs attract broad participation in many states, including Minnesota. According to the 4-H National Headquarters, the numbers of youth involved in the swine educational curricula ranged from approximately 140,000 to 212,000/y from 1996 to 2003. Currently, there is little documentation of the relationships these youth have with the commercial swine industry. The purpose of the study reported here was to characterize the swine population shown by 4-H participants and to evaluate its potential importance to the epidemiology and control of PRRS.

Materials and Methods

Demographics of commercial and show swine populations in Minnesota and the United States— Agricultural youth education programs in Minnesota are seasonal activities that are linked to county fairs. To understand the chronology of 4-H swine exhibition in Minnesota, the schedule of Minnesota Federation of County Fairs information for 2004 was obtained.[22] Data of participation in 4-H swine programs in Minnesota from 2000 to 2005 were obtained from the state 4-H office. These data included the name, address, county, and year of participation for each participant. Data were summarized and aggregated by county and year. The data were then imported into a geographic information systems software program[a] for geoprocessing and standardization of data formats. Geographic information systems objects were exported as shape (.SHP) files for exploratory spatial analysis by use of software.[b] To evaluate the existence of coclustering of commercial swine production and 4-H production in counties, the spatial distribution of 4-H participation data was compared with that of commercial swine populations described by the NASS,[23] MPCA,[c] and MBAH.[d] Procedures used to assess spatial autocorrelation were univariate LISA, multivariate LISA, and the Moran I statistic.[24,25] The LISA statistic yields a measure of spatial autocorrelation for each individual location examined. Univariate LISA maps show the spatial autocorrelation between 1 variable (in this case, 4-H swine program participation) in an area (eg, state or county) and the same variable in all adjacent areas. Bivariate LISA maps show the spatial autocorrelation between one variable (eg, 4-H swine program participation) in an area and another variable (commercial swine production) in adjacent areas.

Mail survey and interviews of 4-H participants— A 64-question survey instrument[e] was developed to describe 4-H participants' livestock activities and to assess their knowledge of swine health and biosecurity. In Minnesota, in 2005, 2,738 youths registered to show pigs in the 4-H program, of which 1,725 were in the seventh grade or above. The arbitrary selection of seventh grade was chosen to focus on older participants likely to have more experience and education related to swine production. By use of a random number–generating function in a spreadsheet program,[f] a random sample of 200 participants was selected from those students in seventh grade or higher who had mailing addresses in Minnesota and who were not members of the same household as another selected participant. Students were encouraged to complete the survey without help from others. The initial survey mailing was followed by a reminder postcard mailing after 2 weeks and then a second mailing of the complete survey to nonrespondents. Descriptive statistics of survey responses were compiled with 95% CIs. Multivariate logistic regression analysis was performed to evaluate relationships between survey responses and participant characteristics, including age, gender, and family involvement in commercial swine production. The relative importance of swine diseases as perceived by 4-H participants was ranked as the ratio of the number of respondents rating a disease as important to the number who were unfamiliar with the disease. Two diseases not known to occur in the United States (and therefore deemed of negligible importance) were deliberately included for comparative purposes.

Forty-three 4-H participants showing pigs in 2 Minnesota counties were interviewed when they registered their pigs for exhibition. The questionnaire (available upon request) was administered to 20 participants in Rice County and 23 in Stevens County. The survey explored reasons for participation and also asked participants to list measures that can be implemented to decrease pathogen transmission among pigs. For descriptive purposes, the measures listed were categorized as equipment and facility sanitation, personal sanitation, pest control, separation or isolation, source health, vaccination or medication, or other. In addition, at the Minnesota State Fair in 2005, a convenience sample of 172 4-H participants registered in ninth grade or higher from 53 counties (of 220 participants from 54 counties) was asked a short series of questions regarding the origin and PRRS vaccination status of their pigs.

Seroprevalence and seroconversion to PRRS virus—County officials were contacted to confirm the

dates of county fairs and whether the 4-H shows were terminal (requiring pigs to go to slaughter following the fair). The seroprevalence of PRRS infection in pigs shown by 4-H participants was estimated in pigs from 9 county fairs, which shipped pigs to a regional slaughterhouse after livestock exhibition. Selection of the counties was by convenience, but 5 of the counties rank among the highest hog-producing counties in Minnesota (Martin, 1st; Nicollet, 4th; Mower, 5th; Brown, 10th; and Watonwan, 12th). The other counties (Rice, Steele, Le Sueur, and Fillmore) have less dense commercial swine populations. Samples were collected from the collaborating slaughterhouse on 5 occasions. Blood samples were collected from individual pigs (n = 661) following stunning without interference with the procedures of the plant. To assess the incidence of PRRS seroconversion following fairs, 2 counties (Blue Earth and Winona) with nonterminal fairs were selected. At these fairs, participants were invited to participate in the study if they intended to return pigs to their farm for at least 2 weeks. In accordance with institutional animal care and use committee requirements, participants gave informed consent for collection of blood samples from their pigs. Blood samples were collected from pigs (n = 32) on the day of exhibition, and participants were later contacted to arrange collection of a second blood sample 2 weeks after the fair. The presence of serum antibodies against PRRS virus was determined by use of a PRRS antibody test kit[g] performed at the University of Minnesota Veterinary Diagnostic Laboratory. For the recommended cutoff of a standard-to-positive ratio of 0.4 that we used, the manufacturer provides estimates for sensitivity (97.4%) and specificity (99.6%),[26] which we used with the Rogan-Gladen estimator to calculate true prevalence from apparent prevalence.[27] One-way ANOVA was used to compare mean PRRS sample-to-positive ratios among counties, and χ^2 analysis was used to compare the proportions of seropositive pigs. Association of seropositivity with hog farm density (by use of NASS, MPCA, and MBAH data) and 4-H participant density was assessed for these 9 counties by use of the Spearman rank correlation method. The McNemar χ^2 test was used to test for differences in seropositivity in paired samples of serum collected from pigs at fairs and 2 weeks later.

Results

Demographics of 4-H and commercial swine populations in Minnesota—All county fairs in Minnesota were scheduled between weeks 24 and 37 in 2005, and more than half of county fairs were held in the month preceding the Minnesota State Fair in early September. Only 7 of 79 (9%) county fair boards contacted required that animals be sent to slaughter at the end of the fair. In 2005, 2,318 students who were 4-H members registered to show pigs in the state of Minnesota, similar to a mean of 2,592 over the 5 preceding years. Participation in 4-H swine programs varied markedly across Minnesota, with the greatest concentration in the southeastern counties. Significant spatial clustering of the swine population shown by 4-H members was found in the southeastern corner of the state, by use of univariate LISA analysis. Multivariate LISA analysis by use of either NASS or MPCA data indicated that 4-H swine program participation was geographically correlated with commercial swine production at the county scale (Moran I, 0.37; bootstrap estimated $P = 0.001$). A slightly different pattern of coclustering was observed by use of the MBAH data, with high-high clustering occurring in both the south-central and central portions of the state (Moran I, 0.24; bootstrap estimated $P = 0.001$). Although results of the analysis differed among the databases of commercial swine production selected, all analyses indicated that participation in the 4-H swine program has significant geographic correlation with commercial pork production in Minnesota (**Figure 1**).

Mail survey and interviews of 4-H participants—A response rate of 66.5% (133/200) was achieved for the mail survey of randomly selected 4-H participants. Although most participants exhibited pigs at only 1 show the previous year (median, 1; mean, 2.5; range, 1 to 35), 1 participant claimed to have exhibited pigs at 35 shows. The mean number of pigs registered for the current year was 4.8 (median, 3; range, 0 to 30), and 54% (95% CI, 45% to 63%) of respondents intended to show their pigs at locations other than their local county fair in 2005. One-sixth of participants were also participating in the FFA swine program (FFA is a youth leadership program including livestock projects similar to 4-H). In FFA, pigs can be exhibited concurrently with 4-H and open class pigs at county fairs. Twenty-four percent (95% CI, 17% to 32%) of 4-H respondents had contact with pigs other than their own at least once a week and 77% (95% CI, 69% to 84%) had livestock other than swine kept at the same location as their show pigs (cattle [56%], poultry [28%], sheep [26%], goats [8%], and other [21%]). Seventy-four percent (95% CI, 65% to 81%) of 4-H respondents obtained their show pigs from off-farm sources, and 13% (95% CI, 8% to 20%) obtained pigs from another state. Of the 82% of participants who purchased pigs, 95 of 111 (86%) purchased the pigs in the months of March to May. Commercial pig production was undertaken by 39% (95% CI, 31% to 48%) of families of 4-H respondents, and 36% (95% CI, 28% to 45%) of 4-H respondents indicated that other (commercial) pigs were kept at the same site as their show pigs. Of 47 respondents from farms rearing both 4-H and commercial pigs, 15 (32%) kept both groups in the same barns. For 4 respondents without any family involvement in commercial production, 55% indicated that other pigs were located within 2 miles of the site where they kept their show pigs.

With respect to knowledge and attitudes toward biosecurity and swine health, respondents ranked clean transportation and obtaining pigs from sources with good health status to be the most important measures to ensure pig health (**Table 1**). When asked how important 14 diseases were to commercial pork producers, respondents perceived swine influenza, *Escherichia coli* infection, and *Salmonella* infection to be the most important diseases of swine, with PRRS ranked fifth (**Table 2**). Forty-one percent of respondents were not familiar with PRRS, compared with 51% for porcine epidemic diarrhea, a disease never reported in the United States. However, 30% indicated that their pigs had been either vaccinated against PRRS or treated for PRRS in-

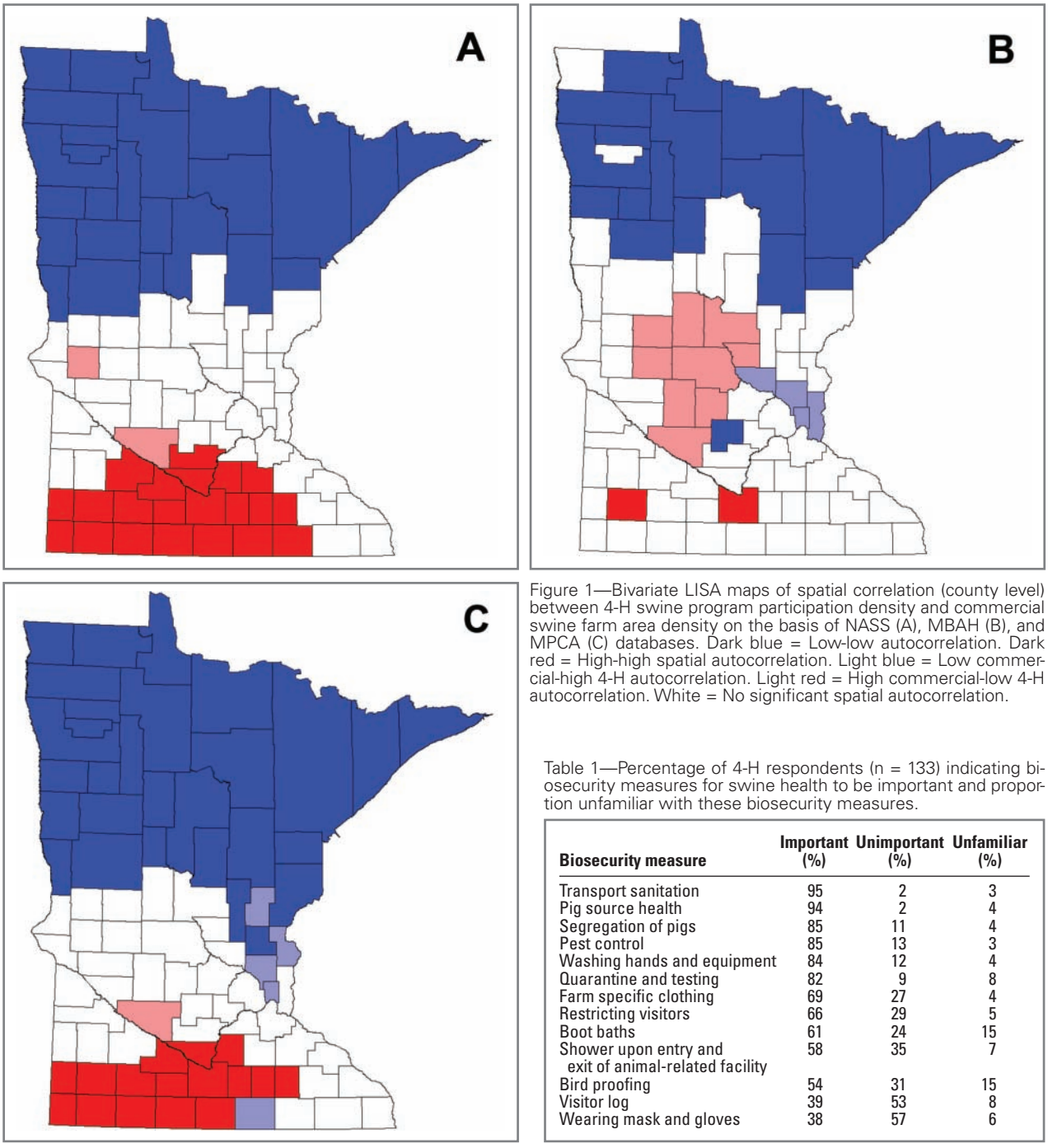

Figure 1—Bivariate LISA maps of spatial correlation (county level) between 4-H swine program participation density and commercial swine farm area density on the basis of NASS (A), MBAH (B), and MPCA (C) databases. Dark blue = Low-low autocorrelation. Dark red = High-high spatial autocorrelation. Light blue = Low commercial-high 4-H autocorrelation. Light red = High commercial-low 4-H autocorrelation. White = No significant spatial autocorrelation.

Table 1—Percentage of 4-H respondents (n = 133) indicating biosecurity measures for swine health to be important and proportion unfamiliar with these biosecurity measures.

Biosecurity measure	Important (%)	Unimportant (%)	Unfamiliar (%)
Transport sanitation	95	2	3
Pig source health	94	2	4
Segregation of pigs	85	11	4
Pest control	85	13	3
Washing hands and equipment	84	12	4
Quarantine and testing	82	9	8
Farm specific clothing	69	27	4
Restricting visitors	66	29	5
Boot baths	61	24	15
Shower upon entry and exit of animal-related facility	58	35	7
Bird proofing	54	31	15
Visitor log	39	53	8
Wearing mask and gloves	38	57	6

fection. Logistic regression analyses indicated that the odds of having regular contact with other pigs, having no other species of livestock, and certification by educational programs beyond the 4-H program all increased significantly for participants from families who raised commercial swine. Awareness of biosecurity and perceived importance of diseases was not influenced by age group, gender, or family involvement in commercial pork production.

Of the convenience sample of 172 participants of 4-H interviewed at the Minnesota State Fair, most were from southern Minnesota. Thirty-three percent of these had registered home-raised pigs, not purchased from an outside source, and 15% were exhibiting pigs that originated from other states. Nineteen (11%) participants stated that they had vaccinated their pigs for PRRS. Survey responses collected from participants at the Rice and Stevens county fairs were similar with respect to grade in school, years in 4-H, whether pigs would return home after the show, and intended participation in other shows. Thirty-three percent of exhibitors were planning to show their pigs at other exhibitions, and 48% of Stevens County 4-H swine show participants were bringing their show pigs home from the county

fair. The primary motivations for participation were to have fun (88%), to learn about pigs and livestock husbandry (54%), and to go to the state fair (30%). Only 16% of participants listed that winning was their motivation for participation.

Seroprevalence and seroconversion to PRRS virus—Across all 9 county fairs where blood samples were collected from show pigs at slaughter (n = 661), the apparent seroprevalence of PRRS was 48% (95% CI, 44% to 52%). By use of the Rogan-Gladen estimator, true prevalence was calculated to be 49% (95% CI, 45% to 53%). Both mean sample-to-positive ratio and seroprevalence differed significantly ($P < 0.001$) among counties, with apparent seroprevalence ranging from 29% to 76% **(Figure 2)**. Of the 32 pigs with blood samples collected during county fairs, 19 (59%) were seropositive. Of these, 27 pigs (17 seropositive and 10 seronegative at the fair) were available for follow-up blood sample collection. Seven of the 10 initially seronegative pigs had seroconverted by 2 weeks after the fair. However, 4 of the 17 previously seropositive pigs became seronegative at the farm and the McNemar χ^2 test for symmetry showed that differences in seroprevalence at the fair and on the farm were not significant ($\chi^2 = 0.82$; $P = 0.37$).

Table 2—Proportion of 4-H respondents (n = 133) indicating specific diseases to be important and proportion unfamiliar with the disease.

Disease condition	Important (%)	Unfamiliar (%)	Ratio*
Influenza	71	25	2.84
Escherichia coli scours	65	28	2.32
Salmonella infection	63	28	2.25
Mycoplasma infection	62	37	1.68
PRRS	58	41	1.41
Pseudorabies	55	41	1.34
Mange	43	48	0.90
Epidemic diarrhea†	43	51	0.84
Erysipelas	44	54	0.81
Parvovirus infection	39	58	0.67
Leptospirosis	31	67	0.46
Ileitis	31	67	0.46
Streptococcus suis infection	30	67	0.45
Teschen disease and Talfan disease†	28	68	0.41

*Ratio of proportion ranking a disease as important to proportion unfamiliar with disease. †Exotic diseases thought likely to be unfamiliar to participants.

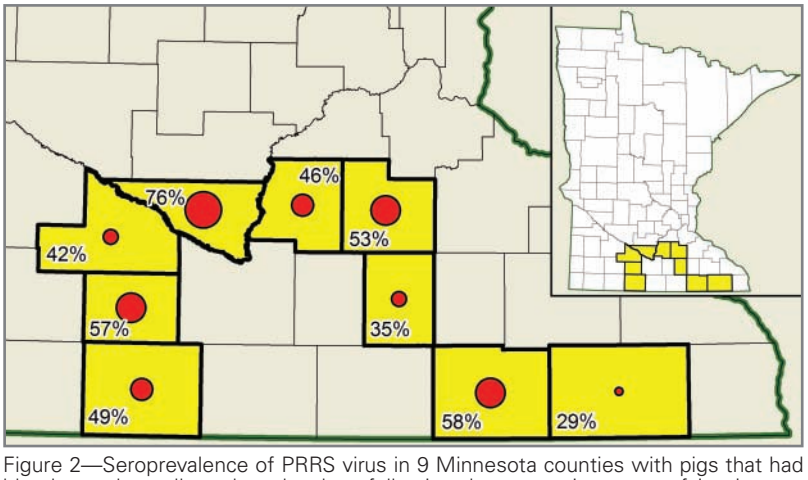

Figure 2—Seroprevalence of PRRS virus in 9 Minnesota counties with pigs that had blood samples collected at slaughter following the respective county fairs. Inset—Locations in Minnesota.

Discussion

For over 2 decades, persistent and severe economic losses from PRRS virus infections in the United States have provided strong motivation to develop and implement effective control programs for this disease. Local spread of virus among farms despite considerable investment in biosecurity is the most frustrating and problematic aspect of PRRS control.[28] Knowledge of the demographics of all potential reservoirs of an infectious agent is an important prerequisite for assessing the feasibility of any regional control or eradication program. From the perspective of the pork industry, the epidemiological importance of any potential reservoir population is a function of its size, the prevalence of pathogens of concern, and its proximity to and interactions with commercial swine populations.

In Minnesota, in 2005, the number of registrants in 4-H, raising a mean of 4.8 pigs, indicates a total 4-H population on the order of 12,000 pigs concentrated in the period from March to September. This is a small population relative to the estimated inventory of 6.5 million and sale of 14.6 million pigs in Minnesota in 2005.[29] However, the importance is elevated when one considers that participation in 4-H swine programs is geographically associated with commercial swine production. Within Minnesota, significant clustering of 4-H and commercial production was found at county level, and 39% of 4-H participants reared pigs on the same locations as commercial pigs. Furthermore, the frequent existence of other swine populations within 2 miles of pigs shown by 4-H participants also suggests a considerable risk of bidirectional transmission of PRRS between 4-H and other pig populations in Minnesota.[14]

A national survey of PRRS seroprevalence in US finishing pigs found > 50% of finishing pigs were seropositive for PRRS.[30] In the same study,[30] 75% of 639 blood samples from pigs on 43 Minnesota hog farms were seropositive, and 36 of 43 (84%) Minnesota finishing herds had at least 1 seropositive pig.[h] Our observations that 49% of pigs shown by 4-H participants that had blood samples collected at slaughter and 59% of pigs that had blood samples collected at fairs were seropositive for PRRS virus indicate exposure risks of similar magnitude in both the commercial and 4-H populations. Again, this is unsurprising given the close proximity and interactions we found between these sectors of swine activity. Seropositive results in some pigs shown by 4-H participants (and also commercial pigs) are likely to be attributable to vaccination, although only 11% of state fair participants claimed to have vaccinated their pigs for PRRS. Based on population sizes alone, it is evident overall that commercial swine farms currently present much higher risk of exposure to 4-H populations than the reverse. However, particularly for boar studs and nucleus or multiplier breeding herds, for which the economic consequences of PRRS outbreaks can be extreme, the risk presented

by small noncommercial populations in their vicinity is nontrivial. Investigations of PRRS outbreaks in commercial herds have implicated nearby backyard operations or show pigs as sources.[i–k] In both cases, genomic analysis confirmed sequence identity between viruses at the commercial (previously PRRS negative) and neighboring sites. Because of the seasonality of fairs, show pig populations are often transient because pigs are commonly purchased and raised for the express purpose of exhibition. Consequently, risks to commercial herds are likely to be highly variable over time.

The limited blood sample collection we conducted of pigs at fairs yielded only 10 seronegative pigs for follow-up testing. However, the fact that 7 of these animals had seroconverted by 2 weeks after the fair supports the axiom that congregation of animals from multiple sources is a high-risk activity for transmission of infectious diseases. Until Minnesota was officially declared free from pseudorabies, government regulations required that swine exhibitions were terminal. Subsequent to pseudorabies eradication from commercial swine, most county fair boards have opted to hold nonterminal shows, and the frequent intention of participants to show pigs at multiple events is facilitated by such policies. The concentrated seasonal schedule of county fairs and the repeated mixing of animals at multiple events are likely to facilitate transmission and could present substantial challenges to traceability in the event of a suspected foreign animal disease outbreak.[31–33] Better information is also important to understand the potential role of other subpopulations of swine that may also serve as sources of entry of foreign diseases or reservoirs of endemic agents.[34]

The diseases ranked highest in importance by 4-H participants (swine influenza, *E coli* infection, and *Salmonella* infection) are caused by pathogens that attract considerable media attention as a result of their impact on human health (recognizing that the important distinction between *E coli* types causing disease in pigs and humans is unlikely to be understood by much of the general public). In contrast, despite its unquestioned primacy among swine pathogens in the United States, as a highly host-specific agent, PRRS is rarely mentioned in the mainstream media. We infer that the perceptions of the importance of diseases by 4-H participants were probably driven more by media emphasis on zoonotic risks than participants' familiarity and experience with livestock. The low level of awareness among participants of PRRS as the major swine health challenge in swine indicates that education about swine diseases and control should receive more emphasis in youth educational programs. This need is reinforced by the fact that overall participants ranked porcine epidemic diarrhea (an exotic disease never reported in the United States) to be more important than several prominent endemic swine pathogens (porcine parvovirus, erysipelas, and *Streptococcus suis*).

4-H youth programs have a history of youth education and development related to agriculture. The survey indicated that although respondents indicated familiarity with common biosecurity measures, a large proportion were unfamiliar with diseases common to swine. Although show pigs represent a small population of pigs overall, common practices of 4-H participants, including sourcing pigs from distant sources and showing pigs at multiple shows, can magnify these pigs' importance as potential reservoirs. It is important that many more participants were motivated by the desire to have fun and to learn about pigs and livestock husbandry than by the prospect of winning. If true, this implies likely receptivity to swine industry initiatives such as provision of pigs for 4-H participants by local producers, which has been encouraged by veterinarians in Minnesota. As the commercial swine industry increasingly looks toward regional strategies to reduce the impact of PRRS,[17] the industry should seek to engage with educational programs. Specific education on biosecurity risks and disease control is a necessary component of this engagement.

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