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Association of Fecal Coliform Levels in Kansas Streams and Prevalence of Infection with Escherichia Coli

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Association of Fecal Coliform Levels in Kansas Streams and Prevalence of Infection with *Escherichia coli*

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Abstract

Changes in livestock operations over the past decade have led to concern over the increased number of Concentrated Animal Feeding Operations (CAFOs) in the United States. These livestock facilities can impair surface and groundwaters with high levels of nitrogen and pathogens. Utilizing geostatistical simulations of fecal coliform levels, this study aimed to assess the impact of livestock operations on prevalence of Escherichia Coli in Kansas between 1997 and 2003. Fecal coliform levels were negatively associated with prevalence of E. Coli in all years, although only reaching significance in 1998. Empirical Bayes estimates indicated higher prevalence dominating the western part of the state. The negative association with E. Coli suggest that prolonged exposure to high fecal coliform levels may be protective against infection. Other studies have indicated that previous exposure to E. Coli may result in partial resistance or complete immunity to subsequent infection.
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Contributions

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Introduction

Over the past decade and a half, industrialization of livestock operations has resulted in an increase in the number of Concentrated Animal Feeding Operations (CAFOs) in the United States. This change in animal husbandry practices has led to concerns about the waste generated by the livestock, which can be up to three times as much as raw human waste. While only a small percentage of all livestock operations, it is estimated that CAFOs account for nearly half of the 500 million tons of manure generated from livestock facilities (USEPA 2003).

Animal Feeding Operations are designated as CAFOs if they have over 1000 animal units or have between 300 and 1000 animal units and meet certain conditions involving discharge and proximity to waterbodies (USEPA 2003). Waste from CAFOs are either stored in engineered lagoons or spread over fields (Krapac et al. 2002). In response to concerns over the increasing numbers of CAFOs, the U.S. Environmental Protection Agency issued a new set of regulations regarding CAFOs in 2003 (Centner 2004).

Respiratory problems have been associated with occupational exposure to CAFOs (Cole et al. 2000) as well as the community. Prolonged exposure to airborne emission from livestock operations can increase headaches, nausea, and eye irritation (Schiffman et al. 2005). Quality of life reported as the number of times a person could not open windows or go outside was lower for residents living in the proximity of CAFOs (Wing and Wolf 2000).

Waste from CAFOs can impair groundwaters. High levels of nitrates have been found in aquifers below agricultural systems (Burkart and Stoner 2002). In a study of
over 200 wells in Delaware used for private water, nitrate concentrations in areas with poultry production were three times higher than those with farming and nearly 40 times higher than forested areas (Ritter and Chirnside 1987). Nitrate concentrations in excess of 10 mg/L in drinking water are of concern because it may lead to methemoglobinemia, also known as blue-baby syndrome (Johnson and Kross 1990). CAFOs also pose a threat to surface waters. Antimicrobial residues have been found in surface waters near land where waste was applied (Campagnolo et al. 2002).

There are several pathways of exposure to pathogens from livestock production. Application of waste to fields can lead to runoff into streams and leaching into the water table. Runoff from grazing livestock or livestock housed in indoor units can reach streams. Livestock can enter into streams and ditches directly contaminating the water. Rats, mice, and birds can serve as intermediary vectors between livestock and humans (Hooda et al. 2000). Contamination of waters can occur from improperly constructed waste lagoons (Miner 1999). In addition to elevated nitrate levels, high levels of fecal streptococcus have been found in groundwaters below waste lagoons (Krapac, Dey et al. 2002).

Pathogen levels are higher in domestic and livestock animal feces than in wildlife, increasing the risk associated with livestock operations (Cox et al. 2005). Cryptosporidium, Escherichia Coli, Salmonella, Giardia and other pathogens associated with fecal contamination can be transported across watersheds to streams (Tyrrel and Quinton 2003). Primary factors influencing transport are vegetation, slope, and rainfall (Davies et al. 2004). Rain events are particularly influential, as saturated soil can lead to rapid overland transport of bacteria to collecting waterbodies (Muirhead et al. 2006). In
addition, surface waters can recharge aquifers and impair groundwater (Nnadi and Fulkerson 2002)

Most studies of the public health impact of livestock practices have utilized various measures of animal density. The ratio of cattle to human population has been associated with increased incidence of shiga toxin producing *E. Coli*. (Valcour et al. 2002) *E. Coli* *O157:H7* has also been associated with high cattle density (Michel et al. 1999). *Campylobacter* incidence was associated with high animal density in Canada and Sweden (Nygard et al. 2004; Green et al. 2006). Pediatric hemolytic-uremic syndrome resulting from infection with *E. Coli. O157:H7* was associated with cattle density and the ratio of calves to children younger than 15 years old (Haus-Cheymol et al. 2006).

While animal density is a good indicator of livestock production practices, it is not necessarily the good indicator of the environmental impact of CAFOs on pathogen exposure. Fecal coliform levels are a common indicator utilized by states and the Federal government to characterize pathogen impairment of streams. The hypothesis of this study is that higher fecal coliform levels will be associated with a higher prevalence of reported infection with *Escherichia Coli*.

**Methods**

The study area consists of the Kansas’s 105 counties and 23,731 miles of stream. Kansas has more than 2,000 active CAFOs. It is the second leading state in cattle production, ninth leading hog producer and 23rd most in dairy cows (USEPA 2002). The Kansas Department of Health and the Environment (KDHE) cites failure to meet pathogen criteria as a leading source of impairment in streams (KDHE 2004).
Fecal coliform levels in streams were monitored by the KDHE between 1997 and 2003. Several measurements were taken each year at each monitoring site. Because of the heavy-tailed distribution of fecal coliform levels, the estimate of average yearly exposure was the mean of the log-transformed values. The number of monitoring sites each year varied between 195 and 223 because of periodically dry riverbeds in the western part of the state and yearly rotations between monitoring sites (Cringan 2005).

Surveillance of enteropathogenic E. Coli is conducted by the KDHE. Cases are based on isolation of E. Coli from a clinical specimen and do not require clinical illness. Cases are aggregated to the county level for reporting. Prevalence between 1997 and 2003 for each county was calculated with population estimates from the 2000 census. Statistical analyses were done with the R statistical software (R Development Core Team 2005).

Exploratory data analysis was done with the spdep package for R (Bivand 2005). Poisson probability maps were constructed to identify counties which had a statistically significant high or low number of cases based on the expected counts for the number of residents. In order to reduce the noise introduced by the different population sizes and the rarity of reported E. Coli cases, local empirical Bayes estimates of prevalence were calculated to identify regional trends of the disease in Kansas (Marshall 1991). In addition, local Moran’s I was estimated to identify any autocorrelation in the prevalence. Moran’s I is analogous to a spatially weighted Pearson’s correlation coefficient.

For the analysis of the exposure effect on prevalence of E. Coli, a modified form of the transformation suggested by Cressie was utilized: $V_i = \log\left\{\frac{100(s_i + 1)}{n_i}\right\}$ where $V_i$ is the transformed rate of county $i$, $s_i$ is the number of cases in county $i$ and $n_i$ is the
population of county i (Cressie 1993). The transformation normalizes the incidence and removes any dependence of the variance on the mean. Also, this has the advantage of distinguishing between counties with few or no cases and different population sizes (Waller and Gotway 2004). The transformed prevalence was the dependent variable in a linear regression.

Exposure to fecal coliforms for each county was based on predictions from the existing data at stream monitoring sites of coliform levels at the centroids of the county. It would be improper to insert these values into the linear regression without incorporating the error in predicting the values. In order to account for this spatially structured error, 1000 geostatistical simulations of fecal coliform values at each county centroid were estimated from the data using the kriging and simulation functions of the geoR package for R (Ribeiro Jr. and Diggle 2001).

Cressie and Hawkins robust variogram estimator was used to estimate the empirical semivariogram. Initial parameters for fitting the semivariogram were chosen with the eyefit function in geoR. Spherical covariance models were fitted to the semivariograms with weighted least squares. The covariance model was passed to the krig.conv function to execute 1000 conditional geostatistical simulations of the observed coliform spatial process. This procedure was repeated for each year between 1997 and 2003.

Each simulation was regressed on the transformed prevalence. Since the very old and very young have an increased risk of infection with E. Coli, the proportion of residents under the age of 5 or over the age of 65 was included as a dependent variable. The parameter estimates from the regressions collectively represent an empirical
distribution of the betas. The median of this distribution is the effect estimate for each independent variable. The 2.5\textsuperscript{th} and 97.5\textsuperscript{th} percentiles were the confidence interval for a two-tailed alpha of .05.

**Results**

The prevalence of *E. Coli.* cases in Kansas between 1997 and 2003 was 9.41 per 100,000 residents. Yearly prevalence decreased during the middle of the study before rising sharply in the final two years. (Figure 1) There were 51 counties which did not report any cases during the study period. The median number of counties each year reporting at least one case was 17. The average of the log coliforms for all sites combined decreased during the study period. (Figure 2)

Figure 3 shows the raw cumulative prevalence of *E. Coli* in Kansas between 1997 and 2003. Figure 4 represents the Poisson probability of the number of cases in each county exceeding or falling below the number expected during the study period. One county had a significantly lower risk of *E. Coli* for an alpha of .05 and 13 counties exceeded the expected number of cases for the population. In the western part of the state, counties with a high risk of *E. Coli* have small populations and reported more than one case during the study period. Moran’s I statistic for the prevalence had a p value of .2198, indicating there is no autocorrelation in the rates.

A map of empirical Bayes estimates of *E. Coli* showed higher rates in the western part of the state. (Figure 5) The southeastern portion of Kansas had low prevalence rates with the exception of one county. The central and northeastern part of the states had moderate prevalence.
Table 1 lists the results of regressions on the geostatistical simulations. Fecal coliform levels were marginally significant in 1998, but not in any other year. However, the direction of the effect was consistently negative for all years. This may indicate that exposure to high levels of fecal coliforms is protective against infection. Previous studies have shown that prior infection with *E. Coli* confers some resistance to new infections (Steinsland et al. 2003) as well as decreasing prevalence of symptomatic diarrhea from infection (Valentiner-Branth et al. 2003). In addition, in a study of an *E. Coli* outbreak due to contaminated water in Wyoming, visitors to the town had a higher attack rate than residents, indicating possible conference of partial immunity from prolonged exposure (Olsen et al. 2002).

The proportion of residents under the age of 5 or over 65 was a significant variable and showed a consistent effect for each year. However, age was correlated with population, as young professionals tend to mass in urban areas. While the age effect is significant, it may be a product of the transformation applied to the prevalence.

**Discussion**

Most studies of the effect of livestock operations on pathogen infection incidence have used various measures of animal density as the exposure variable. This is not necessarily an accurate surrogate for the impact of CAFOs on human health. Many factors can influence the fecal shedding of pathogens including age, feed (Berg et al. 2004), and transportation (Bach et al. 2004). In addition, the impact of livestock operations is minimized by properly constructed lagoons and appropriately handled waste (Miner 1999).
This study utilized a common parameter used by state and Federal agencies to assess environmental impairment from pathogens. Although the study showed little effect of fecal coliform levels on *E. Coli* prevalence, the averaging of levels for the year may mask important seasonal trends in pathogen contents of waste (Miller et al. 2003). In addition, pathogen levels are significantly higher after rain events. (Lipp et al. 2001). Assessing the potential risk of human exposure to pathogens from livestock waste should account for the increased loads after heavy rains.

Since 1998, Kansas has increased efforts to better manage livestock wastes, possibly leading to the decreasing trend in coliforms over the study period. The direction of the main effects indicates that fecal coliforms may be negatively associated with *E. Coli* prevalence, although this should be interpreted cautiously. It is possible that exposure to coliforms builds resistance to infection. However, the disease rarely leads to serious complications and since the case definition requires a positive lab result, cases may be underreported.

The high prevalence in western Kansas is the result of multiple cases in rural counties with populations less than 10,000. Ten of the 13 counties with significantly more cases than expected were in the western half of the state. This may indicate a problem with the High Plains Aquifer, which supplies most of the irrigation and drinking water to the region.

Infection with common agents is not the only concern of the confluence of pathogens and livestock operations. Many managers administer antibiotics prophylactically to the animals. This has the potential to rapidly accelerate the promulgation of antibiotic resistant bacteria in the environment. Future research should
explore the possibility of an association of livestock operations with emerging antibiotic-resistant strains of bacteria.


KDHE (2004). "Kansas Water Quality Assessment (305(b) Report)."


USEPA (2002). State Compendium-Region 7: programs and regulatory activities related to animal feeding operations.


Figures and Tables

**Figure 1.** Yearly prevalence of *E. Coli.* in Kansas. Prevalence nearly doubled in the final two years of the study.
Figure 2. Yearly mean fecal coliforms levels in Kansas streams. Beginning in 1998, the KDHE increased efforts to minimize the impact of Animal Feeding Operations in the environment.

<table>
<thead>
<tr>
<th>Year</th>
<th>Fecal Coliforms</th>
<th>Proportion &lt;5 and &gt;65</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>-0.4457 (-0.1654, 0.0206)</td>
<td>-5.0361 (-5.6502, -4.6541)</td>
</tr>
<tr>
<td>1998</td>
<td>-0.0937 (-0.1990, -0.0003)</td>
<td>-4.9440 (-5.6110, -4.6044)</td>
</tr>
<tr>
<td>1999</td>
<td>-0.0800 (-0.1786, 0.0148)</td>
<td>-5.9809 (-6.5687, -5.5936)</td>
</tr>
<tr>
<td>2000</td>
<td>-0.0652 (-0.1665, 0.0388)</td>
<td>-6.2153 (-6.7859, -5.8617)</td>
</tr>
<tr>
<td>2001</td>
<td>-0.0623 (-0.1616, 0.0301)</td>
<td>-5.6037 (-6.2082, -5.2883)</td>
</tr>
<tr>
<td>2002</td>
<td>-0.0417 (-0.1361, 0.0511)</td>
<td>-4.3470 (-4.8779, -4.0424)</td>
</tr>
<tr>
<td>2003</td>
<td>-0.0390 (-0.1439, 0.0598)</td>
<td>-4.8071 (-5.3502, -4.5042)</td>
</tr>
</tbody>
</table>

Table 1. Parameter estimates from the regressions on the geostatistical simulations. Confidence intervals are in parentheses. While the effect of fecal coliforms only reached significance in 1998, the direction of effects for all years indicates that exposure to higher fecal coliform levels may be protective against *E. Coli.*
Figure 3. Raw cumulative prevalence of *E. Coli.* per 100,000 residents in Kansas between 1997 and 2003. Overall prevalence during the study period was 9.41. Fifty-one counties did not report a case during the study period.
Figure 4. Poisson probabilities of the number of cases observed exceeding or falling below the number expected during the study period. Many of the counties with higher risk had more than one case reported with small populations. Sedgwick county, which had lower risk, contains Wichita, the largest city in Kansas.
Figure 5. Local empirical Bayes estimates of *E. Coli* cumulative prevalence per 100,000 residents between 1997 and 2003. Overall prevalence during the study period was 9.41. Western Kansas had substantially higher rates than the rest of the state.