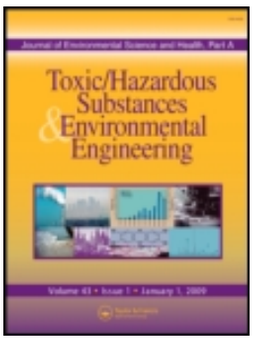

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Journal of Environmental Science and Health, Part A
Toxic/Hazardous Substances and Environmental Engineering

ISSN: 1093-4529 (Print) 1532-4117 (Online) Journal homepage: http://www.tandfonline.com/loi/lesa20

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To cite this article: I. B. Slizovskiy, L. A. Conti, S. J. Trufan, J. S. Reif, V. T. Lamers, M. H. Stowe, J. Dziura & P. M. Rabinowitz (2015) Reported health conditions in animals residing near natural gas wells in southwestern Pennsylvania, Journal of Environmental Science and Health, Part A, 50:5, 473-481, DOI: 10.1080/10934529.2015.992666

To link to this article: http://dx.doi.org/10.1080/10934529.2015.992666

Journal of Environmental Science and Health, Part A (2015) **50**, 473–481

ISSN: 1093-4529 (Print); 1532-4117 (Online)
DOI: 10.1080/10934529.2015.992666

Reported health conditions in animals residing near natural gas wells in southwestern Pennsylvania

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Natural gas extraction activities, including the use of horizontal drilling and hydraulic fracturing, may pose potential health risks to both human and animal populations in close proximity to sites of extraction activity. Because animals may have increased exposure to contaminated water and air as well as increased susceptibility to contaminant exposures compared to nearby humans, animal disease events in communities living near natural gas extraction may provide "sentinel" information useful for human health risk assessment. Community health evaluations as well as health impact assessments (HIAs) of natural gas exploration should therefore consider the inclusion of animal health metrics in their assessment process. We report on a community environmental health survey conducted in an area of active natural gas drilling, which included the collection of health data on 2452 companion and backyard animals residing in 157 randomly-selected households of Washington County, Pennsylvania (USA). There were a total of 127 reported health conditions, most commonly among dogs. When reports from all animals were considered, there were no significant associations between reported health condition and household proximity to natural gas wells. When dogs were analyzed separately, we found an elevated risk of 'any' reported health condition in households less than 1km from the nearest gas well (OR = 3.2, 95% CI 1.07–9.7), with dermal conditions being the most common of canine disorders. While these results should be considered hypothesis generating and preliminary, they suggest value in ongoing assessments of pet dogs as well as other animals to better elucidate the health impacts of natural gas extraction on nearby communities.

Keywords: Animal sentinels, environmental health, hydraulic fracturing, natural gas.

Introduction

Modern natural gas extraction activity

Over the past two decades, the United States has seen increased exploration and development of unconventional sources of fuel, including natural gas from underground shale formations.[1,2] The growth of modern shale-based natural gas exploration and production is an outcome of the implementation of two novel extractive techniques. First, the use of a drilling technology known as *directional drilling* is implemented by guiding a drill bit downhole at a 90° angle to extend along the internal seam of existing gas-rich shale bedrock. Second, fissures and gaps are created in the rock via *hydraulic fracturing* at varying intervals.[3] Hydraulic fracturing ('hydrofracing' or 'hydrofracking') is a process that entails the pumping and injection of fluids and a propping agent through a drilled and encased hole under significant pressure, gradually creating fissures and cracks within the target shale bed.[3,4]

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/lesa.

Potential health related exposures

Although hydraulic fracturing fluids are composed largely of water and sand proppant, the process also involves use of multiple chemical additives. These compounds vary in range of toxicity and public health concern,[5] and the precise mixture of chemicals is often unknown.[6]

While additives and coadjuvants present in hydraulic fracturing fluids are of particular concern, further consideration needs to be given to naturally occurring hazards including heavy metals, naturally occurring radioactive materials and volatile organic compounds (VOCs) of natural origin, some of which could become airborne during gas extraction activities.[7] Such chemicals could pose a potential health concern to nearby communities through water, soil, and air exposure. Of the millions of gallons of water used to hydraulically fracture a shale gas well once, 30–70% can remain underground and potentially impact groundwater supplies,[5] although some migration of shale-based chemicals may occur naturally.[8]

In terms of air exposures, in addition to methane releases, a recent analysis of air contaminants associated with natural gas drilling operations in a rural western Colorado area found that well pads can be potential sources of non-methane hydrocarbon releases, including VOCs, into the air.[9]

Public health concerns

Communities in proximity to natural gas drilling and hydraulic fracturing operations have the potential to experience public health impacts of natural gas extraction activities, although documentation of such impacts remains limited. Published case reports and recent small-scale studies have described health effects, including respiratory and dermal conditions and stress, in individuals living near natural gas wells.[7,10,11]

Animals as sentinels

Since the publication of the National Research Council's 1991 *Animals as Sentinels of Environmental Health Hazards,*[12] evidence has accumulated suggesting that monitoring the health status of animal populations can add to existing efforts to assess the risk of environmental health hazards.[13,14] Such consideration and assessment of "shared risks" of environmental exposures between humans and animals could lead to earlier detection and prevention of health hazards in the environment.[15] Domestic and wild animals may experience higher levels of exposure to a particular environmental hazard compared to nearby humans. In addition, increased susceptibility or decreased latency period between exposure and development of disease for animals relative to humans may result in the appearance of health effects in animals before they are detected in humans.[14,15] Case reports of animal morbidity and mortality attributed to oil and gas extraction activity, as well as reports of ecosystem disturbances[16,17,18] have raised the possibility that animals could serve as sentinels for environmental health hazards related to natural gas extraction activities.[7]

This article details the results of a systematic cross-sectional study of the health of companion and backyard animals in households located in proximity to natural gas wells in Southwest Pennsylvania, an area of active natural gas exploration. The object of the study was to determine whether there was an association between reported health conditions in animals and household proximity to natural gas wells.

Methods

Description of study area

The Marcellus formation, a principal source of shale-based natural gas in the United States, has been drilled for gas extraction in the southwestern portion of the State of Pennsylvania since 2003. Our study took place in Washington County, Pennsylvania, a region where directional drilling as well as hydraulic fracturing activities have been ongoing in recent years. At the time of the administration of the animal health survey, 624 natural gas wells were active in the county.[16] The county has a rural classification with nearly 40% of the land devoted to agriculture.[17]

Washington County includes 32 spatially large rural townships and 34 spatially minor regions (32 boroughs and 2 cities) with a greater population density, urbanization, and provision of treated municipal water supplies and other major utilities. To focus on households in proximity to natural gas extraction activities where ground-fed domestic water wells would be in use and for which data were available on nearby natural gas wells, we sampled households in 38 contiguous municipalities in the rural region of Washington County not bordering West Virginia (Fig. 1).

Selection of households

The animal health survey was part of a household health survey that also assessed human health. The methods for selection of households have been described elsewhere.[11] Briefly, we selected households in the study area using ArcGIS Desktop 10.0 software (ESRI, Inc., Redlands, CA, USA) to randomly generate 20 sampling points for each municipality. We then located the closest household to each random point. Figure 2 illustrates the spatial randomization for the selection of participants from the study base. The study team visited the households identified through this selection process and determined whether they had access to groundwater wells. At each of the eligible households, the study team visited the house to obtain consent for the survey. A total of 180 consenting households were included in the final household sample. Of these households, 157 reported animals living in the house or backyard adjacent to the house.

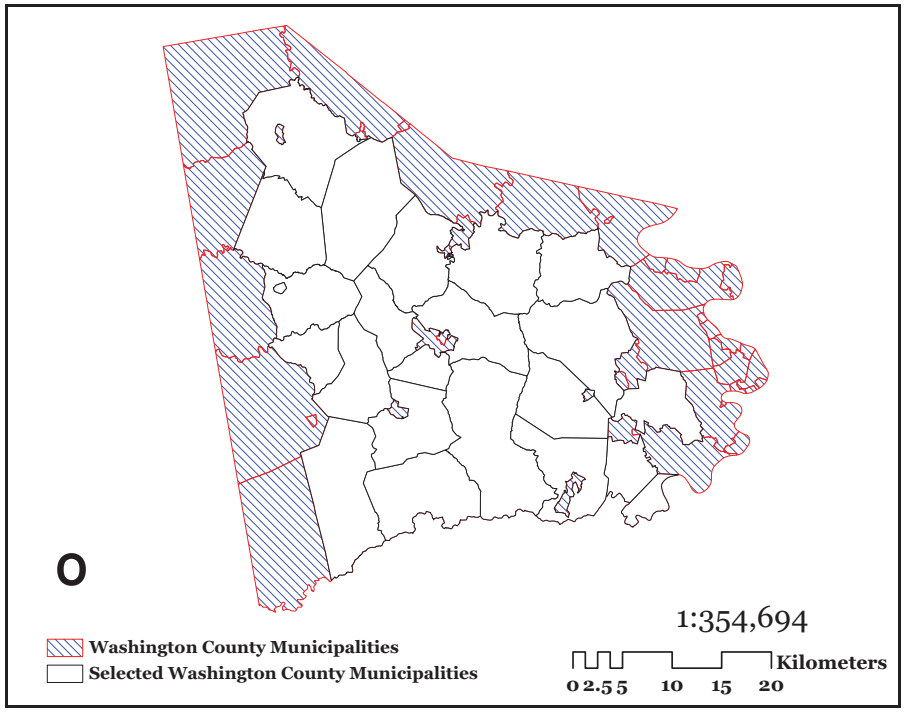

Fig. 1. Selection of relevant study municipalities of Washington County, Pennsylvania, USA.

Survey questionnaire

A confidential community environmental health questionnaire was developed to collect data on both the general health of human household members, as well as the health status of companion animals and backyard livestock at each household. Two veterinarians oversaw the development of the animal health survey questions. These questions included information on the approximate age of each animal, the number of each species, whether the animal was allowed outdoors, the main source of available water (municipal, well, spring, surface, tank), and any reported health problems, changes in production, or

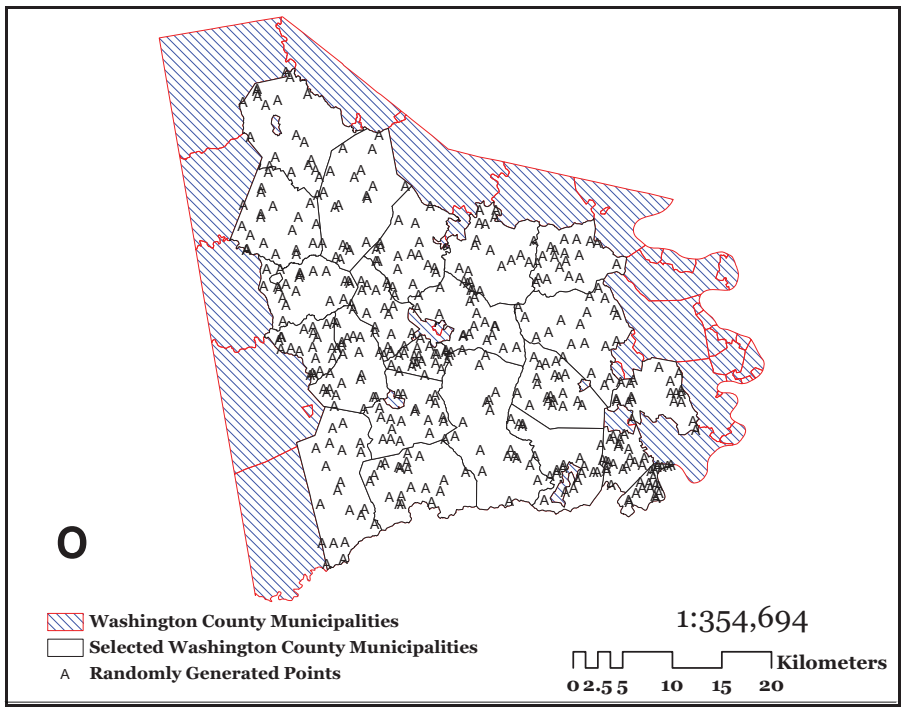

Fig. 2. Distribution of randomly generated sampling points for eligible municipalities of Washington County, Pennsylvania, USA.

deaths that had been noted within one year from the date of the survey. Whenever health problems in animals were reported, the respondent was asked whether there had been a veterinary diagnosis and/or treatment given to the animal.

The survey was pre-tested with community members to ensure comprehensibility of question items. The Yale University School of Medicine Institutional Animal Care and Use Committee (IACUC) reviewed and approved the study protocol for the animal health survey. The human survey was reviewed by the Yale Human Research Protection Program for consideration of risks to human subjects and determined to be exempt from IRB review.

Administration of questionnaire

The household survey was performed during the summer of 2012. At each eligible household, one English speaking person at least 18 years of age with no serious language or mental impairment, who had lived in the given residence for a minimum of one year, was invited to respond to the household questionnaire. The survey was presented as a general environmental health questionnaire and did not mention natural gas drilling. Respondents were asked, however, whether they were aware or concerned about any environmental health hazards in the area. The two interviewers were trained to administer the survey instrument in a uniform and consistent fashion, such that questionnaires could be completed in less than 15–20 min. Eligible respondents were offered a small cash stipend ($25) for participation. A study team member recorded the Global Positioning System (GPS) coordinates of the household using a Garmin GPSMAP® 62S Series handheld GPS device (Garmin International, Inc., Olathe, KS). Survey personnel were not aware of the mapping results for gas well proximity to the households being surveyed.

Household proximity to nearest active gas well

A map of active unconventional gas wells in the county was created using gas well permit data publically available at the Pennsylvania Department of Environmental Protection.[16] Using ArcGIS, we calculated the distance between the household location (as defined by the GPS reading taken during the site visit) and each gas well appearing on the map. We then classified households by distance from the nearest well, as <1 km, 1–2 km or > 2 km.

Classification of animal health problems

A veterinarian on the study team reviewed completed surveys and classified reports of animal health problems according to organ system categories consisting of dermal, respiratory, ocular, neurological, gastrointestinal, reproductive, geriatric, neoplasms, musculoskeletal or other condition categories. The veterinarian classifying these reported animal health conditions was blinded as to the mapping results of proximity to gas wells for each household.

Statistical analysis

Simple prevalence rates and frequencies were calculated for reported categories of health problems in animals located in households at different distances from the nearest gas well. Non-parametric tests of comparison were used to analyze covariates between distance groups. The association between household distance from a well (< 1 km, 1-2 km, or > 2 km) and presence or absence of reported health problems for animals was tested in a generalized linear mixed model (GLMM) logistic regression with a random effect to account for the clustering within a household. Because different covariates were available for backyard animals compared to household pets, two different models were created. Both models were adjusted for respondent awareness of nearby environmental hazards and use of groundwater wells to water animals. The household pet model also included age and whether the animal spent time outdoors. Statistical analyses were conducted using SAS 9.4 (SAS Institute, Cary, NC, USA). Due to the exploratory nature of the study, we did not perform correction for multiple comparisons.

Results

Of the 180 households where the survey was conducted, 157 households reported having at least one household pet or backyard animal present. In these 157 households, respondents reported on health conditions in a total of 2452 companion and/or backyard animals. Table 1 describes the type and number of animals in the household according to category of household proximity to the nearest active natural gas well. Among companion animals, more dogs than cats were reported in the survey. Other household pets included birds (10), rabbits (8), ferrets (3), fish (5), reptiles and amphibians (4), hamster (1), peacock (1) and raccoon (1). In general, 63% of the reported companion animals resided either "indoors," or were considered transient among indoor and outdoor environments at equal proportions. Among backyard animals, livestock (cows and horses) were most common, followed by poultry. Other backyard animals included rabbits (5), bee hive (1) and koi fish (20). The majority of households reported using groundwater to water their animals.

As shown in Table 2, a total of 127 health problems were reported having occurred over the past year among the animals in the survey, representing 5 % of the 2452 surveyed animals. Dogs accounted for 55 of the 127 reported conditions, while 23 reported conditions occurred in cats and 38 in livestock. The frequency of reported health

Table 1. Species type and number of animals surveyed in 157 households reporting animals, by distance to the nearest natural gas well.

Distance from Well	*<1 Km*	*1–2 Km*	*>2 Km*	*All*
Number of Households	56	53	48	157
Number of animals (N (%))				
Feline	83 (44)	64 (34)	40 (21)	187
Canine	91 (38)	74 (31)	74 (31)	239
Other Pets	9 (27)	6 (18)	18 (55)	33
Livestock	624 (40)	631 (40)	319 (20)	1574
Poultry	123 (31)	77 (20)	193 (49)	393
Other Backyard	4 (15)	2 (8)	20 (77)	26
Total number of animals	934 (38)	854 (35)	664 (27)	2452
Using Groundfed Water (by animal)	907 (97)	835 (98)	605 (91)	2347
Average Age (pets only)*	5.8 ± 4.1	6.8 ± 4.6	5.9 ± 4.2	6.1 ± 4.3
Respondent Awareness of Environmental Risk	14 (37)	16 (42)	8 (21)	38

* 407 of 459 pets had age recorded

problems in other animal species, including poultry, was very low. The most frequently reported animal health problems were in the dermal, musculoskeletal, and gastrointestinal categories. Unadjusted chi square values for particular conditions indicated that they were found more frequently in households close to gas wells, such as dermal and gastrointestinal in pets and other unspecified illnesses in backyard animals.

Many of the health event categories reported for dogs and cats (e.g., musculoskeletal, neurologic, and gastrointestinal problems) were not reported for livestock. However, the majority of reported reproductive problems (7/8) occurred among livestock species surveyed. Veterinarians were consulted by 6 of the 61 households (10%) reporting backyard animal health conditions, and 16 of the 149 households (11%) reporting pet conditions.

Association of animal health condition and household proximity to gas wells

Tables 3a and 3b show the results of the hierarchical regression model of reported animal health conditions and proximity to gas wells for backyard animals (Table 3a) and household pets (Table 3b). For household pets overall, after adjusting for age, spending time outdoors, water supply, and owner's reported awareness of environmental hazards, there was not a significant association between household proximity to natural gas wells and reported animal health conditions (Table 3b). However when only dogs were considered separately (Table 3c) an association was found between any reported condition and residing in a household less than 1 km from the nearest natural gas well (OR = 3.2, 95% CI 1.07–9.7). Although the adjusted odds ratios for residence in a household < 1 km from the nearest gas well were higher for dermal, and gastrointestinal conditions compared to residence in households 1-2 or greater than 2 km from a gas well, these associations were not statistically significant.

For backyard animals, no significant association between proximity to natural gas wells and reported health conditions was apparent after adjusting for water supply and respondent awareness of environmental hazards (Table 3a).

Discussion

This spatially random household survey of companion and backyard livestock animal health in a region with an extensive number of active natural gas wells illustrates some of the complexities and challenges in attempting to systematically use animal sentinel data to better understand environmental health risks. The study was exploratory and hypothesis generating in nature, and any reported associations should be considered preliminary. When questions about animal health were included in a general health survey, the number of reported health problems in animals was generally small, with the health events reported most frequently in dogs compared to other species.

When all household pets or backyard animals were considered as groups, we did not find, in adjusted models, any significant associations between mapped distances of the household to the nearest natural gas well and the frequency of any specific health problem. However, when dogs, which were both the most numerous companion species in the sample and the most likely to have reported health conditions, were analyzed separately, elevated risks of any reported condition were found. Among these canine health conditions, dermal conditions were the most common. This is a finding of interest since we have previously reported an increased risk of dermal conditions and upper respiratory complaints in humans living in the same households close to natural gas wells,[11] and previous case reports in animals and humans have also mentioned skin conditions as possibly related to natural gas extraction exposures.[7]

Table 2. Prevalence of reported health problems by distance from well (Total = 127 reported conditions).

Backyard Animals n(%) N = 1993	*<1 Km*	*1-2 Km*	*>2 Km*	*Unadjusted Chi Sq (P)*
Any Reported Condition (n = 42)	10 (24)	23 (55)	9 (21)	7.0 (0.03)
Dermal (n = 10)	2 (20)	4 (40)	4 (40)	1.5 (0.46)
Gastrointestinal (n = 0)	0 (0)	0 (0)	0 (0)	—
Geriatric (n = 0)	0 (0)	0 (0)	0 (0)	—
Musculoskeletal (n = 0)	0 (0)	0 (0)	0 (0)	—
Neoplasia (n = 2)	0 (0)	2 (100)	0 (0)	3.6 (0.16)
Neurological (n = 0)	0 (0)	0 (0)	0 (0)	—
Ocular (n = 9)	0 (0)	6 (67)	3 (33)	6.0 (0.05)
Reproductive (n = 7)	4 (57)	2 (29)	1 (14)	1.2 (0.54)
Respiratory (n = 0)	0 (0)	0 (0)	0 (0)	—
Other Unspecified (n = 15)	4 (27)	10 (67)	1 (7)	6.8 (0.03)
All Pets n(%) N = 459	*<1 Km*	*1-2 Km*	*>2 Km*	*Unadjusted Chi Sq (P)*
Any Reported Condition (n = 74)	41 (55)	18 (24)	15 (20)	8.9 (0.01)
Dermal (n = 23)	12 (52)	9 (39)	2 (9)	4.8 (0.09)
Gastrointestinal (n = 12)	9 (75)	1 (8)	2 (17)	6.5 (0.04)
Geriatric (n = 12)	5 (42)	3 (25)	4 (33)	0.26 (0.88)
Musculoskeletal (n = 18)	8 (44)	4 (22)	6 (33)	0.7 (0.7)
Neoplasia (n = 2)	2 (100)	0 (0)	0 (0)	3.0 (0.22)
Neurological (n = 1)	0 (0)	0 (0)	1 (100)	2.4 (0.3)
Ocular (n = 5)	1 (20)	2 (40)	2 (40)	0.84 (0.66)
Reproductive (n = 1)	1 (100)	0 (0)	0 (0)	1.5 (0.47)
Respiratory (n = 1)	1 (100)	0 (0)	0 (0)	1.5 (0.47)
Other Unspecified (n = 9)	6 (67)	3 (33)	0 (0)	4.3 (0.12)
Dogs Only n(%) N = 239	*<1 Km*	*1–2 Km*	*>2 Km*	*Unadjusted Chi Sq (P)*
Any Reported Condition (n = 48)	30 (63)	9 (19)	9 (19)	15.2 (0.0005)
Dermal (n = 17)	11 (65)	5 (29)	1 (6)	7.14 (0.03)
Gastrointestinal (n = 11)	8 (73)	1 (9)	2 (18)	6.03 (0.05)
Geriatric (n = 3)	3 (100)	0 (0)	0 (0)	4.9 (0.08)
Musculoskeletal (n = 16)	7 (43)	4 (25)	5 (31)	0.3 (0.8)
Neurological (n = 0)	0 (0)	0 (0)	0 (0)	—
Neoplasia (n = 2)	2 (100)	0 (0)	0 (0)	3.3 (0.19)
Ocular (n = 4)	1 (25)	1 (25)	2 (50)	0.7 (0.7)
Reproductive (n = 1)	1 (100)	0 (0)	0 (0)	1.6 (0.44)
Respiratory (n = 1)	1 (100)	0 (0)	0 (0)	1.6 (0.44)
Other Unspecified (n = 0)	0 (0)	0 (0)	0 (0)	—

Companion and backyard animals live in close association to their human counterparts, and may share similar domestic exposures. Therefore, one possible explanation of these findings in animals is that both animals and humans are experiencing health events related to exposures in the shared environment. It is possible that chemical contaminants in either air or water could explain this co-occurrence of health conditions, and warrants further examination. A number of compounds found in fracking fluids could cause dermal or mucus membrane irritation following either airborne or waterborne exposure. Other explanations are possible, such as exposure to food borne or environmental allergens or infectious agents such as dermatophytes, but there is no apparent *a priori* reason why such conditions would be more prevalent in households closer to natural gas wells. Further studies should assess the relationship between specific chemical exposures and the occurrence of human and animal dermal and other conditions.

The fact that we did not see a significant association of reported animal health problems and gas well proximity when considering all of the animals in our sample could have a number of explanations. One is that some species such as dogs may be better sentinels than other species owing to factors including susceptibility and likelihood of being noticed. A limitation of our study was the reliance on a household respondent noting and reporting on specific animal illnesses. This could result in under or over estimation of the true burden of health problems in the animals, which might be more accurately assessed by an objective examination by a veterinarian or measurement of biomarkers such as urine or blood indices of chemical

Table 3a. Multilevel analysis of reported health conditions of backyard animals by distance from gas wells (n = 1993).*

Outcome	*<1 Km*			*1–2 Km*			
Distance OR (95% CI), P-*value*	*OR*	*95% CI*	P	*OR*	*95% CI*	P	*>2 Km*
Any reported condition	0.5	0.08–2.7	0.40	2.0	0.37–10.4	0.42	Ref.
Dermal	0.2	0.004–14.6	0.48	0.7	0.01–41.7	0.86	Ref.
Gastrointestinal	—	—	—	—	—	—	
Geriatric	—	—	—	—	—	—	
Musculoskeletal	—	—	—	—	—	—	
Neoplasia**	—	—	—	—	—	—	
Neurological	—	—	—	—	—	—	
Ocular	0.001	0.0001- inf	0.99	0.59	0.003-137	0.85	Ref.
Reproductive	1.7	0.1–30.7	0.70	0.82	0.03–20.4	0.90	Ref.
Respiratory	—	—	—	—	—	—	
Other Unspecified	2.3	0.06–78.1	0.65	9.7	0.32–296	0.19	Ref.

*Hierarchical logistic regression models in all cases adjusted for water source and owner awareness of nearby environmental risks.
** Multivariate model did not converge.
"Ref." refers to the fact that the > 2 km group is the reference category for comparisons.

Table 3b. Multilevel analysis of reported health conditions of all pets by distance from gas wells (n = 407).*

Outcome	*<1 Km*			*1–2 Km*			
Distance OR (95% CI), P-*value*	*OR*	*95% CI*	P	*OR*	*95% CI*	P	*>2 Km*
Any reported condition	1.9	0.7–5.2	0.2	0.8	0.3–2.3	0.7	Ref
Dermal	3.9	0.7–22.6	0.13	3.5	0.6–21.4	0.17	Ref
Gastrointestinal	1.5	0.2–10.9	0.7	0.4	0.02–5.8	0.5	Ref
Geriatric**	—	—	—	—	—	—	
Musculoskeletal	1.0	0.3–3.8	0.95	0.4	0.09–1.9	0.26	Ref
Neoplasia**							
Neurological**							
Ocular	0.4	0.03–5.0	0.5	0.7	0.07–6.0	0.7	Ref
Reproductive**	—	—	—	—	—	—	
Respiratory**							
Other Unspecified**	—	—	—	—	—	—	

*Hierarchical logistic regression models in all cases adjusted for animal age, water source, whether the animals spent time inside, outside, or both and owner awareness of nearby environmental risks. 52 animals were dropped from the analysis due to missing age data.
** Multivariate model did not converge due to low numbers.
"Ref." refers to the fact that the > 2 km group is the reference category for comparisons.

Table 3c. Multilevel analysis of reported health conditions of dogs only by distance from gas wells (n = 225).*

Outcome	*<1 Km*			*1–2 Km*			
Dogs Only - Distance OR (95% CI, P-*value)*	*OR*	*95% CI*	P	*OR*	*95% CI*	P	*>2 Km*
Any reported condition	3.2	1.07–9.7	0.04	0.9	0.3–3.2	0.9	Ref
Dermal	8.9	0.95–84.1	0.056	5.1	0.5–52.9	0.17	Ref
Gastrointestinal	1.5	0.2–14	0.69	0.5	0.03–7.8	0.59	Ref
Geriatric**	—	—	—	—	—	—	
Musculoskeletal	1.4	0.3–6.1	0.67	0.7	0.1–3.8	0.69	Ref
Neoplasia**	—	—	—	—	—	—	
Neurological	—	—	—	—	—	—	
Ocular	0.4	0.03–6.3	0.52	0.4	0.03–6.4	0.53	Ref
Reproductive	—	—	—	—	—	—	
Respiratory	—	—	—	—	—	—	
Other Unspecified	—	—	—	—	—	—	

*Hierarchical logistic regression models in all cases adjusted for animal age, water source, owner awareness of environmental risks, and whether dog was primarily indoors, outdoors, or both. 14 dogs were dropped from the analysis due to missing age data.
** Multivariate model did not converge due to low numbers.
"Ref." refers to the fact that the > 2 km group is the reference category for comparisons.

exposures or health outcomes. Certainly, the use of open-ended questions to inquire about animal health could have resulted in a lower reporting rate than would have occurred if the survey had inquired about specific problems in animal health or if there was greater access to veterinary diagnostic services. Only 14% of the surveyed households in this study reported the use of diagnostic veterinary care services for any of the reported health events. Future studies should include veterinary diagnostic assessment of animals.

This study reported on animals present in and around households. It is possible that surveys of larger populations of animals, such as can be found in commercial animal agriculture settings, would have greater power to detect problems with reproduction or mortality in the herd- such effects have been reported with exposure to other industrial activities.[18-20] Therefore, future studies of animals living near environmental hazards including natural gas extraction activities should include animals on large commercial farms as well.

Conclusions

Natural gas extraction activities involve a number of putative chemical exposures to both human and animal populations. This study reports the potential value and feasibility, as well as some of the challenges, of monitoring domestic animal health in order to gauge the potential human health implications related to modern-day unconventional shale gas extraction techniques. Owing to their lesser mobility and possibly greater susceptibility to environmental exposures relative to humans, domestic animal populations, in particular dogs, may serve as sentinels for health effects of emerging extractive technologies. Although we report an association between overall health conditions in dogs related to household proximity to natural gas wells, these findings should be considered preliminary and warrant further investigation by implementing larger and longitudinal surveys of human and animal health.

Acknowledgments

The authors would like to thank Fangyong Li, MPH for his assistance with data analysis.

Funding

This study was supported by grants from The Heinz Endowments; as well as The 11th Hour Project, a program of the Schmidt Family Foundation and the Claneil Foundation. None of these funders took part in the planning or conduct of the study including data analysis. Additional support was received from the Yale University School of Public Health Jan A.J. Stolwijk Fellowship fund.

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