

Estimates of Enteric Illness Attributable to Contact With Animals and Their Environments in the United States

Christa R. Hale,^{1,2} Elaine Scallan,³ Alicia B. Cronquist,² John Dunn,⁴ Kirk Smith,⁵ Trisha Robinson,⁵ Sarah Lathrop,⁶ Melissa Tobin-D'Angelo,^{7,a} and Paula Clogher⁸

¹Epidemic Intelligence Service Program, Centers for Disease Control and Prevention, Atlanta, Georgia; ²Colorado Department of Public Health and Environment, Denver; ³Colorado School of Public Health, Aurora; ⁴Tennessee Department of Health, Nashville; ⁵Minnesota Department of Health, St. Paul; ⁶University of New Mexico, Albuquerque; ⁷Georgia Department of Community Health, Atlanta; ⁸Connecticut Emerging Infections Program, New Haven

Background. Contact with animals and their environment is an important, and often preventable, route of transmission for enteric pathogens. This study estimated the annual burden of illness attributable to animal contact for 7 groups of pathogens: *Campylobacter* species, *Cryptosporidium* species, Shiga toxin–producing *Escherichia coli* (STEC) O157, STEC non-O157, *Listeria monocytogenes*, nontyphoidal *Salmonella* species, and *Yersinia enterocolitica*.

Methods. By using data from the US Foodborne Diseases Active Surveillance Network and other sources, we estimated the proportion of illnesses attributable to animal contact for each pathogen and applied those proportions to the estimated annual number of illnesses, hospitalizations, and deaths among US residents. We established credible intervals (CrIs) for each estimate.

Results. We estimated that 14% of all illnesses caused by these 7 groups of pathogens were attributable to animal contact. This estimate translates to 445 213 (90% CrI, 234 197–774 839) illnesses annually for the 7 groups combined. *Campylobacter* species caused an estimated 187 481 illnesses annually (90% CrI, 66 259–372 359), followed by nontyphoidal *Salmonella* species (127 155; 90% CrI, 66 502–219 886) and *Cryptosporidium* species (113 344; 90% CrI, 22 570–299 243). Of an estimated 4933 hospitalizations (90% CrI, 2704–7914), the majority were attributable to nontyphoidal *Salmonella* (48%), *Campylobacter* (38%), and *Cryptosporidium* (8%) species. Nontyphoidal *Salmonella* (62%), *Campylobacter* (22%), and *Cryptosporidium* (9%) were also responsible for the majority of the estimated 76 deaths (90% CrI, 5–211).

Conclusions. Animal contact is an important transmission route for multiple major enteric pathogens. Continued efforts are needed to prevent pathogen transmission from animals to humans, including increasing awareness and encouraging hand hygiene.

Zoonotic diseases are transmitted from animals to humans through many pathways (eg, direct contact with animals, contaminated food or water, and contact with contaminated fomites) and encompass viral, bacterial, fungal, protozoal, and parasitic infections. Worldwide, an estimated 60% of infectious diseases

and 75% of emerging diseases are zoonotic [1]. Included in the zoonotic disease category are enteric pathogens such as *Cryptosporidium* species, nontyphoidal *Salmonella* species, and Shiga toxin–producing *Escherichia coli* (STEC) [2]. Although enteric zoonotic pathogens are commonly transmitted through food or water, recent outbreaks have highlighted direct or indirect contact with an animal reservoir (hereafter, animal contact) as another key route of transmission for these enteric pathogens, especially for young children and other populations at high risk [3]. Recently, there have been outbreaks caused by *Cryptosporidium* species, nontyphoidal *Salmonella* species, and STEC O157 associated with petting zoos, farm visits, and animal exhibits [4–8] and outbreaks of salmonellosis associated

^aPresent affiliation: Georgia Department of Public Health (previously known as the Georgia Department of Community Health).

Correspondence: Christa R. Hale, DVM MPH DACVPM, Centers for Disease Control and Prevention, 1600 Clifton Rd NE, MS E-92, Atlanta, GA 30333 (crhale@cdc.gov).

Clinical Infectious Diseases 2012;54(S5):S472–9

© The Author 2012. Published by Oxford University Press on behalf of the Infectious Diseases Society of America. All rights reserved. For Permissions, please e-mail: journals.permissions@oup.com.

DOI: 10.1093/cid/cis051

with live poultry (eg, chicks, chickens, ducklings, ducks, geese, and turkeys) [9–10], reptiles and amphibians (eg, turtles or African dwarf frogs) [11–14], commercially distributed rodents [15–16], and companion animals (eg, dogs and cats) [17].

In the United States, the incidence of laboratory-confirmed infections caused by several important enteric zoonoses is tracked by the Foodborne Diseases Active Surveillance Network (FoodNet). As a collaborative effort between the Centers for Disease Control and Prevention (CDC), participating state health departments, the US Department of Agriculture's Food Safety Inspection Service, and the Food and Drug Administration, FoodNet conducts active, population-based surveillance in 10 sites covering approximately 45 million persons, or 15% of the US population [18]. FoodNet only tracks the fraction of illnesses confirmed by laboratory testing; however, CDC has developed a statistical model to estimate the overall number of foodborne illnesses in the United States by adjusting for undercounts when ill persons do not seek medical care and submit a stool sample or when laboratories do not test for or identify the causative pathogen [19]. Because these pathogens might be transmitted by multiple routes, this model, as originally implemented, also estimated the proportion of illnesses attributable to eating contaminated food. Estimates of the number of illnesses attributable to contact with animals and their environment are needed to better understand the burden of disease associated with this route of transmission and to direct interventions to reduce illness.

METHODS

We estimated the annual number of illnesses, hospitalizations, and deaths caused by *Campylobacter* species, *Cryptosporidium* species, STEC O157, STEC non-O157, *Listeria monocytogenes*, nontyphoidal *Salmonella* species, and *Yersinia enterocolitica* attributable to animal contact transmission by using CDC's modeling approach to estimate the annual number of foodborne illnesses, hospitalizations, and deaths caused by these pathogens in the United States [19]. Data were mostly from 2000–2010, and all estimates were based on the US population in 2006 (299 million persons). Further details on specific data sources are given below.

Estimating Total Illnesses, Hospitalizations, and Deaths

CDC's methods for estimating the total number of illnesses from these 7 groups of pathogens are summarized here and described in detail elsewhere [19]. First, we obtained data regarding the number of laboratory-confirmed illnesses reported to FoodNet during 2005–2008. Data spanning these years were used because of changing trends in the incidence of laboratory-based cases over time. Because FoodNet conducts

active surveillance, we presumed that all laboratory-confirmed illnesses among persons residing within the surveillance area were reported. To estimate the annual number of laboratory-confirmed illnesses in the United States, the pathogen-specific incidence for the 10 FoodNet surveillance sites was applied to the 2006 US population estimate. Estimates of the number of laboratory-confirmed illnesses were then adjusted for underdiagnosis (ie, adjusted for the factors necessary for the ill person to receive a laboratory-confirmed diagnosis—obtainment of medical care, submission of a stool sample, laboratory testing practices, and test sensitivity) by using data from FoodNet surveys of the general population and clinical laboratories. The proportion of individuals who were hospitalized and the proportion who died were also determined from FoodNet surveillance and applied to the number of laboratory-confirmed illnesses after doubling to adjust for underdiagnosis. International travel-related illnesses were excluded; all other illnesses were presumed to be domestically acquired.

Proportion of Illness Caused by Animal Contact

We defined animal contact as direct contact with pets (eg, cats, dogs, or reptiles), domesticated or food-producing animals and livestock (eg, horses, goats, llamas, cattle, or chickens), or wild animals (eg, free-roaming elk) or as indirect contact with the animal's feces, bodily fluids, or environment (eg, contaminated litter boxes, water from turtle or frog tanks, or pets' cages or bedding). We included direct or indirect contact with a food-producing animal at the point of slaughter but excluded contact with meat after processing. For example, an illness in a worker exposed while slaughtering or processing chickens at a chicken processing plant would be attributed to animal contact transmission, whereas the route of transmission would be considered foodborne if a person was exposed while preparing chicken for a meal. Likewise, an illness caused by exposure to recreational or drinking water contaminated by animal feces would be considered to be waterborne, not caused by animal contact.

To estimate the pathogen-specific proportion of illnesses attributable to animal contact, we (1) reviewed the sources used to estimate the burden of foodborne illness [19] and (2) conducted a literature review by using US publications indexed at PubMed for 2000–2010 to identify any additional data sources. The span of the literature review was longer than that of the FoodNet data used because of the paucity of data and publications for several pathogens. Available data sources used to estimate the proportions attributable to animal contact included case-control studies of risk factors for sporadic disease (*Campylobacter*, *Cryptosporidium*, and nontyphoidal *Salmonella* species), outbreak summaries (STEC non-O157), both case-control studies and outbreak summaries (STEC O157),

Table 1. Data Sources Used to Estimate the Proportion of Illnesses Attributable to Animal Contact

Pathogen	Animal Contact		Data Sources
	%	Range ^a	
<i>Campylobacter</i> species	17	9–29	FoodNet case-control study of sporadic <i>Campylobacter</i> infection in the United States [20]
STEC O157	6	3–11	Two sources of data were available for this pathogen: outbreaks reported to CDC from 1982–2002 [21], which identified 4% of infections attributable to animal contact, and a FoodNet case-control study [22], which identified 8% of infections attributable to animal contact. We used the mean (6%) of these 2 proportions.
STEC non-O157	8	4–15	Outbreaks were reported to CDC from 1990–2008 [23].
<i>Listeria monocytogenes</i>	1	0.5–2	Value is presumed to be low. No animal contact outbreaks were reported to CDC during 2000–2011. A FoodNet case-control study of sporadic illness showed limited risk from animal contact transmission [24].
<i>Salmonella</i> species, nontyphoidal	11	6–20	A FoodNet case-control study of sporadic illness attributed 6% of illnesses to reptile exposure; investigation questions inquired about other animals and water, but no illnesses were attributed to these exposures. [11]. However, well-documented outbreaks of salmonellosis associated with live poultry [9–10] and other animals and animal products [15–17, 25] indicate that salmonellosis associated with animals other than reptiles do occur. Additionally, there has been an apparent increase in cases related to reptiles and amphibians. Therefore, we chose 6% as the lower limit of the PERT distribution, with a middle value of 11%.
<i>Yersinia enterocolitica</i>	1	0.5–2	Data are substantially limited; animal contact transmission has been reported, with approximately 1% of illnesses presumed to be caused by animal contact [26].
<i>Cryptosporidium</i> species	16	9–28	Values were determined on the basis of a FoodNet case-control study of sporadic disease [27].

Abbreviations: CDC, Centers for Disease Control and Prevention; FoodNet, Foodborne Diseases Active Surveillance Network; STEC, Shiga toxin-producing *Escherichia coli*.

^a 100% increased/decreased odds of % on an odds scale.

and previously published estimates (*L. monocytogenes* and *Y. enterocolitica*) (Table 1). We then applied these proportions to the total number of domestically acquired illnesses, hospitalizations, and deaths for each pathogen to estimate the number of illnesses, hospitalizations, and deaths attributable to animal contact.

Uncertainty Analysis

The estimates in this study were derived from multiple inputs, each with some measure of uncertainty. To account for this uncertainty, we used the same approach used by Scallan et al [19]; that is, we used probability distributions rather than point estimates to describe the model inputs. For our estimates of the proportion of illnesses attributable to animal contact, we generated generic upper and lower error bounds that were based on a 100% increase or decrease on an odds scale and described these model inputs by using a PERT distribution, which describes minimum, maximum, and middle values. By use of these data, we iteratively generated sets of independent pathogen-specific adjustment factors and used

these to estimate illnesses, hospitalizations, and deaths attributable to animal contact transmission. After 100 000 iterations, we obtained empirical distributions of counts corresponding to Bayesian posterior distributions. We then used these posterior distributions to generate a point estimate and upper and lower 90% credible limits (CrIs) for the numbers of illnesses, hospitalizations, and deaths. Analysis was conducted by using SAS, version 9.2 (SAS Institute; Cary, NC).

RESULTS

Of the estimated annual 3.2 million (90% CrI, 1.9–5.2 million) domestically acquired illnesses caused by these 7 groups of enteric pathogens, 445 213 (90% CrI, 234 197–774 839) were estimated to be attributable to animal contact. This equates to 14% of domestically acquired illnesses overall. The pathogen-specific proportions attributable to animal contact (ie, the proportions of each pathogen that were transmitted by animal contact) were as follows: *Campylobacter* species, 17%;

Cryptosporidium species, 16%; nontyphoidal *Salmonella* species, 11%; STEC non-O157, 8%; STEC O157, 6%; *L. monocytogenes*, <1%; and *Y. enterocolitica*, <1% (Table 1).

Of these 7 groups of pathogens, we estimated that *Campylobacter* species caused 42% of the total number of illnesses attributable to animal contact, with 187 481 illnesses annually (90% CrI, 66 259–372 359), followed by nontyphoidal *Salmonella* species (127 155; 90% CrI, 66 502–219 886) and *Cryptosporidium* species (113 344; 90% CrI, 22 570–299 243). STEC non-O157 and O157 caused an estimated 10 097 and 5960 illnesses, respectively (Table 2). Only a small proportion of *L. monocytogenes* and *Y. enterocolitica* illnesses were attributed to animal contact.

Illnesses attributable to animal contact resulted in an estimated 4933 hospitalizations (90% CrI, 2704–7914) and 76 deaths (90% CrI, 5–211). Nontyphoidal *Salmonella* species (2392; 90% CrI, 935–4956) were the leading cause of hospitalization, followed by *Campylobacter* species (1877; 90% CrI, 839–3599) and *Cryptosporidium* species (412; 90% CrI, 108–1039). Pathogens from these 3 genera were also responsible for the majority of estimated deaths, with nontyphoidal *Salmonella* species causing 47 deaths (90% CrI, 0–131), *Campylobacter* species causing 17 (90% CrI, 0–76), and *Cryptosporidium* species causing 7 (90% CrI, 0–37).

DISCUSSION

An important fraction of illness caused by the 7 groups of enteric pathogens in this study is attributable to animal contact; after adjustment for underdiagnosis, we estimated that organisms from these 7 groups caused almost 450 000 animal contact illnesses annually. The leading causes of illness, hospitalization, and death were *Campylobacter*, nontyphoidal *Salmonella*, and *Cryptosporidium* species. Though STEC infections caused fewer illnesses attributable to animal contact, STEC O157 and, to a lesser extent, STEC non-O157 infections can cause severe illness (including bloody diarrhea and hemolytic uremic syndrome [28]), highlighting the need to prevent the transmission of these infections by all potential modes of transmission, including animal contact.

Estimating the proportion of illness attributable to animal contact was challenging. We used data from outbreak summaries, case-control studies, and the published literature, but the majority of pathogens only had 1 data source available. Moreover, the best data source for estimating the proportion of illnesses attributable to animal contact is unknown. For example, we used data from a FoodNet case-control study to estimate the proportion of *Campylobacter* illnesses attributable to animal contact (17%); however, 80% of *Campylobacter* illnesses were previously estimated to be foodborne [19], leaving only 3% that could be attributed to waterborne

transmission, which is another known transmission route [29–30]. Data from outbreaks were available for STEC O157 and non-O157; however, the extent to which outbreaks represent the burden caused by sporadic cases of disease is unknown. For STEC O157, an estimated proportion attributable to animal contact of 8% was derived by using outbreak data, whereas an estimate of 4% was derived by using data from the sporadic case-control study. In another example, because of recent animal contact outbreaks of salmonellosis associated with a number of different animals, we assumed that the 6% of illnesses attributed to reptile exposure in a sporadic case-control survey was the minimum proportion due to animal contact (with a mean of 11%), although 94% of nontyphoidal *Salmonella* infections were previously attributed to foodborne transmission [19].

Although data were not available to partition illnesses by animal type for our estimates, previous outbreak reports and research articles indicate that certain animals are likely to be associated with the transmission of enteric pathogens via animal contact. For example, contact with livestock is a key exposure method for certain pathogens examined in this study. As such, exposures routinely occur among farmers, veterinarians, and others in occupations involving frequent livestock contact. A recent review of zoonotic health concerns in farming communities emphasized that more education was needed among individuals working with livestock and recommended increased collaboration between health care professionals and veterinary specialists working in these settings to prevent the transmission of pathogens by animal contact [31]. Livestock might shed enteric pathogens intermittently, making it challenging to control pathogen transmission. Methods to control fecal shedding among livestock (eg, using vaccinations, probiotics, or bacteriophage feed additives) are under investigation [32]. Thus far, the efficacy of these methods has not been proven, and many studies focus on their benefits to the animals and their productivity, rather than on the benefits to public health.

Live poultry are an important reservoir for nontyphoidal *Salmonella* species, and purchasing baby chicks and ducklings in the spring as pets for young children has been identified as a source of infection among this age group [10]. This exposure route might become even more important as contact with pullets and hens becomes more common because of the increasing popularity of keeping a small backyard flock of chickens. This so-called urban farming frequently takes place in both urban and suburban areas, and its increase has the potential for increasing animal contact transmission from livestock in urban and suburban settings where transmission of enteric pathogens from livestock animals was previously not a concern outside of exhibit settings. Internet sites (eg, CDC's Keeping Live Poultry [<http://www.cdc.gov/features/>]

Table 2. Estimated Annual Number of Domestically Acquired Illnesses, Hospitalizations, and Deaths, Total and Attributable to Animal Contact Transmission, for 7 Groups of Enteric Pathogens, United States

Pathogen	% Of Domestically Acquired Illnesses Attributable to Animal Contact	Annual No. of Domestically Acquired Illnesses		Annual No. of Domestically Acquired Illnesses That Resulted in Hospitalization		Annual No. of Domestically Acquired Illnesses That Resulted in Death	
		Total ^a	Attributable to Animal Contact	Total ^a	Attributable to Animal Contact	Total ^a	Attributable to Animal Contact
		Mean (90% CrI)	Mean (90% CrI)	Mean (90% CrI)	Mean (90% CrI)	Mean (90% CrI)	Mean (90% CrI)
Bacterial							
<i>Campylobacter</i> species	17	1 058 387 (423 255–2 019 498)	187 481 (66 259–372 359)	10 600 (5405–19 091)	1877 (839–3599)	95 (0–417)	17 (0–76)
STEC O157	6	93 094 (26 046–219 676)	5960 (1518–14 606)	3152 (813–6801)	202 (47–448)	30 (0–167)	2 (0–11)
STEC non-O157	8	138 063 (14 080–350 891)	10 097 (1005–27 073)	332 (0–1188)	28 (0–104)	0 (0–0)	0 (0–0)
<i>Listeria monocytogenes</i>	1	1607 (563–3193)	17 (6–36)	1470 (526–3048)	16 (5–34)	257 (0–740)	3 (0–8)
<i>Salmonella</i> species, nontyphoidal	11	1 095 079 (687 126–1 790 225)	127 155 (66 502–219 886)	20 607 (9107–39.952)	2392 (935–4956)	403 (0–1077)	47 (0–131)
<i>Yersinia enterocolitica</i>	1	108 490 (33 797–190 605)	1159 (334–2292)	593 (0–1298)	6 (0–15)	32 (0–192)	0 (0–2)
Parasitic							
<i>Cryptosporidium</i> species	16	678 828 (147 796–1 940 626)	113 344 (22 570–331 635)	2472 (705–5949)	412 (108–1039)	42 (0–219)	7 (0–37)
Total		3 173 548 (1 922 355–5 167 038)	445 213 (234 197–774 839)	39 225 (23 516–58 156)	4933 (2704–7914)	860 (203–1832)	76 (5–211)

Abbreviations: CrI, credible interval; STEC, Shiga toxin-producing *Escherichia coli*.

^a Estimates of total annual number of domestically acquired illnesses, hospitalizations, and deaths [19].

salmonellapoultry] and Healthy Pets, Healthy People [<http://www.cdc.gov/healthypets/>]) can educate owners and others about the risks associated with contact with livestock and pets. Public health authorities are also attempting to reduce illnesses by issuing press releases in the spring to warn parents about the risks associated with baby chick and duckling purchases.

STEC O157, nontyphoidal *Salmonella*, *Cryptosporidium*, and *Campylobacter* infections have been commonly linked to animal exposures in public settings, including visits to petting zoos, fairs, pet stores, agricultural feed stores, and educational exhibits. The number of reported outbreaks has increased in recent years, with a wide variety of animals implicated, including baby chicks and ducklings, goats, and calves [3]. Efforts to prevent disease transmission in these settings have included the publication of the *Compendium of Measures to Prevent Disease Associated With Animals in Public Settings* [8]. Produced by the National Association of State Public Health Veterinarians, this report highlights zoonotic disease transmission where animals are displayed in public settings and provides guidance to public health officials, animal exhibitors, health care professionals, and event attendees regarding minimizing risks. Specifically, the report emphasizes the importance of such control measures as ensuring the availability of well-stocked hand-washing stations, prohibiting food consumption in animal exhibit areas, providing visitors with information about transmission risk and prevention, and proper care and management of exhibited animals.

Contact with domestic pets (eg, cats and dogs) also presents an opportunity for infection, especially when the pets are experiencing diarrhea, as pets have been linked to cases of nontyphoidal *Salmonella* and *Campylobacter* infection [20, 33]. Dogs and cats also serve as a transmission source for cryptosporidiosis, although such transmission is probably more of a concern among immunocompromised persons [34]. Human salmonellosis also has been associated with the handling of dry dog and cat food and pet treats [25, 35]. Pet owners should be aware of these risks and encouraged to follow proper hand-washing and storage procedures for these products. Pet food should not be stored near human foodstuffs, and care should be taken to prevent young children, who might ingest such products, from having contact with pet food [36]. Owners who feed their domestic pets a raw food diet might be at an even higher risk if the raw pet food is contaminated with bacteria. They could acquire salmonellosis from direct exposure to the contaminated raw food or from contact with the pet because pets eating contaminated raw diets might shed more bacteria in their feces [37].

Reptiles and amphibians are an important source of nontyphoidal *Salmonella* illness [11, 13–14]. Like domestic pet foods, reptile foods such as frozen rodents have also been implicated

as a source of multistate outbreaks of *Salmonella* infection [16]. Therefore, educating owners on hygiene and sanitation related to the care of their reptiles is an important prevention tool. Information on best practices is available in recent literature [13–14] and Internet sites (eg, CDC's Healthy Pets, Healthy People site [<http://www.cdc.gov/healthypets/>]). Recommendations include, but are not limited to, diligent performance of hand washing after handling the pet, its cage, food and food bowls, feces, or anything in the areas where the animal lives or roams; refraining from cleaning reptile or amphibian items (eg, tanks and food bowls) in areas where human food is prepared, served, or consumed; prohibiting children aged <5 years from handling live poultry, reptiles, or amphibians; and closely monitoring older children when they are handling these animals. In addition, legislative measures (eg, the federal ban on turtles with carapace lengths <4 inches) have been effective strategies for reducing illnesses attributable to animal contact [38].

In this study, we estimated the annual number of illnesses, hospitalizations, and deaths attributable to animal contact transmission, using the same modeling approach used by CDC to estimate the annual number of foodborne illnesses, hospitalizations, and deaths. This assumes that the disease severity and frequency with which cases are underdiagnosed are independent of the mode of transmission. In addition, we estimated the overall pathogen-specific proportion of illnesses attributable to animal contact; however, the proportion of illnesses attributable to animal contact may vary by age because of differences in exposures and behaviors. For example, children are more likely than adults to be exposed to pathogens at petting zoos and educational farms because of inadequate hand washing and a lack of understanding regarding the risk for disease [39]. Children also display more frequent hand-to-mouth activities (eg, thumb-sucking and eating with their hands), resulting in a greater potential for the ingestion of pathogens, especially if close supervision by adults is lacking [40]. There may also be differences in exposure between persons living in urban and rural areas. For example, a 2009 investigation of an STEC O157 outbreak among Denver stock show attendees determined that only children from urban and suburban areas were infected, even though children from all over Colorado attended (unpublished data, Colorado Department of Public Health and Environment). Whether this pattern was a result of differences in behavior (eg, the frequency of visits to interactive areas that housed the infected animals), knowledge (eg, awareness of the importance of hand washing after animal contact), or greater immunity among rural children that might result from more frequent contact with livestock is unknown.

In conclusion, the estimated annual burden of illness from the transmission of enteric pathogens by animal contact is

substantial, especially for illnesses resulting from infection with *Campylobacter*, *Cryptosporidium*, and nontyphoidal *Salmonella* species. The estimates of illnesses, hospitalizations, and deaths attributed to animal contact transmission emphasize the need to implement interventions and educational programs (eg, those recommended in the *Compendium of Measures to Prevent Disease Associated With Animals in Public Settings* [8]). Illnesses can be prevented by educating the public and occupational workers about potential risks and by ensuring that interventions (eg, hand-washing stations) are in public places where persons come into contact with animals. Illnesses can also be reduced by educating pet owners about the risks associated with animal contact, through such outlets as CDC's Healthy Pets, Healthy People Internet site (<http://www.cdc.gov/healthypets>) and through consistent reinforcement of these messages by veterinarians, pet retailers, and agricultural feed stores.

Notes

Acknowledgments. We thank Barbara Mahon, MD, MPH (Enteric Diseases Epidemiology Branch, CDC), Casey Barton Behravesh, DVM, DrPH (Outbreak Response and Prevention Branch, CDC), and Robert M. Hoekstra (Division of Foodborne, Waterborne, and Environmental Diseases, CDC), for their important feedback on the manuscript; and Joan Brunkard, PhD, Elizabeth Ailes, PhD, Sarah Collier, and Michael Beach, PhD (Waterborne Disease Prevention Branch, CDC), for vital assistance in estimating proportions for the parasitic pathogens included in this study.

Disclaimer. The contents of this work are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention.

Supplement sponsorship. This article was published as part of a supplement entitled "Studies From the Foodborne Diseases Active Surveillance Network," sponsored by the Division of Foodborne, Waterborne, and Environmental Diseases of the National Center for Emerging and Zoonotic Infectious Diseases from the Centers for Disease Control and Prevention, and the Association of Public Health Laboratories.

Potential conflicts of interest. All authors: No reported conflicts.

All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

References

- Taylor LH, Latham SM, Woolhouse ME. Risk factors for human disease emergence. *Phil Trans R Soc Lond* **2001**; 356:983–9.
- Tauxe RV. Emerging foodborne diseases: an evolving public health challenge. *Emerg Infect Dis* **1997**; 3:425–34.
- Steinmuller N, Demma L, Bender JB, Eidson M, Angulo FJ. Outbreaks of enteric disease associated with animal contact: not just a foodborne problem anymore. *Clin Infect Dis* **2006**; 43:1596–602.
- Goode B, O'Reilly C, Dunn J, et al. Outbreak of *Escherichia coli* O157:H7 after petting zoo visits, North Carolina State Fair, October–November 2004. *Arch Pediatr Adolesc Med* **2009**; 163:42–8.
- Centers for Disease Control and Prevention. Outbreak of Shiga-toxin producing *Escherichia coli* O157 infection associated with a day camp petting zoo—Pinellas County, Florida, May–June 2007. *MMWR Morb Mortal Wkly Rep* **2009**; 58:426–8.
- Smith KE, Stenzel SA, Bender JB, et al. Outbreaks of enteric infections caused by multiple pathogens associated with calves at a farm day camp. *Pediatr Infect Dis J* **2004**; 23:1098–104.
- Kiang KM, Scheftel JM, Leano FT, et al. Recurrent outbreaks of cryptosporidiosis associated with calves among students at an educational farm programme, Minnesota, 2003. *Epidemiol Infect* **2006**; 134:878–86.
- Centers for Disease Control and Prevention. Compendium of measures to prevent disease associated with animals in public settings, 2011: National Association of State Public Health Veterinarians, Inc. *MMWR Recomm Rep* **2011**; 60:1–24.
- Centers for Disease Control and Prevention. Multistate outbreak of *Salmonella* infections associated with live poultry—United States, 2007. *MMWR Morb Mortal Wkly Rep* **2009**; 58:25–9.
- Centers for Disease Control and Prevention. Three outbreaks of salmonellosis associated with baby poultry from three hatcheries—United States, 2006. *MMWR Morb Mortal Wkly Rep* **2007**; 56:273–6.
- Mermin J, Hutwagner L, Vugia D, et al. Reptiles, amphibians, and human *Salmonella* infection: a population-based, case-control study. *Clin Infect Dis* **2004**; 38(Suppl 3):S253–61.
- Harris JR, Bergmire-Sweat D, Schlegel JH, et al. Multistate outbreak of *Salmonella* infections associated with small turtle exposure, 2007–2008. *Pediatrics* **2009**; 124:1388–94.
- Centers for Disease Control and Prevention. Multistate outbreak of human *Salmonella* Typhimurium infections associate with pet turtle exposure—United States, 2008. *MMWR Morb Mortal Wkly Rep* **2010**; 59:191–6.
- Centers for Disease Control and Prevention. Notes from the field: update on human *Salmonella* Typhimurium infections associated with aquatic frogs—United States, 2009–2011. *MMWR Morb Mortal Wkly Rep* **2011**; 60:628.
- Swanson SJ, Snider C, Braden CR, et al. Multidrug-resistant *Salmonella enterica* serotype Typhimurium associated with pet rodents. *N Engl J Med* **2007**; 356:21–8.
- Fuller CC, Jawahir SL, Leano FT, et al. A multi-state *Salmonella typhimurium* outbreak associated with frozen vacuum-packed rodents used to feed snakes. *Zoonoses Public Health* **2008**; 55:481–7.
- Wright JG, Tengelsen LA, Smith KE, et al. Multidrug-resistant *Salmonella Typhimurium* in four animal facilities. *Emerg Infect Dis* **2005**; 11:1235–41.
- Scallan E. Activities, achievements, and lessons learned during the first 10 years of the Foodborne Diseases Active Surveillance Network: 1996–2005. *Clin Infect Dis* **2007**; 44:718–25.
- Scallan E, Hoekstra RM, Angulo FJ, et al. Foodborne illness acquired in the United States—major pathogens. *Emerg Infect Dis* **2011**; 17:7–15.
- Friedman CR, Hoekstra RM, Samuel M, et al. Risk factors for sporadic *Campylobacter* infection in the United States: a case-control study in FoodNet sites. *Clin Infect Dis* **2004**; 38(Suppl 3):S285–96.
- Rangel JM, Sparling PH, Crowe C, et al. Epidemiology of *Escherichia coli* O157:H7 outbreaks, United States, 1982–2002. *Emerg Infect Dis* **2005**; 11:603–9.
- Voetsch AC, Kennedy MH, Keene WE, et al. Risk factors for sporadic Shiga toxin-producing *Escherichia coli* O157 infections in FoodNet sites, 1999–2000. *Epidemiol Infect* **2007**; 135:993–1000.
- Centers for Disease Control and Prevention. Non-O157 Shiga toxin-producing *E. coli* (STEC) outbreaks, United States. Memorandum to the record 2010. Available at: http://blogs.cdc.gov/publichealthmatters/files/2010/05/nono157stec_obs_052110.pdf. Accessed 10 January 2011.
- Varma JK, Samuel MC, Marcus R, et al. *Listeria monocytogenes* infection from foods prepared in a commercial establishment: a case-control study of potential sources of sporadic illness in the United States. *Clin Infect Dis* **2007**; 44:521–8.
- Centers for Disease Control and Prevention. Multistate outbreak of human *Salmonella* infections caused by contaminated dry dog

- food—United States, 2006–2007. *MMWR Morb Mortal Wkly Rep* **2008**; 57:521–4.
26. Schmitz AM, Tauxe RV. *Yersinia enterocolitica* infections. In: Evans AS, Brachman PS, eds. *Bacterial infections of humans: epidemiology and control*. 4th ed. New York, NY: Springer, **2009**: 939–57.
 27. Roy SL, DeLong SM, Stenzel SA, et al. Risk factors for sporadic cryptosporidiosis among immunocompetent persons in the United States from 1999 to 2001. *J Clin Microbiol* **2004**; 42:2944–51.
 28. Griffin PM, Mead PS, Sivapalasingam S. *Escherichia coli* O157:H7 and other enterohemorrhagic *E. coli*. In: Blaser M, Smith P, Greenberg H, et al. eds. *Infections of the gastrointestinal tract*. Philadelphia: Lippincott Williams & Wilkins, **2002**: 627–42.
 29. Centers for Disease Control and Prevention. Surveillance for waterborne-disease outbreaks associated with recreational water—United States, 2001–2002. *MMWR Surveill Summ* **2004**; 53:1–22.
 30. Centers for Disease Control and Prevention. Surveillance for waterborne-disease outbreaks associated with drinking water—United States, 2001–2002. *MMWR Surveill Summ* **2004**; 53:23–45.
 31. LeJeune J, Kersting A. Zoonoses: an occupational hazard for livestock workers and a public health concern for rural communities. *J Agric Saf Health* **2010**; 16:161–79.
 32. Sargeant JM, Amezcua MR, Rajic A, Waddell L. Pre-harvest interventions to reduce the shedding of *E. coli* O157 in the faeces of weaned domestic ruminants: a systematic review. *Zoonoses Public Health* **2007**; 56:260–77.
 33. Younus M, Wilkins MJ, Davies HD, et al. The role of exposures to animals and other risk factors in sporadic, non-typhoidal *Salmonella* infections in Michigan children. *Zoonoses Public Health* **2010**; 57:170–6.
 34. Bowman D, Lucio-Forster A. Cryptosporidiosis and giardiasis in dogs and cats: veterinary and public health importance. *Exp Parasitol* **2010**; 124:121–7.
 35. Centers for Disease Control and Prevention. Human salmonellosis associated with animal-derived pet treats—United States and Canada, 2005. *MMWR Morb Mortal Wkly Rep* **2006**; 55:702–5.
 36. Behravesh CB, Ferraro A, Deasy M, et al. Human *Salmonella* infections linked to contaminated dry dog food and cat food, 2006–2008. *Pediatrics* **2010**; 126:477–83.
 37. Finley R, Ribble C, Aramini J, et al. The risk of *Salmonellae* shedding by dogs fed *Salmonella*-contaminated raw food diets. *Can Vet J* **2007**; 48:69–75.
 38. Cohen ML, Potter M, Pollard R, Feldman RA. Turtle-associated salmonellosis in the United States: effect of public health action, 1970 to 1976. *JAMA* **1980**; 243:1247–9.
 39. McMillian M, Dunn JR, Keen JE, et al. Risk behaviors for disease transmission among petting zoo attendees. *J Am Vet Med Assoc* **2007**; 231:1036–8.
 40. Xue J, Zartarian V, Moya J, et al. A meta-analysis of children's hand-to-mouth frequency data for estimating nondietary ingestion exposure. *Risk Anal* **2007**; 27:411–20.