

## Review

# Role of rodents in transmission of *Salmonella* and *Campylobacter*

Bastiaan G Meerburg<sup>1\*</sup> and Aize Kijlstra<sup>1,2</sup>

<sup>1</sup>Animal Sciences Group, Wageningen University and Research Centre, Lelystad, The Netherlands

<sup>2</sup>Department of Ophthalmology, Faculty of Medicine, University of Maastricht, Maastricht, The Netherlands

**Abstract:** *Salmonella* and *Campylobacter* are generally regarded as the most important food-borne pathogens in the world. Reduction or elimination of these pathogens in the first part of the food chain (on the farm) is important to prevent disease among consumers of animal products. In organic farming, elimination becomes more difficult, as food animals are allowed outdoors and have easy access to potential sources of hazardous pathogens. Whilst rodents are often associated by organic farmers with infrastructural damage and eating or spoiling of stored feed and products, their zoonotic risks are frequently underestimated. They can amplify the number of pathogens in the environment and transfer them to food animals. Thus organic farmers should be aware of the need for rodent control from a food safety perspective. Preferably, rodent control should form an integral part of a total package of hygiene measures to prevent transfer of food-borne pathogens. These should also include e.g. control of wild birds and flies and obligatory disinfection of boots/clothes and equipment for farm workers and visitors.

© 2007 Society of Chemical Industry

**Keywords:** rodents; *Campylobacter*; *Salmonella*; transmission; contamination; rodent control

## INTRODUCTION

Prevention of food hazards in the first part of the food chain is essential to prevent illness of consumers. Control or better elimination of zoonotic pathogens such as *Salmonella* and *Campylobacter* is a priority in today's farming, as human campylobacteriosis and salmonellosis are important causes of gastroenteritis in the industrialised world.<sup>1</sup>

In organic animal production systems, elimination is more difficult, as the animals are allowed outdoors and have easy access to potential sources of hazardous bacteria and/or parasites. Rodents that are present on organic farms can form one of these sources. Organic farms offer an ideal environment for them owing to the application of roughage and straw. Moreover, organic farmers are often less willing to use rodenticides, since they perceive rodent presence as an integral part of the agro-ecosystem.<sup>2</sup>

Whilst rodents are often associated with infrastructural damage and eating or spoiling of stored feed and products, their zoonotic risks are frequently underestimated. Wild rodents can be reservoirs and vectors of a number of agents that cause disease in food animals and humans (e.g. *Leptospira* spp., *Salmonella* spp., *Campylobacter* spp., *Trichinella* spp., *Toxoplasma* spp.).<sup>3,4</sup> In this review we focus on the role of rodents in transmission of *Salmonella* and *Campylobacter* to food animals on farms, particularly when organic production systems are adopted.

## CAMPYLOBACTER

*Campylobacter* are mainly spiral-shaped, S-shaped or curved, rod-shaped bacteria. There are 16 species and six subspecies assigned to the genus *Campylobacter*, of which the most frequently reported in human disease are *C. jejuni* (subspecies *jejuni*), *C. coli* and *C. fetus*. Other species such as *C. laridis* and *C. upsaliensis* are also regarded as primary pathogens but are reported far less frequently in cases of human disease. *Campylobacter* are generally regarded as the most common bacterial cause of gastroenteritis worldwide.<sup>5</sup> In both developing and developed countries they cause more cases of diarrhoea than e.g. food-borne *Salmonella*. Although *Campylobacter* do not show any seasonal variation in developing countries, they do in the developed world, where they peak in summer.<sup>6</sup> *Campylobacter* can survive in the environment for several weeks at temperatures around 4 °C but can also be present in surface water at higher temperatures.<sup>7</sup> Although it is unknown why, in almost all developed countries the incidence of human *Campylobacter* infections has increased steadily over recent years, apart from in 2002 when for the first time a 5% decrease was reported in the European Union (EU).<sup>8</sup> In the Netherlands the rise in *Campylobacter* infections until 2002 could be partially explained by an increase in the level of Dutch poultry meat consumption, which rose from 17.3 kg per head in 1990 to 22.4 kg per head in 2002.<sup>9</sup> It is unlikely that consumption of

\* Correspondence to: Bastiaan G Meerburg, Animal Sciences Group, Wageningen University and Research Centre, PO Box 65, NL-8200 AB Lelystad, The Netherlands

E-mail: [bgmeerburg@gmail.com](mailto:bgmeerburg@gmail.com)

(Received 20 December 2005; revised version received 30 November 2006; accepted 30 November 2006)

Published online 19 September 2007; DOI: 10.1002/jsfa.3004

© 2007 Society of Chemical Industry. J Sci Food Agric 0022–5142/2007/\$30.00

organic poultry meat will have affected these figures, since the market share during this period was less than 1%. While, in the developed world, incidence peaks in infants and young adults, in developing countries, *Campylobacter* infections in children under the age of 2 years are especially frequent, sometimes resulting in death.<sup>10</sup> A total of 149 287 cases of human campylobacteriosis were reported in the EU and Norway in 2002<sup>8</sup> (39 cases per 100 000 inhabitants). Individuals acquire *Campylobacter* infections mainly through contaminated poultry (chicken and turkey) or via consumption of untreated surface water or unpasteurised milk. Infection can also be acquired by direct contact with infected animals, mainly in particular situations such as that of workers in poultry processing plants.<sup>11</sup>

When ingested, *C. jejuni* moves to the ileum and adheres to the surface of epithelial cells of the mucus membrane. Then a toxin is released which leads to the over-secretion of electrolytes into the gut. This results in diarrhoea, which may be bloody, accompanied by headache, fever, vomiting and abdominal pain. These symptoms last for 2–7 days. *Campylobacter fetus* is even more invasive. Infection can lead to spread of the organism from the gut, leading to systemic infection. This can result in septicaemia, pneumonia, meningitis and, in pregnant females, infection of the foetus, which can sometimes lead to spontaneous abortion. Moreover, *Campylobacter* are also linked to Guillain Barré syndrome, a rare but serious paralytic autoimmune disease. Serological evidence of *C. jejuni* infection occurs in about 30% of patients with Guillain Barré syndrome.<sup>12</sup>

*Campylobacter* are frequently encountered in poultry flocks.<sup>13</sup> They spread easily among live birds<sup>14</sup> through faeces, shared water sources<sup>15</sup> or in the slaughterhouse. In 2002, prevalence in broiler flocks in the Netherlands was 27% and in Denmark 42%.<sup>8</sup> Mostly, *C. jejuni* was isolated, which does not cause disease in chickens but can result in food-borne illness. In poultry meat, *Campylobacter* prevalence was around 30% in the Netherlands in 2002.<sup>8</sup> In France a contamination rate of 88.7% was shown on poultry meat at retail level.<sup>8</sup> In pig herds, high infection rates of 50–80% can also be encountered,<sup>8</sup> but low contamination rates (2.1–4.7%) were found in pig meat. In order to reduce the number of cases of human campylobacteriosis, some countries (Denmark, Sweden, the Netherlands and Norway) have started monitoring programmes on *Campylobacter*. In these monitoring schemes, faecal samples or cloacal swabs are taken at the farm, at the slaughterhouse or at both locations. In 2005, all faecal samples from organic broiler farms ( $n = 9$ ) in the Netherlands were positive for *C. jejuni*.<sup>16</sup> High antibiotic resistance was observed against amoxicilline, doxycycline (tetracycline), metronidazole and the quinolones nalidixine and ciprofloxacin. However, no difference in antibiotic resistance was observed between *C. jejuni* samples obtained from organic and regular broilers. Of interest is the observation that *C.*

*jejuni* is not often found in faeces from organic pig herds, whereas *C. coli* was found on 24 of 31 farms tested (77%).<sup>16</sup>

## SALMONELLA

*Salmonella* are rod-shaped, motile Gram-negative bacteria of the family Enterobacteriaceae. Non-motile exceptions are *S. gallinarum* and *S. pullorum*. More than 2300 serotypes have been described,<sup>17</sup> most of which are non-host-specific.<sup>1</sup> The serotypes *S. typhi* and *S. paratyphi* are adapted to humans. Individuals usually obtain *Salmonella* by eating contaminated beef, pork, poultry or eggs or by eating vegetables contaminated with animal faeces. Infection with *Salmonella* often causes gastroenteritis with symptoms similar to those seen in *Campylobacter* infections. Young children, older people and immunosuppressed persons are more susceptible to acquiring severe symptoms after infection.<sup>18</sup> The onset of a *Salmonella* infection starts with attachment and internalisation of *Salmonella* to the cells of the small intestine. The invasion of enterocytes results in the extrusion of infected epithelial cells into the intestinal lumen with consequent villus blunting and loss of absorptive surfaces. Furthermore, *Salmonella* elicit a polymorphonuclear leucocyte influx into infected mucosa and induce watery diarrhoea.<sup>19</sup> If the bacteria are then passed out of the mucosa cells into the underlying tissues, the more severe type of infection can result as bacteria reach the blood and are distributed widely.

In the EU and Norway in 2002 a total of 145 231 cases of human salmonellosis were reported<sup>8</sup> (38 cases per 100 000 inhabitants). *Salmonella enteritidis* was found to be dominant in human salmonellosis, causing 67% of all notified cases in the EU and Norway.<sup>8</sup> *Salmonella typhimurium* caused 17% of all cases. Other important types were *S. infantis*, *S. virchow* and *S. hadar*.<sup>8</sup> Besides health problems, economic losses due to human infection with *Salmonella* and *Campylobacter* are also considerable. In a study on the socio-economic impact of infectious intestinal disease in England, average costs per case were £606 for *Salmonella* and £315 for *Campylobacter*.<sup>20</sup>

Results from monitoring programmes at slaughterhouses suggest that 20% of broiler chickens in the USA are contaminated with harmful *Salmonella* strains.<sup>21</sup> A 27% incidence of *Salmonella* was found in faeces from organic pig farms, similar to that found on conventional farms monitored during the same period (2003–2005).<sup>16</sup> Of interest was the observation that farms that had just recently started organic pig production encountered *Salmonella* more frequently than farms that had a longer experience with organic production. A recent study could not detect *Salmonella* in faeces from organic broilers.<sup>16</sup>

*Salmonella* are very persistent. In a study on the survival of *S. enteritidis* in poultry units and poultry food it was found that the organisms could persist for at least 1 year in a trial house stocked with broilers.<sup>21</sup>

Moreover, it was shown that *S. enteritidis* could survive at least 26 months in artificially contaminated poultry food.<sup>22</sup> To date, no reports have been published addressing possible differences in *Salmonella* contamination rates between organic and conventional feeds.

### INFECTION OF RODENTS WITH *SALMONELLA* AND *CAMPYLOBACTER*

Wild birds and mammals are generally regarded as the main reservoir for *Salmonella* and *Campylobacter* in the environment. These warm-blooded animals can carry both bacteria in their intestinal tracts, mostly without showing any clinical symptoms of disease.<sup>23</sup> Infected animals can then cause transmission of pathogens from the farm environment to food animals, as is often mentioned in studies on *Campylobacter* and *Salmonella* epidemiology.<sup>11,24–26</sup> Laboratory studies prove that rodents can in principle be infected with *Salmonella* and *Campylobacter*.

Several studies have been undertaken to estimate the prevalence of *Salmonella* and *Campylobacter* in wild rodents (Table 1). In some of these studies the estimation was based on the analysis of faecal pellets. However, as faecal pellets can become infected by deposition in a contaminated environment, the reliability of these studies is probably lower than that of studies based on the analysis of swabs or intestinal contents.

The degree of contamination and transmission risks may differ substantially between different habitats, so a distinction must be made between rodents living in nature (e.g. woodlands, grasslands), those living in urban environments and those living on farms (Table 1). Contamination and transmission may be different on organic farms as compared with conventional farms in view of the fact that the faeces of held animals is shed in the outdoor run. The condition of the outdoor run (paved with concrete or consisting of a soil base) will determine whether the faeces can be removed or not. If infected faeces remains in the outdoor run for prolonged periods of time, this may result in carryover of pathogenic organisms to rodents. As yet, no studies have been carried out to compare the degrees of infection of rodents caught on conventional and organic farms.

Studies on wild rodents in woodlands have shown that only limited numbers are infected with *Campylobacter*. During a study in Norway, *Campylobacter* were not detected in any of the 44 bank voles and wood mice investigated.<sup>27</sup> Faecal pellets voided by 13 bank voles (*Clethrionomys glareolus*), 17 field voles (*Microtus agrestis*) and 12 wood mice (*Apodemus sylvaticus*) trapped in woodlands and grasslands were investigated for *Campylobacter* presence.<sup>28</sup> The authors were able to detect *Campylobacter* in ten out of 13 bank voles tested; the other bank voles were not infected. Isolates from the bank voles resembled a type of *C. fetus* associated with infectious infertility in cattle. In a study on small

rodents (in which water voles (*Microtus richardsoni*), longtail voles (*Microtus longicaudus*), Western jumping mice (*Zapus princeps*) and deer mice (*Peromyscus maniculata*) were trapped) in alpine meadows in the USA, *C. coli* was recovered in less than 1% of the isolates.<sup>29</sup> However, the authors proved that, after artificial inoculation with *C. jejuni*, water voles (*M. richardsoni*) can shed the bacterium for several weeks and have the potential to act as a reservoir in high mountainous areas. Although these studies prove that rodents living in nature can be infected, the risk that they may cause food-borne infections is generally low. For wild rodents living on or nearby agricultural premises, this risk is expected to be higher, whereby, as mentioned above, the risk for rodents on organic animal farms may be higher than on conventional livestock farms.

The environment around livestock farms varies considerably but is usually rural. Wildlife, including rodents, is attracted to spilled feedstuffs, the availability of water and the presence of shelter. Since organic farmers often feed their animals in the outdoor run, the chance that rodents are attracted to these easily accessible sites is higher as compared with conventional systems. Generally, the species diversity around farm buildings corresponds to what can be encountered in the surrounding natural or semi-natural environment.<sup>30</sup>

Within poultry farms, infected rodents are often reported, although no distinction has been revealed between organic and conventional systems. Some authors<sup>31</sup> found a high prevalence (24%) of *S. enteritidis* in commensal rodents present on contaminated chicken layer farms. On the other hand, in the same study, *S. enteritidis* was not detected in mice on clean farms. This is logical, as another study revealed that the prevalence of *S. enteritidis* in mice from environmentally positive houses was nearly four times that in mice from environmentally negative houses.<sup>32</sup> In another study, mice (*Mus musculus*) captured in hen houses were assessed for the presence of *Salmonella* in their spleens<sup>33</sup> during two consecutive years. It was found that, during the first and second years, 25 and 18% of the spleens respectively were positive for *S. enteritidis*. Furthermore, passage of *S. enteritidis* in mice may also selectively amplify more egg-invasive and virulent strains.<sup>34</sup> The risks of rodents regarding *Salmonella* persistence in poultry houses have been evaluated in only a few studies: in broiler breeder and layer breeder houses in the UK<sup>13,26</sup> and in layer houses in the USA.<sup>31–33,35</sup> Persistence studies have not yet been reported for organic livestock farms. Chances of *Salmonella* persistence on farms are about two times higher when rodents are encountered by farmers.<sup>36</sup> Rodents can be long-term sources of *Salmonella* infection: it was found that 3-week-old chicks can acquire infection via mice artificially infected with *S. enteritidis* 2 and 5 months previously.<sup>26</sup> Artificially and naturally infected rodents (commensal *M. musculus*) were

Table 1. Studies on *Salmonella* and *Campylobacter* in rodents

Study	Trapping location	Focus	Species trapped	Number	% infected	Remarks
Rosef <i>et al.</i> <sup>27</sup>	Woodlands	Campylobacter	<i>C. glareolus</i> (bank vole) <i>A. sylvaticus</i> (wood mouse)	24	0	Swabs
Fernie and Park <sup>28</sup>	Woodlands and grasslands	Campylobacter	<i>C. glareolus</i> (bank vole)	22 13	0 77	Faecal pellets
Pacha <i>et al.</i> <sup>29</sup>	Alpine meadows	Campylobacter	<i>A. sylvaticus</i> (wood mouse) <i>M. agrestis</i> (field vole) <i>M. richardsoni</i> (water vole) <i>M. longicaudus</i> (longtail vole) <i>Z. princeps</i> (western jumping mouse) <i>P. maniculatus</i> (deer mouse) Species not specified	12 17 551 in total, not specified	0 0 <1	Faecal pellets
Hald <i>et al.</i> <sup>49</sup>	Cattle, pig and poultry farms	Campylobacter	Species not specified	44	17	
Henzler and Optiz <sup>31</sup>	Layer farms	Salmonella	<i>M. musculus</i> (house mouse) <i>R. norvegicus</i> (Norway rat) <i>P. maniculatus</i> (deer mouse)	713 2 1	24 (species unspecified)	
Garber <i>et al.</i> <sup>32</sup> Singh <i>et al.</i> <sup>50</sup>	Layer farms Urban	Salmonella Salmonella	<i>M. musculus</i> (house mouse) <i>Rattus</i> (species not specified) <i>M. musculus</i> (house mouse)	129 254 109	4 6 10	Swabs
Davies and Wray <sup>26</sup>	Broiler and layer breeder farms	Salmonella	Species not specified	83 dead mice, 152 droppings	47 (intestinal analysis)	
Guard-Petter <i>et al.</i> <sup>33</sup>	Layer houses	Salmonella	<i>M. musculus</i> (house mouse)	621 (year 1) 526 (year 2)	35 (liver analysis) 9 (droppings) 25 (year 1) 18 (year 2)	Spleens
Pocock <i>et al.</i> <sup>48</sup> Hilton <i>et al.</i> <sup>51</sup>	Mixed agricultural farms Urban	Salmonella Salmonella	<i>M. musculus</i> (house mouse) <i>R. norvegicus</i> (Norway rat)	341 50 carcasses 100 faecal swabs	0 10 (carcasses) 8 (swabs)	Faecal pellets
Davies and Breslin <sup>43</sup>	Free range layer farms	Salmonella	<i>M. musculus</i> (house mouse) <i>R. norvegicus</i> (Norway rat)	25 4	44 0	Faecal pellets
Shimi <i>et al.</i> <sup>52</sup> Jensen <i>et al.</i> <sup>1</sup>	Not specified Organic pig farms	Salmonella Salmonella	<i>M. musculus</i> (house mouse) <i>M. musculus</i> (house mouse) <i>M. musculus</i> (house mouse) <i>R. norvegicus</i> (Norway rat) <i>A. sylvaticus</i> (wood mouse) <i>M. agrestis</i> (field vole) <i>M. musculus</i>	170 2 2 9 8 83	10 0 0	Intestinal contents
Meerburg <i>et al.</i> <sup>46</sup>	Organic pig and poultry farms	Salmonella and Campylobacter	<i>R. norvegicus</i> Other ( <i>A. sylvaticus</i> , <i>M. arvalis</i> , <i>M. minutus</i> (harvest mouse), <i>M. agrestis</i> , <i>C. glareolus</i> )	8 62	1 ( <i>Salmonella</i> ) 10 ( <i>Campylobacter</i> ) 0 ( <i>Salmonella</i> ) 12.5 ( <i>Campylobacter</i> ) 0 ( <i>Salmonella</i> ) 0 ( <i>Campylobacter</i> )	Intestinal contents

found to excrete  $10^4$ – $10^6$  colony-forming units (cfu)  $g^{-1}$  in some individual droppings,<sup>23,26</sup> while their droppings can be contaminated for up to 3 months post-infection.<sup>37</sup> Only a few bacteria are necessary to infect a mouse: in the case of *Salmonella*, 15 are sufficient.<sup>31,38</sup> Mice are also easily colonised by *Campylobacter*.<sup>39,49</sup> Rodents can further amplify the number of pathogens present in the environment: isolates from mice contained three times more *Salmonella* than isolates from the environment of contaminated houses.<sup>31</sup> It has therefore been suggested that rodents constantly reintroduce unstable, orally invasive phenotypes back into the environment of poultry.<sup>40,41</sup> The presence of a resident infected mouse population is thus an important risk factor for egg contamination.<sup>42</sup> Rodents can be a source for oral infection of laying hens with *Salmonella*. In this case, high cell density growth will take place in the intestines of layer hens and the bacteria will have easy access to the eggs. If human pathogenic variants of *Salmonella* survive within the eggs, this could lead to human disease after consumption of contaminated eggs. Molecular fingerprinting<sup>40</sup> demonstrated a close relationship between orally invasive phenotypes by laying hens that resulted in egg contamination and isolates obtained from naturally infected mice. A source for oral infection of poultry is rodent droppings, which are actively sought out by the broilers or layers when mixed in their food or bedding,<sup>26</sup> thus increasing chances of further colonisation. Dead mice can also be a problem, especially if their carcasses are found in poultry houses which have been cleaned and disinfected: *Salmonella* in them may be a hazard for the new flock, as they contain higher levels of organisms than droppings, and dead mice may be pecked and consumed by mature chickens.<sup>26,43</sup>

Rodents can acquire their infection from various sources: they can come into contact with faeces of infected livestock on the farm (a known *Salmonella* infection route<sup>44</sup>), acquire it from other wild animals (e.g. wild birds) or get it from their own family members. Rodents tend to live close to each other, thus enabling the infections to remain resident in the population.<sup>50,51,52</sup>

On swine farms, infected rodents can also be encountered. In a recent study, 5% of the 180 mice caught on swine farms were *Salmonella*-positive.<sup>45</sup> However, in other ecological compartments in that study, *Salmonella* were even more abundant: in cats (12% of samples positive), boots (11%), bird faeces (8%) and flies (6%). It needs to be said that the pigs on nine of the 12 investigated farms were shedding *Salmonella* in their faeces. In an earlier study by our group on organic pig farms we found that about 10% of the house mice (*M. musculus*) were *Campylobacter*-positive and 1% *Salmonella*-positive.<sup>46</sup> Moreover, one out of eight Norway rats was *Campylobacter*-positive. Other rodent species and all insectivores (shrews) were negative for *Campylobacter* and *Salmonella*.<sup>46</sup>

*Salmonella* are not always encountered in rodents on farms, as has been shown by three studies.<sup>1,47,48</sup> In two

of these studies, no *Salmonella* were detected in isolates of any of the house mice caught on the farms.<sup>47,48</sup> In the other study, all small mammals (rats and mice) on the farms were negative.<sup>1</sup> On the other hand, the true *Salmonella* prevalence could be underestimated in these studies, as faecal pellets were analysed.

The use of antimicrobials for prophylaxis, therapy and growth promotion in conventional animal production has led to an increase in antimicrobial resistance of animal pathogens and commensal bacteria, among others *Salmonella* and *Campylobacter*. This can have important implications for human health, as antibiotics used to cure infected humans will work less effectively. Resistance of food animals to some antimicrobials is high. In a recent study on pigs,<sup>53</sup> susceptibilities of *Campylobacter* strains were determined for five antimicrobial drugs. Resistance to tetracycline and erythromycin was high (79 and 55% respectively).<sup>53</sup> Susceptibility testing of *Campylobacter* isolated from poultry showed similar results concerning antimicrobial resistance.<sup>54</sup> Unfortunately, no information is currently available on antimicrobial drug resistance of *Salmonella/Campylobacter* isolates from rodents on conventional farms.

The presence of rats on farms has been associated with an increased risk of *Campylobacter* introduction into broiler houses.<sup>15</sup> Another study found that 87% of rat faecal samples tested were positive for *C. jejuni*.<sup>55</sup> Within poultry operations, *Campylobacter* can also be found in mice intestines.<sup>4</sup> A study in New Zealand revealed that seven out of 65 house mice (*M. musculus*) caught in snap traps on a dairy farm were infected with *C. jejuni*.<sup>56,57</sup> These infected rodents may contaminate feed and water, which can then become a source for *Campylobacter* colonisation of food animals.

Potential transmission risks of rodents are probably even higher in organic farming,<sup>5,58,59</sup> as rodents live in closer contact with food animals within these farming systems for the following reasons: (1) food animals have the possibility to go outdoors; (2) food animals are offered roughage and straw in which rodents often hide themselves; (3) organic farmers are less willing to use rodenticides for rodent elimination as it does not fit into their farming philosophy. Moreover, cleaning of outdoor paddocks and practising good hygiene may be difficult in an organic context.<sup>60</sup>

Some studies on pigs<sup>61,62</sup> have shown that risks of meat juice samples being *Salmonella*-positive are higher for free range and organic pig herds than for conventional herds (based on cut-off OD% >10, where OD% is the optical density of the sample relative to the optical density of a positive reference sample).

## IMPORTANCE OF RODENT CONTROL

Decontamination of farms is an important step in the reduction of *Salmonella* and *Campylobacter* infection throughout the food chain. Although the disinfection procedure is the main risk factor for pathogen persistence after cleansing and disinfection,<sup>36</sup> the

efficacy of a proper disinfection procedure is often reduced by the presence of *Salmonella*-infected mice remaining on or returning to the farm after cleansing and disinfection.<sup>37</sup> Mice can acquire infections from inaccessible parts of the livestock houses or outdoor paddocks and then deposit contaminated droppings in places where food animals reside. Because of this food safety risk, even the smallest infestation with rats or mice on farms needs to be addressed.<sup>63,64</sup> It has been shown that rodent control measures can effectively decrease *S. enteritidis* in the hen house.<sup>21,65,66</sup> In one study, 100 conventional flocks were monitored for one production cycle to investigate risk factors for *Campylobacter* infection of broiler flocks.<sup>13</sup> The authors did not encounter evidence of environmental survival of *Campylobacter* in broiler houses after adequate cleansing and disinfection. Further, they did not find that rodents were a source of infection, although they state that most sites operated effective vermin control programmes.<sup>13</sup> Farmers generally apply rodent control to prevent economic losses, as rodents can cause considerable feed losses or structural damage on farms (e.g. gnawing on insulation). However, they only do so when rodent densities exceed a certain subjective threshold.<sup>63</sup> This threshold apparently varies between different countries and between farming systems (conventional *vs* organic). In Denmark it was found that mice were regularly observed on 69% of the farms but that their presence was rarely considered a problem by the farmers.<sup>30</sup> Only 9% of the farmers considered the presence of mice problematic. Rats were more often seen as a problem (by 26% of the farmers), though they were only observed regularly on 39% of the farms. Of the farmers, 53% performed rat control on a regular basis, while for mice the figure was 25%.<sup>30</sup> On the other hand, a survey of 526 farmers in the USA showed that 28% of the farmers considered their farms to have a moderate or severe problem with mice, but only 9% with rats.<sup>21</sup> However, nearly all (99%) the farmers used some method of rodent control. Chemicals or baits were by far the most common method of rodent control. Traps or sticky tape were used on almost half (46%) of the farm sites but were the primary method of rodent control on only 7% of the farm sites. A professional exterminator was used on 14% of the farm sites that practised at least one method of rodent control.<sup>21</sup>

Another survey<sup>63</sup> has demonstrated that there is a difference in rodent control methods between conventional and organic farmers. Conventional farmers mainly use rodenticides, whereas organic farmers also use traps and cats. Sometimes organic farmers also make use of natural predators by stimulating the presence of barn owls, buzzards and kestrels on their farm by placing perches or nest boxes.<sup>63</sup> Recently, it was found that the use of live traps can be an alternative to the use of poison to reduce rodent pressure on organic farms.<sup>2</sup> Live traps are advantageous for the welfare of non-target animals

and cause less pollution. These aspects are in line with the organic farming philosophy. On the other hand, the improvement in animal welfare for the trapped rodent compared with poisoning is questionable and farmers need more time to check the traps on a regular basis. Also, live traps are less cost-effective in the short term.<sup>2</sup> A recent mathematical study<sup>67</sup> has demonstrated that the use of cats as rodent exterminators by organic farmers is not recommendable from a food safety perspective. The presence of a large number of cats was found to be positively correlated with *Toxoplasma gondii* seroprevalence in organic pigs.<sup>67</sup> This protozoan parasite causes toxoplasmosis, which in turn can result in serious health disorders in humans, including mental retardation, encephalitis and blindness. Organic farmers should thus limit the access and number of cats on their farms.<sup>67</sup>

## CONCLUSION

Both *Salmonella* and *Campylobacter* can cause serious health problems in humans. Therefore elimination of these pathogens in the first part of the food chain should have priority, especially in an organic context. Wild rodents are generally not much of a problem as they do not come into close contact with food animals, but rodents in agro-ecological surroundings can be infected with *Salmonella* and *Campylobacter* and transfer these pathogens to food animals or amplify the number of bacteria in the farm environment. A resident infected rodent population could lead to continuously returning infections in the farm environment.

Rodent control should therefore not only be applied by organic farmers to prevent economic losses but also from a veterinary perspective. Although many farmers already use various methods of rodent control (some more effective than others), most only apply them after a certain subjective threshold is passed and mainly to prevent economic losses or structural damage. Therefore there is a clear need to stress the importance of rodent control for food safety purposes in organic farming.

Because of their ecology, commensal rodents (house mice and rats) pose a particular threat as they live close to livestock and have good reproduction capabilities. Preferably, rodent control should form an integral part of a total package of hygiene measures. These should also include e.g. control of wild birds and flies and obligatory disinfection of boots/clothes and equipment for farm workers and visitors. Continuous monitoring of rodent populations and prevention (e.g. proofing of farm buildings, removal of piles of old material, removal of habitat elements for rodents near stables, limiting access to feed and water) will limit the development of high rodent densities on organic farms. In this way, contact opportunities between rodents and food animals are reduced as much as possible.

## REFERENCES

- 1 Jensen AN, Lodal J and Baggesen DL, High diversity of *Salmonella* serotypes found in an experiment with outdoor pigs. *NJAS-Wageningen J Life Sci* 52:109–117 (2004).
- 2 Meerburg BG, Reimert HGM and Kijlstra A, Live-traps vs. rodenticides on organic farms: which method works best? *Joint Organic Congress*, Odense. [Online]. (2006). Available: <http://orgprints.org/7107/> [24 November 2006].
- 3 Gratz NG, Rodents as carriers of disease, in *Rodent Pests and Their Control*, ed. by Buckle AP and Smith RH. CAB International, Oxford, pp. 85–108 (1994).
- 4 Hiatt KL, Stern NJ, Fedorka-Cray P, Cox NA, Musgrove MT and Ladely S, Molecular subtype analyses of *Campylobacter* spp. from Arkansas and California poultry operations. *Appl Environ Microbiol* 68:6220–6236 (2002).
- 5 Heuer OE, Pedersen K, Andersen JS and Madsen M, Prevalence and antimicrobial susceptibility of thermophilic *Campylobacter* in organic and conventional broiler flocks. *Lett Appl Microbiol* 33:269–274 (2001).
- 6 Blaser MJ, Reller LB, Luechtefeld NW and Wang WL, *Campylobacter* enteritis in Denver. *West J Med* 136:287–290 (1982).
- 7 Skirrow MB and Blaser MJ, Clinical and epidemiologic considerations, in *Campylobacter jejuni: Current Status and Future Trends*, ed. by Nachamkin I, Tompkins LS and Blaser MJ. American Society for Microbiology, Washington, DC, pp. 3–9 (1992).
- 8 Trends and sources of zoonotic agents in animals, feedingstuffs, food and man in the European Union and Norway in 2002. *SANCO/29/2004*, European Commission, Health & Consumer Protection Directorate-General, Brussels (2004).
- 9 Boogaardt MJ, Mangen M-JJ, De Wit GA, Nauta MJ and Havelaar AH, Controlling *Campylobacter* in the chicken meat chain: towards a decision support model. *RIVM Rep 250911005/2004*, National Institute for Public Health and the Environment (RIVM), Bilthoven (2004).
- 10 Taylor DN, Echeverria P, Pitarangsi C, Seriwatana J, Bodhidatta L and Blaser MJ, Influence of strain characteristics and immunity on the epidemiology of *Campylobacter* infections in Thailand. *J Clin Microbiol* 26:863–868 (1988).
- 11 Jacobs-Reitsma W, *Epidemiology of Campylobacter in Poultry*. Wageningen Agricultural University, Wageningen (1994).
- 12 Winer JB, Guillain Barré syndrome. *J Clin Pathol* 54:381–385 (2001).
- 13 Evans S and Sayers A, A longitudinal study of *Campylobacter* infection of broiler flocks in Great Britain. *Prev Vet Med* 46:209–223 (2000).
- 14 Shreeve JE, Toszeghy M, Pattison M and Newell DG, Sequential spread of *Campylobacter* infection in a multipen broiler house. *Avian Dis* 44:983–988 (2000).
- 15 Kapperud G, Skjerve E, Vik L, Hauge K, Lysaker A, Aalmen I, et al, Epidemiological investigation of risk factors for *Campylobacter* colonization in Norwegian flocks. *Epidemiol Infect* 111:245–255 (1993).
- 16 Hoogenboom LAP, Bokhorst JG, Northolt MD, Broex NJG, Mevius D, Meijs JAC, et al, Contaminanten en micro-organismen in biologische producten: vergelijking met gangbare producten. *RIKILT Rep 2006.002*, Wageningen (2006).
- 17 Popoff M and Le Minor L, *Antigenic Formulas of the Salmonella Serovars* (2nd edn). Institute Pasteur, Paris (1997).
- 18 Swanenburg M, *Salmonella in the Pork Production Chain: Sources of Salmonella on Pork*. Utrecht University, Utrecht (2000).
- 19 Wallis TS and Galyov EE, Molecular basis of *Salmonella*-induced enteritis. *Mol Microbiol* 36:997–1005 (2000).
- 20 Roberts JA, Cumberland P, Sockett PN, Wheeler J, Rorigues LC, Sethi D, et al, The study of infectious intestinal disease in England: socio-economic impact. *Epidemiol Infect* 130:1–11 (2003).
- 21 Highlights of Layers '99 Study results: *Salmonella enterica* serovar *enteritidis*. [Online]. Available: <http://www.aphis.usda.gov/vs/ceah/ncahs/nahms/poultry/Layers99/lay99se.pdf> [25 March 2005].
- 22 Davies RH and Wray C, Persistence of *Salmonella enteritidis* in poultry units and poultry food. *Br Poultry Sci* 37:589–596 (1996).
- 23 Blaser MJ, Duncan DJ, Warren GH and Wang WL, Experimental *Campylobacter jejuni* infection of adult mice. *Infect Immun* 39:908–916 (1983).
- 24 Stern NJ, Reservoirs of *Campylobacter jejuni* and approaches for intervention in poultry, in *Campylobacter jejuni: Current Status and Future Trends*, ed. by Nachamkin I, Tompkins LS and Blaser MJ. American Society for Microbiology, Washington, DC, pp. 49–60 (1992).
- 25 Van de Giessen A, Mazurier SI, Jacobs-Reitsma W, Jansen W, Berkers P, Ritmeester W, et al, Study on the epidemiology and control of *Campylobacter jejuni* in poultry broiler flocks. *Appl Environ Microbiol* 58:1913–1917 (1992).
- 26 Davies RH and Wray C, Mice as carriers of *Salmonella enteritidis* on persistently infected poultry units. *Vet Rec* 137:337–341 (1995).
- 27 Rosef O, Gondrosen B, Kapperud G and Underdal B, Isolation and characterization of *Campylobacter jejuni* and *Campylobacter coli* from domestic and wild mammals in Norway. *Appl Environ Microbiol* 46:855–859 (1983).
- 28 Fernie DS and Park RWA, The isolation and nature of *Campylobacters* (microaerophilic vibrios) from laboratory and wild rodents. *J Med Microbiol* 10:325–329 (1977).
- 29 Pacha RE, Clark GW, Williams EA, Carter AM, Scheffella JJ and Debusschere P, Small rodents and other mammals associated with mountain meadows as reservoirs of *Giardia* spp. and *Campylobacter* spp. *Appl Environ Microbiol* 53:1574–1579 (1987).
- 30 Leirs H, Lodal J and Knorr M, Factors correlated with the presence of rodents on outdoor pig farms in Denmark and suggestions for management strategies. *NJAS-Wageningen J Life Sci* 52:133–143 (2004).
- 31 Henzler DJ and Opitz HM, The role of mice in the epizootiology of *Salmonella enteritidis* infection on chicken layer farms. *Avian Dis* 36:625–631 (1992).
- 32 Garber L, Smeltzer M, Fedorka-Cray P, Ladely S and Ferris K, *Salmonella enterica* serotype *enteritidis* in table egg layer house environment and in mice in U.S. layer houses and associated risk factors. *Avian Dis* 47:134–142 (2003).
- 33 Guard-Petter J, Henzler DJ, Rahman MM and Carlson RW, On-farm monitoring of mouse-invasive *Salmonella enterica* serovar *enteritidis* and a model for its association with the production of contaminated eggs. *Appl Environ Microbiol* 63:1588–1593 (1997).
- 34 Humphrey TJ, Williams A, McAlpine K, Lever MS, Guard-Petter J and Cox JM, Isolates of *Salmonella enterica enteritidis* PT4 with enhanced heat and acid tolerance are more virulent in mice and more invasive in chickens. *Epidemiol Infect* 117:79–88 (1996).
- 35 Henzler DJ, Ebel E, Sanders J, Kradel D and Mason J, *Salmonella enteritidis* in eggs from commercial chicken layer flocks implicated in human outbreaks. *Avian Dis* 38:37–43 (1994).
- 36 Rose N, Beaudeau F, Drouin P, Toux J, Rose V and Colin P, Risk factors for *Salmonella* persistence after cleansing and disinfection in French broiler-chicken houses. *Prev Vet Med* 39:9–20 (2000).
- 37 Davies RH and Wray C, Observations on disinfection regimens used on *Salmonella enteritidis* infected poultry units. *Poultry Sci* 74:638–647 (1995).
- 38 Welch H, Ostrolenk M and Bartram M, Role of rats in the spread of food poisoning bacteria of the *Salmonella* group. *Am J Public Health* 31:332–340 (1941).
- 39 Berndtson E, Danielsson-Tham ML and Engvall A, Experimental colonization of mice with *Campylobacter jejuni*. *Vet Microbiol* 41:183–188 (1994).
- 40 Parker C, Liebana E, Henzler D and Guard-Petter J, Lipopolysaccharide O-chain microheterogeneity of *Salmonella* serotypes *enteritidis* and *typhimurium*. *Environ Microbiol* 3:332–342 (2001).

- 41 Liebana E, Garcia-Migura L, Clouting C, Clifton-Hadley F, Breslin M and Davies R, Molecular fingerprinting evidence of the contribution of wildlife vectors in the maintenance of *Salmonella enteritidis* infection in layer farms. *J Appl Microbiol* **94**:1024–1029 (2003).
- 42 USDA, *Salmonella enteritidis Risk Assessment: Shell Eggs and Egg Products*. US Department of Agriculture, Washington, DC (1998).
- 43 Davies RH and Breslin M, Observations on *Salmonella* contamination of commercial laying farms before and after cleaning and disinfection. *Vet Rec* **152**:283–287 (2003).
- 44 Oosterom J, Epidemiological studies and proposed preventive measures in the fight against human salmonellosis. *Int J Food Microbiol* **12**:41–51 (1991).
- 45 Barber D, Bahnson P, Isaacson R, Jones C and Weigel R, Distribution of *Salmonella* in swine production ecosystems. *J Food Protect* **65**:1861–1868 (2002).
- 46 Meerburg BG, Jacobs-Reitsma W, Wagenaar J and Kijlstra A, Presence of *Salmonella* and *Campylobacter* spp. in wild small mammals on organic farms. *Appl Environ Microbiol* **72**:960–962 (2006).
- 47 Healing TD and Greenwood MH, Frequency of isolation of *Campylobacter* spp., *Yersinia* spp. and *Salmonella* spp. from small mammals from two sites in southern Britain. *Int J Environ Health Res* **1**:54–62 (1991).
- 48 Pocock MJO, Searle JB, Betts WB and White PCL, Patterns of infection by *Salmonella* and *Yersinia* spp. in commensal house mice (*Mus musculus domesticus*) populations. *J Appl Microbiol* **90**:755–760 (2001).
- 49 Hald B, Madsen JJ, Rahbek C, Chriel M, Nielsen EM, Bang DD, *et al*, *Campylobacter* spp. carriage by wild birds, rodents, insects and other animals in the immediate environment of cattle, pigs and poultry farms in Denmark. Abstract: Twelfth International Workshop on *Campylobacter*, *Helicobacter* and Related Organisms. Aarhus, Denmark, 6–10 September 2003, International Journal of Medical Microbiology **2g3**, pp.140 (Suppl. no.35).
- 50 Singh SP, Sethi MS and Sharma VD, The occurrence of salmonellae in rodent, shrew, cockroach and ant. *Int J Zoonoses* **7**:58–61 (1980).
- 51 Hilton AC, Willis RJ and Hickie SJ, Isolation of *Salmonella* from urban wild brown rats (*Rattus norvegicus*) in the West Midlands, UK. *Int J Environ Health Res* **12**:163–168 (2002).
- 52 Shimi A, Keyhani M and Hedayati K, Studies on salmonellosis in the house mouse, *Mus musculus*. *Lab Anim* **13**:33–34 (1979).
- 53 Payot S, Dridi S, Laroche M, Federighi M and Magras C, Prevalence and antimicrobial resistance of *Campylobacter coli* isolated from fattening pigs in France. *Vet Microbiol* **101**:91–99 (2004).
- 54 Ledergerber U, Regula G, Stephan R, Danuser J, Bissig B and Stärk KDC, Risk factors for antibiotic resistance in *Campylobacter* spp. isolated from raw poultry meat in Switzerland. *BMC Public Health* **39**:1–21 (2003).
- 55 Kasrazadeh M and Genigeorgis C, Origin and prevalence of *Campylobacter jejuni* in ducks and duck meat at the farm and processing plant level. *J Food Protect* **50**:321–326 (1987).
- 56 Adhikari B, Madie P, Connolly JH, Davies PR, Layland M and Rogers L, Wild birds, flies, and rodents as reservoirs of *Campylobacter* spp. on dairy farms. *MAF Tech Paper 2002/18* (2002).
- 57 Adhikari B, Connolly JH, Madie P and Davies P, Prevalence and clonal diversity of *Campylobacter jejuni* from dairy farms and urban sources. *NZ Vet J* **52**:378–383 (2004).
- 58 Engvall A, May organically farmed animals pose a risk for *Campylobacter* infections in humans? *Acta Vet Scand* **95**:85–88 (2001).
- 59 Meerburg BG, Zoonotic risks of rodents in livestock production. *PhD Thesis*, University of Amsterdam (2006).
- 60 Jensen AN, Dalsgaard A, Baggesen DL and Nielsen EM, The occurrence and characterization of *Campylobacter jejuni* and *C. coli* in organic pigs and their outdoor environment. *Vet Microbiol* **116**:96–105 (2006).
- 61 Wingstrand A, Dahl J and Lo Fong Wong DMA, *Salmonella*-prevalences in Danish organic, free-range, conventional and breeding herds, in *Proceedings of the 3rd International Symposium on the Epidemiology and Control of Salmonella, Washington, DC, 5–7 August 1999*, ed. by Bahnson P. Biomedical Communication Center, Urbana Town, IL, pp. 186–189 (1999).
- 62 Van der Wolf PJ, Elbers ARW, Van der Heijden HMJF, Van Schie FW, Hunneman WA and Tielen MJM, *Salmonella* seroprevalence at the population and herd level in pigs in The Netherlands. *Vet Microbiol* **80**:171–184 (2001).
- 63 Meerburg BG, Bonde M, Brom FWA, Endepols S, Jensen AN, Leirs H, *et al*, Towards sustainable management of rodents in organic animal husbandry. *NJAS-Wageningen J Life Sci* **52**:195–205 (2004).
- 64 Davies RH and Wray C, Studies of contamination of three broiler breeder houses with *Salmonella enteritidis* before and after cleansing and disinfection. *Avian Dis* **40**:626–633 (1996).
- 65 Henzler DJ, Kradel DC and Sischo WM, Management and environmental risk factors for *Salmonella enteritidis* contamination of eggs. *Am J Vet Res* **59**:824–829 (1998).
- 66 Rodenburg TB, Van der Hulst-Van Arkel MC and Kwakkel RP, *Campylobacter* and *Salmonella* infections on organic broiler farms. *NJAS-Wageningen J Life Sci* **52**:101–108 (2004).
- 67 Meerburg BG, Van Riel JW, Cornelissen JB, Kijlstra A and Mul MF, Cats and goat whey associated with *Toxoplasma gondii* infection in pigs. *Vector Borne Zoonot Dis* **6**:266–274 (2006).