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Review

Bioexclusion of diseases from dairy and beef farms: Risks of introducing infectious agents and risk reduction strategies

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ABSTRACT

Infectious disease represents a major threat to the productivity and welfare of cattle herds throughout the world. The introduction of infectious agents into dairy and beef farms may be through direct transmission (purchased cattle, reintroduced resident cattle and contact with contiguous cattle) or indirect transmission (fomites, visitors, other species, and biological materials) and this article reviews the evidence supporting these transmission routes. In the absence of eradication programmes for many endemic infectious diseases, bioexclusion is the key management process for risk reduction. Various ameliorative bioexclusion strategies have been recommended and the evidence supporting these protocols is considered.

Introduction

Biosecurity has been defined as a strategy of management practices to prevent the introduction of diseases and pathogens to an operation and to control spread within the operation (Wells, 2000). Biosecurity comprises two components, namely, bioexclusion and biocontainment. Bioexclusion relates to preventive measures (risk reduction strategies) designed to avoid the introduction of pathogenic infections (hazards), whereas biocontainment relates to measures to limit within-farm transmission of infectious hazards and onward spread to other farms.

The implementation of bioexclusion plans on dairy or beef farms is voluntary in almost all countries (an exception being larger dairy farms in Denmark; Kristensen and Jakobsen, 2011). Therefore, farmers need to be motivated to both change existing behaviours and to continue to implement effective practices to avoid biosecurity breakdowns (Truyers et al., 2011). However, currently there is a lack of consensus internationally in the published literature regarding bioexclusion protocols (Daly, 2011; Moore et al., 2008), their efficacy (van Winden et al., 2005; Faust et al., 2001) and their cost-effectiveness. These barriers may explain the slow adoption of such practices by many farmers (Gunn et al., 2008; Heffernan et al., 2008; Moore et al., 2008).

There has been no recent published review focusing specifically on the bioexclusion aspects of biosecurity on European cattle farms. This gap was recently identified by Animal Health Ireland (AHI) as a key task which needed addressing prior to the development of farmer guidelines on biosecurity. AHI is a not-for-profit, partnership-based organisation providing national leadership and coordination of non-regulatory animal health issues in Ireland (More et al., 2011).

The objective of the present article is to examine the existing scientific literature on bioexclusion in dairy and beef cattle enterprises and to summarise current best practice based on that literature. The review focuses on routes of transmission, the risks associated with introduction of infection and how these risks can be reduced through bioexclusion. An empirical hierarchy of risks has been established from the published literature, cognisant of the fact that the relative importance of each risk varies with the disease. Added animals (either purchased or hired, and reintroduced resident cattle) and contiguous cattle represent the highest biosecurity risks, in that order of risk ranking (Van Winden et al., 2005; Lindberg and Alenius, 1999).

Purchased (and hired) cattle

Overview

Purchase of cattle, where incoming stock remains in direct contact with the recipient herd for an extended period of time,

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Table 1
Risks (odds ratios) and outcomes of introducing specific infections with purchased cattle.

Infection	Outcome	Odds ratio	Case-control comparison (all compared to no purchase)	Reference
Bovine herpes virus-1	Seropositivity	1.4	Purchase of more than one cow	Van Winden et al. (2005)
Bovine virus diarrhoea virus	Infection	1.8	Purchase of a pregnant cow	Valle et al. (1999)
Contagious mastitis pathogens	Infection	1.4–1.6	Purchase of heifers or cows	Agger et al. (1994)
Escherichia coli O157	Infection	1.9	Purchase of cattle within the last 2 years	Schouten et al. (2004)
Leptospira spp.	Seropositivity	1.5–1.6	Purchase of cattle	Oliveira et al. (2010)
Mycobacterium avium subspecies *paratuberculosis*	Seropositivity	2.1	Purchase of a large number ($\geqslant$25%) of cattle	Wells (2000)
Mycobacterium bovis	Herd breakdown	2.0	Purchase from a market	Ramírez-Villaescusa et al. (2010)
Mycoplasma bovis	Seropositivity	10.8	Purchase of adult cattle	Burnens et al. (1999)
Salmonella spp.	Infection	3.4	Purchase of cattle	Van Winden et al. (2005)

presents the highest risk for introducing infectious hazards. Farming practices, such as hiring a bull and returning it after the breeding season, significantly increase the risk of entry of venereally-transmitted infections such as bovine virus diarrhoea (BVD), infectious bovine rhinotracheitis (IBR) and leptospirosis (Bishop et al., 2010; Sibley, 2010; Bazeley, 2011). The asymmetry of information between vendor and purchaser about seller herd health status may result in cattle for sale, particularly in markets (Chi et al., 2002a) with a higher prevalence of disease than in the general cattle population. The concept of asymmetrical information, with the seller knowing more about the product than the buyer, is described in detail by Akerlof (1970) as 'Akerlof's lemons'. The published empirical evidence supporting cattle purchase as a route of transmission of infection is summarised below on a disease-by-disease basis (see Table 1).

Bluetongue virus

Purchase of pregnant heifers from bluetongue restriction zones resulted in the introduction of the bluetongue virus (BTV-8) during the midge-free season through transplacental and contact transmission into an expanding naïve dairy herd in Northern Ireland, a BTV-8-free region (Menzies et al., 2008). Subsequent Dutch work confirmed a role for vertical transmission in the epidemiology of BTV-8 in cattle (Santman-Berends et al., 2010).

Bovine herpes virus-1 (BHV-1)

While cattle purchase is an important risk factor for the introduction of BHV-1 (van Schaik et al., 2002), interactions with herd size (purchase risk only detected for small herds with $\leqslant$50 cattle; Boelaert et al., 2005) and herd type (strong association for dairy herds and a weak association for mixed herds; Van Wuijckhuise et al., 1998) have been shown. Purchase of asymptomatic cattle of uncertain health status is a particular risk for BHV-1 introduction (Hemmingsen and Bitsch, 1983).

Bovine respiratory syncytial virus

Seroconversion and severe outbreaks of respiratory disease in isolated dairy herds caused by bovine respiratory syncytial virus have been associated with the purchase of new animals (Elvander, 1996). Imported cattle were linked to the introduction and consequent outbreaks of BRSV in multiple Norwegian cattle herds in 1995 (Uttenthal et al., 1996).

Bovine viral diarrhoea virus (BVDv)

A well-documented way of introducing BVDv into a herd is purchase of transiently or persistently infected cattle (Valle et al., 1999), or of a dam ('Trojan cow') carrying a persistently infected (PI) fetus (Lindberg and Houe, 2005). Larger herds are at particular risk of BVDv introduction as they are more likely to be open (Bishop et al., 2010). Specific pathogen-free status does not necessarily prevent introduction of BVDv (van Schaik et al., 2002).

Digital dermatitis

Digital dermatitis increases markedly in incidence in expanding dairy herds (Faust et al., 2001), especially after restocking (Holliman, 2003). Buying replacement heifers is a particularly risky strategy. Rodriguez-Lainz et al. (1999) showed that farms which purchased heifers had a significantly higher prevalence of digital dermatitis than farms which did not and that there was a positive association between the risk of digital dermatitis and the number of heifers purchased.

E. coli *0157*

The presence of *E. coli* 0157 on dairy farms has been shown to be significantly associated with recent purchase of animals (Schouten et al., 2004) and with the presence of large numbers of purchased animals (Nielsen et al., 2002).

Leptospira *spp.*

Animal purchase has been identified as a significant risk factor for herd seropositivity to any *Leptospira* serovar (Oliveira et al., 2010) and specifically for *Leptospira interrogans* serovar *hardjo* (van Schaik et al., 2002). The appearance of leptospirosis as a clinical problem has recently been attributed to importation of cattle from high seroprevalence countries (Jones, 2011).

Mastitis

New herd infections caused by transmission of contagious mastitis pathogens (e.g. *Mycoplasma* spp., *Nocardia asteroides*, *Staphylococcus aureus*, *Streptococcus agalactiae*) between herds, both nationally and internationally (Holliman, 2003), has been associated with recent purchase of heifers or cows, for example, following restocking after a disease outbreak (Agger et al., 1994; Cook and Holliman, 2004; Olde Riekerink et al., 2010). In addition, high numbers of cattle introductions ($\geqslant$8) have been associated with a higher incidence of subclinical mastitis and higher bulk milk somatic cell count (Bruower et al., 2010).

Mycobacterium avium *subspecies* paratuberculosis

Purchase of bulls or large numbers ($\geqslant$25%) of breeding females (Wells, 2000), particularly within the previous 5 years (Pillars et al.,

2009) has been strongly associated with higher seroprevalence (Chi et al., 2002b; van Winden et al., 2005; Weering et al., 2005) and clinical incidence (Norton et al., 2009) of Johne's disease in dairy herds. Restocking after herd depopulation and importation of animals have also been associated with Johne's disease (Richardson et al., 2009; Barrett et al., 2011).

Mycobacterium bovis

Herd breakdowns due to bovine tuberculosis (bTB) have been found to be strongly associated with cattle movements (Gilbert et al., 2005). Purchase of stock, in particular from markets, has also been significantly associated with the risk of bTB breakdown on farm, even in areas endemic with bTB (Ramírez-Villaescusa et al., 2010). Gopal et al. (2006) described purchased animals as the most likely source of bTB introduction in 30/31 outbreaks discussed. These new introductions are an important cause of persistence as herds are re-exposed and possibly re-infected each time cattle are purchased.

Mycoplasma bovis

The risk of *Mycoplasma bovis* culture-positive bulk milk (Paschyn et al., 2012) and seropositivity in adults (Burnens et al., 1999), as well as clinical disease (both lameness and respiratory disease) in weanlings (Byrne et al., 2001) and in adults, have each clearly been shown to be associated with purchase of cattle.

Mycotic dermatitis

Ringworm (mycotic dermatitis) has been reported as a particular problem in imported naïve heifers contracting infection following purchase (Holliman, 2003). Papini et al. (2009) reported that prevalence rates of *Trichophyton verrucosum* were also higher when the cattle present in the farm were of mixed origin, rather than when the whole stock had been purchased or born in the farm (92% vs. 88.2% and 85.7%, respectively).

Neospora caninum

Between-herd movement of *Neospora caninum*-infected cattle significantly enhances the spread of *N. caninum*, particularly into low seroprevalence herds after restocking following a disease outbreak (Woodbine et al., 2008). Furthermore, Holliman (2003) described several *N. caninum* abortion outbreaks which followed the purchase of pregnant cattle and Björkman et al. (1996) described a Neospora herd problem which originated with two infected cows which were among the founding cows of the herd.

Salmonella spp.

Farmers who purchase cattle (asymptomatic latent carriers or persistent excretor calves or adults) are significantly more likely to introduce *Salmonella* spp. into their dairy herds (van Winden et al., 2005; Bergevoet et al., 2009), particularly where the purchase is recent (odds ratio [OR] 2.6 for purchase within 14 days compared to no purchase) and from dealers (OR 3.9 compared to purchase from other farmers) (Evans, 1996).

Overall, purchasing cattle is a significant risk factor for many infectious diseases. In their analysis of disease risks, Ortiz-Pelaez and Pfeiffer (2008) identified having an open herd to be the most significant risk factors (OR 6.2 compared to a closed herd) associated with the diagnosis of one or more of the following: *Mycobacterium bovis* infection, BVD, fasciolosis, BHV-1 infection, Johne's disease, mastitis, neosporosis, pneumonia, rotavirus infection and salmonellosis. The stress of transport and mixing may be an additional risk factor in disease recrudescence, e.g. IBR and transmission (Bishop et al., 2010; Holliman, 2003).

Risk reduction strategies

Maintaining a closed herd is the most important biosecurity measure (van Winden et al., 2005) as it eliminates infection risk from purchased cattle. However, even specific pathogen-free and closed herds experience disease breakdowns (van Schaik et al., 2002), reflecting the important role of other transmission routes. Furthermore, self-containment is not always practical where herds are expanding and/or breeding of replacements is impossible. Hence alternative risk reduction strategies (pre-movement, movement and post-movement) have been proposed.

Pre-movement risk reduction strategies

Minimise the number of cattle purchased and the number of source herds

Reducing the number of animals purchased will reduce the risk of introduction of infectious agents (Collins et al., 2006; Davison et al., 2006; Bazeley, 2009). Reducing the number of herds from which the animals are purchased will also reduce the risk of selecting an animal from a high disease prevalence herd. Purchases from markets or dealers present a very high biosecurity risk (Ramírez-Villaescusa et al., 2010; Kristensen and Jakobsen, 2011).

Purchase cattle which have not previously bred

Purchasing non-pregnant animals reduces the risk of transmission of infection from an infected fetus, such as can occur with BVDv (Lindberg and Houe, 2005). Venereal diseases are more likely to be spread by animals which have bred; Sanderson et al. (2000) reported that using non-virgin bulls were associated with an increased risk of both trichomonosis and campylobacteriosis.

Purchase from herds with likely low disease prevalence

The disease prevalence in the source population of purchased cattle will greatly influence the risk of introduction of infectious agents. This principle may be applied at a national level, where farmers should avoid importing cattle from exotic disease-affected regions as well as at the farm level. Herds which are likely to have lower likely disease prevalence include: (1) Certified disease-free herds; the risk of introducing specific diseases can be greatly reduced by purchasing stock from certified disease-free source herds, (Wells, 2000; van Winden et al., 2005; Sibley, 2010) or high health status markets. (2) Closed herds; one key factor associated with increased disease prevalence is having an open rather than a closed herd (Chi et al., 2002b; Weering et al., 2005; Ortiz-Pelaez and Pfeiffer, 2008). (3) Smaller herds; for many diseases seroprevalence in cattle has been found to be proportionate to the size of the source population (Weering et al., 2005; Ortiz-Pelaez and Pfeiffer, 2008). One important example is bovine tuberculosis (bTB). In countries such as Ireland where bTB is endemic, herd risk is significantly associated with herd size (Olea-Popelka et al., 2004; Wolfe et al., 2010).

Obtain cattle disease history

This may include a vendor or veterinary declaration of clinical disease incidence, medication and vaccine usage and previous laboratory results from the source herd (Bergevoet et al., 2009; Moore et al., 2009). Bergevoet et al. (2009) concluded that dairy herds could economically prevent the introduction of *Salmonella* spp. by excluding animals based on bulk milk antibody results. For diseases with long incubation periods (e.g. Johne's disease), pro-active assurances of freedom from clinical disease for 3 years or more is recommended (Pritchard, 1996).

Clinically examine the cattle for sale

While a clinical examination by the purchaser or their veterinary practitioner will not detect asymptomatic carrier animals, and the sensitivity of such examinations is variable, it is recommended for detection of the clinically obvious infectious disease (Pritchard, 1996; Bazeley, 2009; Moore et al., 2009). The examination may include cow-side examinations such as rectal temperature, body condition score, a California mastitis test (CMT), and udder, gait and reproductive examinations. However, such examinations applied singly have low sensitivity (Barkema et al., 2009), though for some diseases (for example, digital dermatitis) clinical examination is the only available diagnostic modality.

Quarantine cattle before movement

Quarantine has been defined as the isolation of cattle in an area that prevents direct contact with other livestock or the possibility of cross-contamination of animal waste (Davison et al., 2003). The recommended period of quarantine ranges from 3 (Maunsell and Donovan, 2008) to 6 weeks (Caldow, 2009), but commonly 4 weeks is advised (Bazeley, 2009) to cover the period of greatest risk of clinical disease after purchase, e.g. salmonellosis (Evans, 1996). Quarantine prior to sampling will improve the value of pre-purchase test results by allowing detectable seroconversion to an exposure that occurred immediately prior to quarantine. In addition, quarantine reduces the risk of post sampling infection on the farm of the vendor, and facilitates multiple observations and examinations.

Test cattle before movement

Laboratory testing prior to animal introduction is commonly recommended for many infectious diseases and can greatly enhance the sensitivity of detecting an infectious animal and therefore reduce risk (Wells, 2000; Maunsell and Donovan, 2008; Moore et al., 2009; Sibley, 2010). In general, the consequences of a false negative far outweigh those of a false positive; sensitivity should be favoured over specificity for pre-introduction tests (Barkema et al., 2009). Test insensitivity, especially in young animals, is a problem with Johne's disease detection but also in non-clinical adults where the probability of non-detection increases with the number of cattle purchased and greater prevalence (Carpenter et al., 2004; Collins et al., 2006). Pre-movement testing is not equally successful for all diseases, being proportionally less successful in BVD, IBR, Johne's disease and salmonellosis, in descending order (van Winden et al., 2005).

Medicate cattle before movement

In some cases, targeted medication can eliminate carrier status or reduce the probability of a carrier becoming infective. In such circumstances, incoming stock can be treated prophylactically to reduce the risk of introduction of infectious agents (preconditioning; Hilton and Olynk, 2011). Treatment with parenteral antibiotics, anthelmintic and flukicide, antibiotic foot-bathing and vaccination has been recommended (Bazeley, 2009), but may have a minimal effect depending on the disease (van Winden et al., 2005). Vaccination courses should be completed at least 2 weeks before release from quarantine (Caldow, 2009). Vaccination of resident cattle at the same time is also important as this can significantly reduce the risk of disease transmission (Nickell et al., 2011).

These strategies are discussed in the order which they are applied. However, if we were to rank the strategies in order of their likely impact our order would be: (1) information on the disease and biosecurity status of the source herd; (2) the number and history of the individuals purchased; (3) pre-introduction testing; (4) quarantine; and (5) medication.

Movement risk reduction strategies

The movement process itself may be targeted to reduce the risk of infection transmission by (1) loading and unloading animals at the perimeter of the farms; (2) not mixing animals from different sources in the transport vehicle; (3) transporting purchased cattle in the purchaser's vehicle (Maunsell and Donovan, 2008; Bazeley, 2009); and (4) minimising transport distances (Greger, 2007) and other stressors such as overcrowding. Legislation to control movement may also reduce the spread of infectious agents (Velthuis and Mourits, 2007), and is a frequent state-mediated reaction to exotic disease outbreaks.

Post-movement risk reduction strategies

Quarantine, testing and medication have been discussed as pre-movement strategies, but all may also be applied at the recipient farm (post-movement). This may reduce infection spread from stressed, clinically affected animals breaking down within weeks of movement, e.g. IBR, salmonellosis, Johne's disease, *Mycoplasma bovis* (Byrne et al., 2001; Bazeley, 2009). It is particularly important to prevent contact with breeding animals, e.g. BVDv (Sibley, 2010). Pregnant cattle should be group-segregated and isolated until calved (O'Farrell et al., 2001). Testing of the progeny of females purchased while pregnant can detect infectious agents transmitted transplacentally, e.g. BVDv and *Neospora* (Sibley, 2010).

Reintroduced resident cattle

Overview

Reintroduction of cattle returning from out-farms, common pastures, common accommodation, contract rearer accommodation, agricultural shows and marts or sales presents a risk of introducing infection. As they are not new additions to the herd, these animals are often not viewed as a threat to the resident herd disease status. However, in addition to the risk of comingling with infectious animals, there is a risk from contact with the external environment, handlers and the transport vehicle.

Co-grazing with cattle from other herds is a significant risk factor for introduction to the resident herd of BHV-1, BVDv (OR 3.4 compared to not sharing pasture), *Leptospira hardjo* (OR 1.63 compared to not sharing pasture) and *Salmonella* spp. (OR 8.9 compared to no co-mingling during contract heifer rearing) (Valle et al., 1999; van Schaik et al., 2002; Davison et al., 2006; Adhikari et al., 2009; Oliveira et al., 2010). Co-grazing with sheep and goats constitutes a risk for BVD, Johne's disease and leptospirosis (Caldow, 2004).

Sharing housing where cattle from different herds co-mingle is a significant risk factor for BVD (OR 15.1 compared to not sharing cattle housing) (Valle et al., 1999). Return of cattle following unsuccessful sale has been reported as a significant risk factor for introduction of BHV-1, BVDv, *E. coli* 0157, *Leptospira hardjo* and *Salmonella* Dublin to the resident herd (Cernicchiaro et al., 2009; van Schaik et al., 2002), although this may not always be the case: see, for example, Davison et al. (2006) who found no such relationship for *Salmonella* spp.). Participation in agricultural shows is a significant risk factor for introduction of BHV-I (van Schaik et al., 2001), *Salmonella* spp. (Davison et al., 2003) and malignant catarrhal fever (MCF) (Moore et al., 2010).

Risk reduction strategies

Ameliorative strategies to reduce the risks associated with reintroduced cattle are in principle similar to those for purchased cattle. Key practices include (1) not using common pastures or shared

cattle housing; (2) not directly returning unsold cattle; (3) selling at high health status physical sales; (4) maintaining cattle-proof boundaries on out-farms; and (5) not participating in agricultural shows. Testing cattle prior to admittance to shows will lower, but does not eliminate, the risk of BHV-1 transmission (Breidenbach et al., 2005).

Contiguous contacts

Overview

Cattle are social animals with individuals and groups interacting whenever possible. Most farm boundaries have evolved to demarcate ownership of property and not for biosecurity purposes. The transmission significance of peripheral farm boundaries has been discussed regarding BHV-1 (van Schaik et al., 2001), bTB (O'Corry Crowe et al., 1996) and BVDv (van Schaik et al., 2002; Scharko et al., 2011). In addition, 71% of brucellosis outbreaks in Northern Ireland were most likely caused by direct contact between contiguous cattle at pasture (Abernethy et al., 2011).

Risk reduction strategies

To reduce the risks associated with contiguous contacts, the following strategies have been recommended based on the principle that there must be no opportunity for straying or for direct contact (Duncan, 1990): (1) Double spaced boundary fencing with a gap of 3 m has been proposed to reduce significantly the risk of spread of disease such as BVD or IBR (Crawshaw et al., 2002). There are no empirical recommendations published on fence height or design. (2) Electric scare wires on each side of the boundary fence or a strip of uninterrupted hedge or trees also ameliorate the risk of transmission of infection (Caldow, 2004); a higher density of hedgerows was found to be negatively correlated with bTB transmission (Mathews et al., 2006). (3) Vaccination against specific pathogens such as BVDv (Scharko et al., 2011).

In a study of contact between cattle farms in the UK, Brennan et al. (2008) found that over half of boundary fences perceived to prevent contact, nose-to-nose contact was in fact possible with animals on adjacent farms.

Fomites

Overview

Fomites have been implicated in the transmission of various cattle pathogens such as BVDv (Stevens et al., 2011), foot-and-mouth disease virus (Sutmoller et al., 2003), cryptosporidium (Nydam and Mohammed, 2005) and ovine herpesvirus 2 (the cause of MCF) (Moore et al., 2010). Contaminated farm machinery, visitor vehicles and veterinary equipment, (e.g. needles and syringes, nose tongs, halters, obstetrical equipment, dosing equipment, dehorning equipment, hoof paring equipment) can all act as mechanical vectors for introduction of infectious agents into herds (DiGiacomo et al., 1985; Gunn, 1993; Lang-Ree et al., 1994; Niskanen and Lindberg, 2003; Makoschey and Beer, 2004).

Risk reduction strategies

In order to reduce the risks posed by such fomites, farmers should use their own cattle equipment rather than veterinarians' equipment (Raaperi et al., 2010) and thoroughly clean, disinfect and rinse equipment before and after use (Morley, 2002).

Visitors

Overview

Visitors to farms are potential infection vectors particularly via their hands (Larson, 1995), but also their clothing, boots, equipment and vehicles (Morley, 2002; Kirk et al., 2003; Ellis-Iversen et al., 2011). Visitors can be categorised as low or high risk. High-risk visitors include collectors of dead stock, other farmers, veterinary practitioners, artificial insemination (AI) technicians, lay scanners and lay foot trimmers.

However, although visitors are known to be potential disease vectors, there is only limited published evidence which quantifies the risk of disease introduction from farm visitors. In a small study with a limited data-set, farms that had professional visitors who did not always use protective clothing had an increased risk of introducing BoHV-1 (OR 2.8) (van Schaik et al., 2001). Not providing boots for visitors has been shown to be a significant risk factor for seropositivity to bovine coronavirus and BRSV (Ohlson et al., 2010).

Risk reduction strategies

The key procedures to reduce the risks posed by high risk visitors are: (1) providing personal protective equipment, e.g. gloves, footwear and overalls (Morley, 2002; van Schaik et al., 2002); (2) restricting visitor contact only to the necessary stock; (3) installing a vehicle bath with appropriate disinfectant at the single farm entrance; (4) providing hand-washing and boot-washing facilities (disinfectant footmats have been shown to significantly reduce bacterial contamination of footwear; Amass, 2006; Dunowska et al., 2006); and (5) moving fallen stock to an area separated from livestock and farm activities and restricting collection service staff access only to this area.

Other species

Overview

Resident cattle may have indirect contact with other non-bovine domestic animals, feral animals, wildlife, vermin and humans (walkers, passing motorists, hunters, etc.). Wildlife is recognised as an important reservoir of infectious agents (Daszak et al., 2000; Simpson, 2002). For example, wild ruminants (deer and mouflon) act as reservoirs and may be involved in the dissemination and persistence of BTV (Garcia-Bocanegra et al., 2011). Many wildlife species have been identified as important reservoirs for *Mycobacterium bovis*, including Eurasian badgers (*Meles meles*) in Ireland and the UK (More, 2009), white-tailed deer (*Odocoileus virginianus*) in the USA (Palmer et al., 2000) and the brushtail possum (*Trichosurus vulpecula*) in New Zealand (Jackson et al., 1995). *Mycobacterium avium* subsp. *paratuberculosis* (MAP) also has a wide host range, though the threat of spread to cattle from other species remains poorly understood (Greig et al., 1999; Beard et al., 2001).

Neospora caninum is a coccidian parasite of domestic dogs (and other canids) (Williams et al., 2000; King et al., 2011). *Cryptosporidium parvum* infection is prevalent in a range of mammalian and avian wildlife, resulting in environmental contamination and the potential for transmission to farmed livestock (Sturdee et al., 1999; Majewska et al., 2009; Samra et al., 2011). Wild deer are a potential source of infection for livestock of a broad range of bacteria, viruses and parasites (Böhm et al., 2007). *Clostridium botulinum* intoxication of cattle has been associated with poultry litter contamination of pasture (McLoughlin et al., 1998).

Risk reduction strategies

Several broad principles are relevant when seeking to reduce risk associated with other species, including providing and maintaining boundaries between known areas of significant wildlife populations and the other areas of the farm (these are not always the peripheral boundaries) and securely storing animal foodstuffs and animal wastes to remove potential attractants to wildlife (including birds). The measures necessary will vary depending on the geographic area and the wildlife species involved; for example, Ward et al. (2010) reviewed options to reduce the risk of *M. bovis* transmission from badgers to cattle.

Biological material

Overview

Introduction of biological material (colostrum, colostrum replacers, whole milk, semen, embryos, vaccines, slurry) into a farm is a potential biosecurity risk. For example, MAP can be transmitted in colostrum or whole milk, as can enzootic bovine leukosis (EBL) virus (Hopkins and DiGiacomo, 1997). Semen and embryos can transmit various infectious agents including BVDv and BHV-1, and cases of vaccine contamination with BVDv have been reported (Lindberg and Alenius, 1999; Barkema et al., 2001). Slurry and dirty water can be a biohazard with *E. coli* O157, *Salmonella* and *Campylobacter* surviving for up to 3 months (Nicholson et al., 2005). Despite being an obligate pathogen, MAP can survive in the environment for over 100 weeks (Whittington et al., 2004).

Risk reduction strategies

Avoiding introduction of biological material of uncertain health status is the best method of avoiding risk. Purchase of semen from AI centres approved for intercommunity trade and of embryos processed by internationally approved sanitary protocols will reduce disease introduction risks (EFSA, 2006; Givens and Marley, 2008). Pasteurisation of colostrum can reduce the load of infectious agents (Godden et al., 2006).

Conclusions

Bioexclusion is fundamental to the protection of herd health. This review has highlighted the relative importance of direct transmission of infectious agents via purchased cattle as the primary biosecurity risk and detailed the key protocols which can reduce this risk. Such protocols need to be prioritised and made farm-specific (Daly, 2011) based on the availability of resources (financial, labour, farm infrastructure) as well as the identified risks and consequences of infection introduction.

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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