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Review

Theoretical implications of best management practices for reducing the risk of drinking water contamination with *Cryptosporidium* from grazing cattle

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ABSTRACT

A synthesis of the literature on the incidence of *Cryptosporidium parvum* in cattle, the fate of both feces and *C. parvum* in the environment, and the implications for BMP to alter both the incidence of exposure of surface water sources to *C. parvum* contaminated feces and its fate was conducted. The results reveal that cattle are a possible source of *C. parvum* contamination to surface water sources in mixed-use watersheds. In a worst case scenario, surface water sources could be exposed to a load of up to 300×10^{10} *C. parvum* oocysts per day in a herd of 300 cow-calf pairs. This would theoretically pose a threat to human health. Six proposed best management practices (BMPs) were examined to determine if they could theoretically reduce the magnitude of the risk that cattle grazing in multiuse water sheds might pose. The BMP of scheduling the access of cattle such that no calves younger than three months of age are permitted near sensitive riparian areas in community watersheds, provided global risk minimization regardless of the site specific BMPs used. Other BMPs including off-stream watering, stubble height management in key areas and silvopasture with off stream watering reduce the risk of *C. parvum* entering surface waters in amounts high enough to cause a risk to drinking water consumers. The BMP of fencing and nose holes to restrict access may be problematic as these create corridors and damage the riparian habitat if they are placed incorrectly. Overall, any risks that are inherent to allowing cattle to graze on the land in multiuse watersheds can be minimized with the use of several best management practices.

1. Introduction

Multi-use watersheds are watersheds that serve as sources for municipal drinking water as well as other activities such as recreation, forestry, and cattle grazing. This is common throughout the Pacific Northwest coast of North America where some watersheds that provide community drinking water are also used for cattle grazing, forestry, and recreational activities. When watersheds are used for multiple purposes, concerns arise as to the implications on water quality and safety for human consumption (Wilber, 1940; Liang et al., 2013; FPB, 2012). The multiple-uses, especially in drinking catchments is a potential source of conflict between upstream and downstream stakeholders (Postel and Thompson, 2005; Ffolliott and Brooks, 1986). The presence of grazing cattle in community watersheds is a concern to regulatory agencies, water purveyors, and the public, particularly for the risk of contaminating drinking water with *Cryptosporidium parvum* (*C. parvum*) which is the primary cause of cryptosporidiosis in humans and can be passed by infected cattle feces to humans by contaminating drinking water sources (Atwill, 1996). Unfortunately, cattle, especially calves, have been identified as potential carriers of *C. parvum*. In British Columbia (BC), two historical cryptosporidiosis events, one resulting in an estimated 2000 cases in the city of Cranbrook, and another in the city of Kelowna with an estimated 10,000 cases have created concern about grazing cattle within community watersheds (Newman et al., 2003). In addition, during an audit in 2010 in two BC interior community watersheds by the Forest Practices Board, cattle feces containing unspeciated *Cryptosporidium* oocysts was found immediately adjacent to a sensitive stream directly upstream of a drinking water intake (FPB, 2012). Furthermore, the BC Ministry of Health's Centre for Disease Control receives an average of 130 reported incidents of cryptosporidiosis annually, aggravating conflict with FLNRO over the presence of cattle in community watersheds.

The implementation of best management practices (BMPs) to mitigate the potential risk has been proposed as a means of resolving this conflict in land uses (Borth, 2011). Within this paper, BMPs are defined as policies, practices, and infrastructure improvements to mitigate the contamination of surface drinking water sources with *C. parvum* via the feces of infected cattle. The following six BMPs have been found in the literature as measures to mitigate the risks to water sources from *Cryptosporidium* from grazing cattle and will be discussed in this paper.

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1. Access scheduling, which limits exposure of sensitive surface water sources to the hazard by restricting when potentially infectious cattle, especially calves, are allowed into areas with these water sources (Atwill et al., 1999).
2. Exclusion fencing, which restricts cattle from accessing areas with sensitive surface water sources (Atwill et al., 2002; Tate et al., 2000).
3. Controlled water access, which allows cattle access to sensitive water sources, but in a very restricted manner to limit potential contamination.
4. Off-stream watering, which provides cattle with an alternative water source that attracts them away from sensitive surface water sources (Sheffield et al., 1997).
5. Key area management, which monitors stubble height in pasture meadows close to sensitive streams to mitigate feces transport into water sources (Atwill et al., 2002; Tate et al., 2004).
6. Silvo-pasture development, which provides attractive forage areas away from sensitive streams, usually also equipped with off-stream watering too.

Although the theory behind BMPs is well discussed and some tests have been done with dairy herds, the implementation of BMPs has not been specifically studied for grazing of beef cow calf pairs distributed on a summer range. There are several distinctions between the two types of activities that warrant further investigation.

1.1. Objective and methods

The purpose of this paper is to provide an understanding from the current literature of the magnitude of the threat that grazing cattle pose to drinking water surface sources, the potential for the suite of BMPs to mitigate the probability of the hazard should it occur, and the potential fate of *C. parvum* in surface water. To accomplish this, the paper first explores the literature to determine the magnitude and threat of grazing cattle as a source of the hazard and factors contributing to and confounding this threat, then it explores two hypothetical scenarios. The first scenario assesses the potential for surface drinking water sources in BC's interior community watersheds to be contaminated with *Cryptosporidium* without the implementation of BMPs. The second scenario assesses the potential mitigation of the hazard by the implementation of the BMPs. In each instance, the pathway for *Cryptosporidium* from defecation to drinking water intake will be outlined summarizing information from the literature.

2. Magnitude of the threat

Cattle grazing on public land is recognized as beneficial for providing economical forage for cattle, increasing biodiversity, inhibiting invasive species, and reducing fuel-loads for fires (Huntsinger et al., 2007). Cattlemen in BC have leased public land to graze cattle for over 140 years. The leases are typically held for 20 or more years, and 419 of the publicly owned pastures overlap community watersheds. In some instances, cattle operations are structured on the basis of access to these pastures.

A typical pasture lease in the BC interior allows for 300 cow-calf pairs to graze for periods of two to six weeks at a time from early June to the middle of October of each year. Pasture boundaries are well defined by man-made fences and/or natural barriers. Historically, crown pasture extents were defined by natural landmarks such as streams. In addition to stipulating the number of cattle that can be grazed in a pasture, leases also specify the date on which cattle can enter a pasture and the date by which they must be removed from a pasture.

Though the benefits of grazing cattle are recognized, their defecation close to surface water sources is recognized as a potential source of *Cryptosporidium* contamination to surface drinking water sources (Atwill, 1996), and is a public health concern in BC (Newman et al., 2003). *Cryptosporidium* is recognized as the cause of the illness cryptosporidiosis in humans and animals (Holscher and Yardley, 1976; Rose, 1988). There are currently 27 identified species of *Cryptosposridium* (Ryan and Hijjawi, 2015), however, *C. parvum's* ability to infect both cattle and humans has made it the primary concern of range, water quality, and public health professionals (Ryan et al., 2014). *C. andersonii* is also common in cattle, however, in 2414 human stool samples collected from 1985 to 2000 in England, only 0.1% were identifiable as *C. andersonii* in contrast to 56.1% for *C. parvum* and 41.7% for *C. hominis* (Leoni et al., 2006). Hence with respect to grazing cattle in community watersheds, *C. parvum* is the major concern.

Cryptosporidium complete their life cycle within their hosts. Host to host transmission is accomplished by non-reproductive oocysts. *C. parvum* oocysts are typically 4 to 6 µm in diameter with a specific gravity of about 1.05 g-cm^{-3} (Searcy et al., 2005). In the environment, zoonotic transmission is facilitated via fecal contamination of water sources (Ryan et al., 2014). A single defecation from an infected animal can introduce from 10^5 to 10^9 oocysts into the environment and a cow or calf can produce as many as 10^{10} oocysts in a 24 h period (Chappell et al., 1996).

Both dairy and beef cattle have been identified as potential sources of *Cryptosporidium*. More data exists for dairy cattle herds, but the threat still exists within beef herds (Olson et al., 2004). In sampling 571 dairy heifers aged 1 to 2 years on 14 eastern US farms, Fayer et al. (2006) detected oocysts in feces from 13 of the farms with an incidence rate of 11.9% in the sample. Previous sampling of 393 pre-weaned calves from the same herds indicated an infection rate of 41% and 26.3% for 447 weaned calves. The high prevalence of infection in dairy herds is reflective of three factors; their confinement in barns and/or enclosed yards, facilitating animal to animal transmission, calving throughout the year, facilitating a temporal chain of infection, and that dairy calves consume much less of their dames' milk, which possibly transmits protection to calves (Olson et al., 2004). In contrast, beef cattle usually reside on open range, are all bred to deliver their calves in a short period in the late winter or early spring, breaking the temporal chain of infection, and the calves consume much greater quantities of their dames' milk.

Gow and Waldner (2006) examined 560 cows and 605 calves in 59 beef herds on 100 farms in western Canada, and found only 5 (1.1%) cows and 19 (3.2%) calves positive for *Cryptosporidium*. The study concluded that *Cryptosporidium* posed a "limited risk from most cow-calf herds", but that it is almost a given that for any cattle herd during calving season, there is a high likelihood of at least some animals being infected. Other research in both Ontario (669 cows on 39 farms) and BC (193 calves on 10 farms) beef cattle herds revealed that *C. parvum* infection rates from a low of 5.2% of gestating cattle to a high of 28% during calving with 13% of BC calves typically infected (McAllister et al., 2005).

Age is an important factor in the incidence of *Cryptosporidium* in a cattle herd. Work with spring and fall calving cow-calf herds in California indicated typically 3.9% of cattle shedding *C. parvum* on average with up to 13% of calves shedding *C. parvum* oocysts, whereas cattle a year or greater in age typically shed 0.6% of the time (Atwill et al., 1999, 2003). The study was conducted across seven distinct regions of the state of California with 38 ranchers sampling feces from 915 calves 1 to 11 months in age and 484 adult cows greater than 12 months in age. Atwill et al. (1999) noted that shedding incidence was 41 times greater for calves from 1 to 4 months in age than among cattle older than 4 months. Geography and climate across the seven regions did not contribute to any statistical differences between the regions. It was also noted that the contamination from calves was 8.7 times greater in May than in June, July, or August.

Research on both *Cryptosporidium* and *Giardia* in cattle (Olson et al., 2004) also concluded that calves usually become infected from one to four weeks of age, and typically lasts two weeks. Shedding of oocysts