Risk Factors for Coliform Bacteria in Sierra Nevada Mountain Wilderness Lakes and Streams

BY ROBERT W. DERLET, JAMES R. CARLSON, and JOHN R. RICHARDS

Abstract: In the Sierra Nevada Mountain wilderness backcountry, debate has occurred regarding the impact of cattle, pack animals, and humans on microbial contamination of the watershed. Using coliform bacteria as a marker, we hypothesized that water from high alpine watersheds with more frequent human or animal use patterns would have increased risks for presence of potentially harmful microbes. We analyzed 80 water samples from alpine wilderness areas in the Sierra Nevada Mountains of California for risk of coliform bacteria. The study found coliform bacteria at 92% of cattle sites and 56% of pack animal sites (horses and mules). In contrast, coliform bacteria were found in 18% of human day use areas, and 14% of backpacker sites. Wild sites, without human or domestic animal impact, had an 18% prevalence of coliforms. Differences in prevalence of coliform bacteria between these sites were statically significant. Heterotrophic bacteria counts were also increased in cattle and pack animal use areas. This study suggests that wilderness usage by cattle and pack animals affects water quality.

Introduction

The Sierra Nevada Mountains watershed provides 50% of California's freshwater for domestic use (Carle 2004). Much of this watershed encompasses roadless, remote backcountry wilderness areas at high elevations that putatively should have outstanding water quality. Melting snow must pass through a fragile ecosystem prior to runoff into lowland reservoirs. This ecosystem, primarily granite or metamorphic rock, has little buffering capacity, and therefore small amounts of environmental pollution may have a significant impact on biotic life. Debate has occurred regarding the impact of cattle, pack animals, and humans on contamination of the watershed, and the cattle industry has pressured the USDA Forest Service to expand cattle grazing tracts (USDA Forest Service 2006). Over the past 50 years, deposition of rate-limiting substances such as phosphates and nitrates from human activity, domesticated animals, and air pollution from the central valley of California has resulted in increasing eutrophication, with changes in phytoplankton species and biomass (Goldman 2000).

Robert W. Derlet.

John R. Richards.

PEER REVIEWED

Preliminary single year data suggests that the biomass of heterotrophic and pathogenic microorganisms are increased in areas of cattle grazing or heavy use by pack animals as a result of deposition of manure either directly or that is washed into lakes and streams (Derlet and Carlson 2004, 2006). Furthermore, the likelihood of finding pathogenic microorganisms decreases in areas where domesticated animals are not found, even when humans use these areas.

Coliform bacteria have been established as indicators of fecal pollution of watersheds (American Public Health Association 1998). The findings of coliforms indicates that the watershed carries a risk for waterborne diseases such as entero-invasive *E. coli*, *Giardia*, *Salmonella*, *Campylobacter*, and *Yersenia* species and other microbial pathogens, some that can survive for extended periods in the environment (Byappanahalli et al. 2003; Harvey et al. 1976). The objective of the current study was to confirm studies from prior years that risk-stratify areas in the watershed and compare the prevalence of coliforms. Understanding factors that impact the water quality from these areas is important for land management decisions.

Methods

A total of 80 sites from lakes and streams in wilderness areas in the Sierra Nevada of California were risk-stratified based on the primary terrestrial usage by either cattle, pack animals, human or nonimpacted "wild and natural" areas. These areas were selected, as each has different rates of fecal pollution into wilderness. Cattle excrete 99- 147 lbs/day (45–67 kg/day) of manure, a horse or mule (pack animal) 44-66 lbs/day (20–30 kg/day), and a healthy human 0.2 to 0.3 lbs/day (0.10 to 0.15 kg/day) (Ohio State University 2006; Rendtorff and Kashgarian 1967). Day hike areas, those wilderness areas where humans may visit by day but not stay overnight, could receive up to 0.3 lbs (0.15 kg) of human waste/person/day. Unvisited areas receive unknown amounts from birds and wild animals. Therefore, risk at each sampling site was defined as (1)Wild: areas rarely visited by humans or domestic animals: the prevalence of coliforms here provides a background from indigenous mammals or birds; (2) Day Hike: day use areas where humans would traverse but not camp overnight and where domesticated animals do not traverse: coliforms here would indicate that even limited human use impacts wilderness area; (3) Backpacker: areas used by humans to camp but where livestock and horses do not traverse; (4) Pack Animal: areas that have horse or mule traffic; and (5) Cattle Grazing tracks.

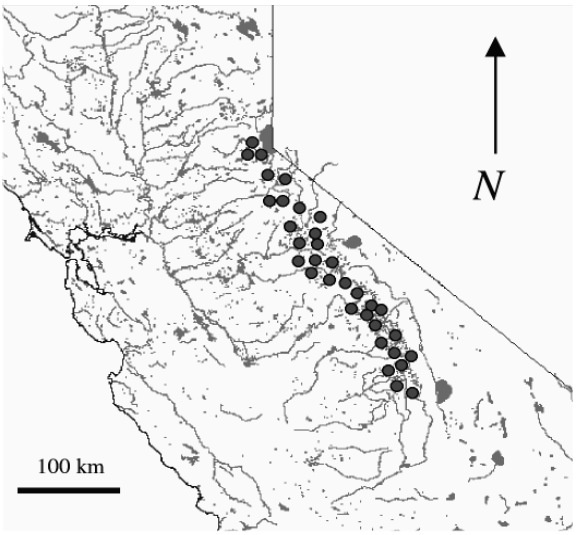

Figure 1—Study area and sample collection sites throughout the Sierra Nevada Mountain range. In some cases, a dot represents more than one sampling site because some sites were too close to individually display.

The risk designation of each site was made based on usage patterns with the assistance of the National Park and USDA National Forest Service. Collection sites were located within national parks, wilderness areas, and proposed wilderness area additions: Yosemite (n=36), Kings Canyon (n=17), Emigrant (n=14), Carson (n=6), and Hoover and proposed Hoover additions (n=7). A location map is shown in figure 1. Cattle are not allowed to graze in national parks, so all cattle risk sites were collected outside national park borders. During July, August, and September of 2005, water was collected in duplicate at each of the 80 sites in sterile test tubes and Millipore coliform samplers and transported to the university laboratories. Water was sampled from within 3.9 inches (10 cm) from the surface, where permitted, and at the deepest point from streams less than 3.9 inches (10 cm) depth. Temperature, elevation, dates and times were recorded at the time of collection. Bacteria were counted, then harvested and subjected to bacterial analysis using standardized techniques. Samples in which coliforms are found are reported as positive or negative. Results of heterotrophic counts reported as colony forming units of bacteria (CFU)/100 ml water. These techniques are described in detail elsewhere (Derlet and Carlson 2004). Total bacteria counts are presented as mean values and 95% confidence intervals. The Chi-square test was used to calculate differences between risk groups, and ANOVA for temperature and elevation.

Results

Wilderness water collection sites ranged from 4,996 to 10,997 ft (1,523 to 3,352 meters) in elevation. Water temperatures ranged from 42.8° F to 71.6° F (6°C to 22°C). Coliforms were found in 18% (2 of 11) of Wild sites, 18% (2 of 11) of Day Hike sites, and 15% (3 of 21) of Backpacker sites. In contrast, coliforms were found in 56%

(14 of 25) of Pack Animal sites and 92% (11 of 12) of Cattle Grazing tracks. Chi-square analysis revealed that the Wild, Day Hike and Backpacker versus Cattle or Pack Animal areas were significant ($p \leq 0.01$). No correlation could be made between water temperature and elevation. Table 1 compares the results from Yosemite and Kings Canyon National Parks to the USDA Forest Service Wilderness areas (see figure 2). Of the 53 national park sample sites, 30% (16/53) were positive for coliforms, compared with Forest Service wilderness areas, where 60% (16/27) were positive. Of the 16 positive Forest Service wilderness samples, 11 were from cattle sites, and 5 from stock sites.

With regard to heterotrophic bacteria, all samples grew normal aquatic bacteria including *Pseudomonas, Ralstonia, Serratia, Proteus*, and non-pathogenic strains of *Yersinia*. Mean bacterial counts and 95% confidence intervals are: Wild areas: 1,400 (500–2,300) CFU/100ml; Day Hike areas: 2,300 (1,400–3,200) CFU/100ml; Backpack sites 3,300 (2,400– 4,200) CFU/100ml, Pack Animal use areas 4,800 (3,600–6,000) CFU/100ml; and sites below Cattle Grazing areas 9,800 (7,800–11,800) CFU/100ml.

Discussion

The results of this study were similar to a smaller study performed in 2004 that examined 60 lakes or streams sites in the Sierra backcountry (Derlet and Carlson 2006). In that 2004 study, 100% of water collected below Cattle Grazing watersheds grew coliforms and 80% of Pack Animal sites had coliforms found. In addition, 7% of Backpacker sites and 7% of Wild sites yielded coliforms, similar to the current study. Day Hiker sites were not included in that analysis, but based on the current study, have the same risk profile as Wild and Backpacker sites. It is not possible to find sites exclusively used by pack animals, as these sites were also used by backpackers (see figure 3), therefore some of the coliforms found at these sites could have originated from human waste. Against this possibility, Backpack sites had no more coliforms than Wild sites. The Wild sites essentially served as control sites that measured background coliform levels.

Figure 2—Bench Lake, Kings Canyon National Park. Photo by R. Derlet.

There are few other studies that have attempted to analyze the risk for finding pathogenic microorganisms in the high Sierra by risk stratifying each sample site (Silverman and Erman 1979; Suk et al. 1987). In the 1970s, Silverman et al. performed an analysis of several lakes in Kings Canyon National Park (Silverman et al. 1979). They found that water from lakes and streams with higher human activity tended to have a higher prevalence of coliforms. However, the study did not differentiate between backpacker only versus backpacker and pack animal traffic. A retrospective review of the data shows that backpacker-only areas had little coliform contamination. For example, Dragon Lake in Kings Canyon is located up a steep granite embankment off-trail and, although has human presence, it rarely sees visits by pack animals. This lake had no coliform contamination in the Silverman study.

The finding that Backpacker sites had a low level of coliforms similar to that found at Wild or Day Hike sites is consistent with a prior study (Derlet and Carlson 2006). One might expect coliform levels to be high, as areas sampled have use by hundreds of backpackers in season. However, unlike for cattle and pack

Table 1. Comparison of National Park and Forest Service areas by risk[a]

Number of Sites with Coliforms/Total Sites by Category						
	Wild	Day Hike	Backpack	Pack Animal	Cattle	Total Sites
Kings Canyon NP	0/0	0/2	1/6	3/9	N/A	4/17
Yosemite NP	2/10	2/7	2/10	6/9	N/A	12/36
N.F. Wilderness	0/1	0/2	0/5	5/7	11/12	16/27
Totals	**2/11**	**2/11**	**3/21**	**14/25**	**11/12**	**32/80**
Percentages	**18%**	**18%**	**14%**	**56%**	**92%**	**40%**

[a]Each risk category and area data show the number of sites positive for coliforms divided by total sites in the risk area. For example, in Kings Canyon NP, 3 of 9 pack animal sites tested positive for coliforms.

animals, human waste is buried in the soil and undergoes decomposition, unlike surface deposition by domesticated animals. We believe this may be an important reason for the finding.

The current study is important for several reasons. First of all, it confirms the results found in a limited study, conducted in the summer of 2004. It also shows that within high alpine wilderness areas, the quality of water differs depending on the usage pattern. In addition, it provides further evidence that cattle grazing tracks result in significant contamination of the watershed with coliforms and potential risk of pathogenic organisms. Although coliform contamination below cow pastures has been described in the literature (Ramos et al. 2006), actual documentation in the Sierra Nevada wilderness is limited, and this study provides important data for federal land management agencies. Furthermore, the finding of coliforms below areas where pack animals have traversed waterways (see figure 4) suggests that management decisions on wilderness stock should be reviewed to ensure a more pristine watershed and, thus, ensuring acceptable water quality for California's largest water source. In addition to microorganisms, cattle and pack animals excrete large amounts of phosphorus and nitrates, which stimulate algae growth and have detrimental effects on the environment (Belsky et al. 1999).

High Sierra wilderness areas used by cattle or livestock are at a higher risk for coliform pollution of lakes and streams than areas used exclusively for day use or backpacking by humans. Humans utilizing water in wilderness areas for drinking and cooking purposes should be aware of the possible presence of pathogenic bacteria. IJW

REFERENCES

American Public Health Association. 1998. *Standard Methods for Examination of Water and Wastewater*, 20th ed. Baltimore, MD: United Book Press Inc., sec. 9, p. 1.

Belsky, A. J., A. Matzke, S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. *Journal of Soil and Water Conservation* 54: 419–31.

Byappanahalli, M., M. Fowler, D. Shively, and R. Whitman. 2003. Ubiquity and persistence of *Escherichia coli* in a midwestern coastal stream. *Appl. Environ. Microbiol*. 69(8): 4549–55.

Carle, D. 2004. *Introduction to Water in California 2004*. Berkeley: University of California Press, pp. 1–32.

Derlet, R. W., and J. R. Carlson. 2004. An analysis of wilderness water in Kings Canyon, Sequoia, and Yosemite National Parks for Coliform and Pathologic Bacteria. *Wilder. Environ. Med*.15: 238–44.

Derlet, R. W., and J. R. Carlson. 2006. Coliform bacteria in Sierra Nevada wilderness lakes and streams: What is the impact of backpackers, pack animals, and cattle? *Wilderness Environ. Med*. 17: 15–20.

Goldman, C. R. 2000. Four decades of change in two subalpine lakes. *Verh. Internat. Verein. Limnol.* 27: 7–26.

Harvey, S., J. R. Greenwood, M. J. Pickett, and R. A. Mah. 1976. Recovery of *Yersinia enterocolitica* from streams and lakes of California. *Appl. Environ. Microbiol*. 32: 352–54.

Ohio State University. 2006. Ohio livestock manure management guide. Bulletin 604–06: 1–9. Columbus: Ohio State University.

Ramos, M. C., J. N. Quinton, and S. F. Tyrrel. 2006. Effects of cattle manure on erosion rates and runoff water pollution by faecal coliforms. *J. Environ. Management* 78(1): 97–101.

Rendtorff, R. L., and M. Kashgarian. 1967. Stool patterns of healthy adult males. *Dis. Colon. Rectum* 10: 222–28.

Silverman, G., and D. C. Erman. 1979. Alpine Lakes in Kings Canyon National Park, California: Baseline conditions and possible effects of visitor use. *J. Environ. Manag*. 8: 73–87.

Suk, T. J., S. K. Sorenson, and P. D. Dileanis. 1987. The relation between human presence and occurrence of *Giardia* cysts in streams in the Sierra Nevada, California. *J. Freshwater Ecol.* 4(1): 71–75.

USDA Forest Service. 2006. Environmental assessment: Rangeland allotments Phase 1. Sonora, CA: Stanislaus National Forest.

Figure 3—Upper Bubbs Creek watershed, Kings Canyon National Park. Photo by R. Derlet.

Figure 4—Pack train, John Muir Wilderness. Photo by R. Derlet.

ROBERT W. DERLET is an MD at the University of California, Davis Medical Center, 4150 V Street, PSSB Suite 2100, Sacramento, CA 95817, USA; email: rwderlet@ucdavis.edu.

JAMES R. CARLSON, PhD, San Mateo Department of Health, San Mateo, CA.

JOHN R. RICHARDS, MD, University of California, Davis.

Risk factors for coliform bacteria in backcountry lakes and streams in the Sierra Nevada mountains: a 5-year study. Derlet, R.W., Ger, K.A., Richards, J.R., Carlson, J.R. Coliform bacteria in Sierra Nevada wilderness lakes and streams: what is the impact of backpackers, pack animals, and cattle? Derlet, R.W., Carlson, J.R.Â An analysis of wilderness water in Kings Canyon, Sequoia, and Yosemite national parks for coliform and pathologic bacteria. Derlet, R.W., Carlson, J.R. An analysis of human pathogens found in horse/mule manure along the John Muir Trail in Kings Canyon and Sequoia and Yosemite National Parks. Derlet, R.W., Carlson, J.R. Coliform and pathologic bacteria in Sierra Nevada national forest wilderness area lakes and streams. Coliform bacteria in Sierra Nevada wilderness lakes and streams: what is the impact of backpackers, pack animals, and cattle? Wild. Environ. Med., 17, 15â€“20. [CrossRef] [Google Scholar]. Derlet R.W., Ger K.A., Richards J.R. andCarlson J.R., 2008. Risk factors for coliform bacteria in backcountry lakes and streams in the Sierra Nevada mountains: a 5-year study. Wild. Environ. Med., 19, 82â€“90. [CrossRef] [Google Scholar]. Derlet R.W., Goldman C.R. andConnor M.J., 2010. Reducing the impact of summer cattle grazing on water quality in the Sierra Nevada Mountains of California: a proposal. â€œRisk factors for coliform bacteria in backcountry lakes and streams in the Sierra Nevada mountains: a 5-year study.â€ Wilderness & environmental medicine 19.2 (2008): 82-90. Surface water from watersheds below cattle areas and those used by pack animals is at high risk for containing coliform organisms. Water from Wild, Day Hike, or Backpack sites poses far less risk for contamination by coliforms. Derlet, Robert W., James R. Carlson, and Mikla N. Noponen. â€œColiform and pathologic bacteria in Sierra Nevada national forest wilderness area lakes and streams.â€ Wilderness & environmental medicine 15.4 (2004): 245-249. Coliform bacteria were detected in 14 of 31 sites (45%). Dennis, David T., et al.