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Backpacking in Yosemite and Kings Canyon National Parks and Neighboring Wilderness Areas: How Safe Is the Water to Drink?

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Objective. The objective of this study was to determine the risk of acquiring disease from popular Sierra Nevada wilderness area lakes and streams. This study examines the relative risk factors for harmful waterborne microorganisms using coliforms as an indicator.
Methods. Water was collected in the backcountry Yosemite and Kings Canyon National Parks and neighboring wilderness areas. A total of 72 sites from lakes or streams were selected to statistically differentiate the risk categories: (1) natural areas rarely visited by humans or domestic animals; (2) human day use–only areas; (3) high use by backpackers; (4) high use by pack animals; and (5) cattle- and sheep-grazing tracts. Water was collected in sterile test tubes and Millipore coliform samplers during the summer of 2006. Water was analyzed at the university microbiology lab, where bacteria were harvested and then subjected to analysis using standardized techniques. Statistical analysis to compare site categories was performed using Fisher's exact test.
Results. Coliforms were found in none of the 13 wild sites, none of the 12 day hike sites, and only 3 of 18 backpacker sites (17%). In contrast, 14 of 20 sites (70%) with pack animal traffic yielded coliforms, and all 9 sites (100%) below the cattle-grazing areas grew coliforms. Differences between backpacker versus cattle or pack areas were significant, $p \leq 0.05$. All samples grew normal aquatic bacteria. Sites below cattle grazing and pack animal use tended to have more total heterotrophic bacteria.
Conclusions. Alpine wilderness water below cattle areas used by pack animals is at risk for containing coliform organisms. Water from wild, day hike, or backpack areas showed far less risk for coliforms.

Yosemite, Kings Canyon National Parks (NP), and adjacent wilderness are popular destinations for backpackers and day hikers from all over the world. The John Muir Trail traverses these areas, and thousands of hikers each summer travel from Yosemite through adjacent wilderness areas and Kings Canyon NP to the top of Mt Whitney in Sequoia NP. Although many hikers treat their drinking water either by filtration or by application of halogen compounds, treatments are not 100% effective. In addition, filters may become clogged and ineffective.

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Coliform bacteria have been established as indicators of fecal pollution or contamination of waterways in the United States, including *Giardia*.[1] Coliforms in wilderness areas may originate from one or a combination of sources: (1) wild animals; (2) humans from day use only; (3) backpackers; (4) horses and pack animals (stock); and (5) cows or commercially grazed animals. Coliform pollution of wilderness areas by humans may occur through inadequate burial and disposal of fecal material. In addition, bathing or swimming in lakes may also result in microbial pollution.[2] Pack animals may pollute by deposition of manure either directly into lakes and streams or indirectly onto trails or meadows and have been documented to import *Giardia* into the Sierra wilderness.[3] This manure may be washed into waterways by either summer storms or annual snowmelt.[4] The US Department of

Agriculture (USDA) Forest Service leases tracts in wilderness areas for cattle grazing.[5] Cattle manure is known to contain many microbes pathogenic to humans, including *Giardia*, *Cryptosporidium*, and *Escherichia coli* O157:H7.[6] Finally, coliform or other bacteria potentially may originate from natural, wild animal zoonotic reservoirs. Within the Sierras, over 3,000,000 acres of land have been designated as official wilderness by the National Park Service or USDA Forest Service and protected from development, logging roads, and motor vehicles.[7] Most of these protected recreational areas range from 1,800 to 4,200 m in elevation. In addition to providing water to hikers and backpackers, these high alpine lakes and streams in NP and wilderness areas are also an important watershed because nearly 50% of California's household domestic water originates in the Sierra Nevada mountains.[8] Therefore, the issue of microbial pollution by day hikers, backpackers, horses and pack animals, and also commercial cattle and sheep grazing is important to multiple users. Pollution may occur from one or more of several potential harmful substances including both microbial organisms and toxic substances.[9] Microorganisms that may cause diarrhea include coliforms, pathogenic bacteria, viruses, and protozoa such as *Giardia* or *Cryptosporidium*.[10] Although concerns have been raised regarding *Giardia* in the Sierra, many authors have presented data that other fecal pathogens such as enterotoxic *E coli* may play a greater role in mountain-acquired illness.[11–14] Debate has ensued on the impact of backpackers, cattle grazing, or livestock such as mules and horses polluting the watersheds in wilderness areas if any. We completed two studies in prior years that surveyed remote Sierra Nevada mountain lakes and streams.[15,16] However, these studies did not provide the statistical power to show significant differences for all the risk factors. This current study has been designed to provide a direct comparison of risk factors.

We hypothesized that wilderness freshwater from watersheds that have different human or animal use patterns would have differing risk for the presence of coliform bacteria. Therefore, the purposes of the study were to analyze wilderness freshwater for coliforms and compare results from watersheds that have different exposures to native animals, humans, and domesticated animals.

Methods

Field Site Collection

Seventy-two sites were prospectively selected to differentiate among environmental risk for different types of bacterial contamination in wilderness areas of Kings Canyon, Sequoia, and Yosemite NP, as well as the following USDA Forest Service wilderness areas: Carson-Iceberg, Emigrant, Hoover, and John Muir. The Hall Natural Research Area adjacent to the eastern boundary of Yosemite and southern boundary of Hoover wilderness was also included. No overnight camping or motor vehicles are allowed in the Hall area and the remote areas used by day hikers. Risk classifications included: (1) wild areas not contaminated by humans or domesticated animals; (2) day hike areas used only by humans; (3) watershed areas used by backpackers without stock; (4) areas used by horses and pack animals (stock); and (5) cattle-grazing tracts. The sites were risk stratified with the assistance of the National Park Service and USDA Forest Service based on user nights by backpackers, pack animals, and cattle allotments in grazing tracts. Cattle grazing is not permitted in NP, so all samples in cattle-grazing tracts were taken from within Forest Service wilderness areas.

Field Water Collection

Water samples were collected from June through September in 2006. Water was collected in (1) sterile test tubes and (2) Millipore total coliform count samplers (Millipore Corporation, Bedford, MA, USA). Samples were collected 5 cm below the water surface, and care was taken not to disturb bottom sediment. All samples were collected in duplicate, and samples were cooled following standardized procedures and transported to the University of California Davis. Sample devices measured bacteria for 1 mL of sample. This was multiplied by 100 as per standardized procedure of reporting colony-forming unit (CFU)/100 mL in the water literature. Water temperature was measured at each site using a stream thermometer (Cortland Line Company Inc., Cortland, NY, USA). Location and elevation were determined using United States Geological Survey topographical maps, guidebooks, backcountry rangers, and 30 years of author backcountry experience.

Bacterial Analysis of Water Samples

Details of analysis for bacteria have been described elsewhere.[15,16] The analysis for coliform counts and total bacterial counts required incubating Millipore counting plate paddles at 35°C for 24 hours. Bacterial colonies were counted and then harvested for further analysis. Colonies were initially plated onto sheep blood and MacConkey agars (Reel Inc., Lenexa, KS, USA). Lactose-fermenting colonies from MacConkey plates were presumed to be coliform bacteria and subjected to further testing. Further screening and initial identification were done by subplating onto Cefsulodin Irgasan Novobiocin (*Yersinia*) agar, sorbitol MacConkey agar, and Lysine Iron Agar and Tripple Sugar Iron tubes.

Statistical significance between groups was calculated with Fisher's exact test using STATA software (STATA, College Station, TX, USA).

Results

The results are summarized in Tables 1–5. Significant differences were found among sample groups. All nine samples (100%) taken from below areas in which cattle grazed or had recently grazed were positive for coliform growth. In areas frequented by pack animals, 14 of 20 samples (70%) had coliforms. In contrast, coliforms were found in only 3 of 18 areas where backpackers camped without the presence of horses or pack animals. None of the 12 sites used by human day hikers (and not used by stock) had coliforms, and similarly, none of the 13 wild sites rarely visited by humans or pack animals contained coliforms. The differences between wild, day hike, or backpacker versus either pack animal sites or cattle sites were statistically significant ($p \geq 0.05$). No statistical differences were found when comparing wild, day hike, and backpacker sites to each other. No statistical differences were found in numbers of coliform bacteria based on water temperature or elevation. Among the 14 pack animal sites with coliforms, 7 were from lakes and 7 from creeks or rivers.

Noncoliform aquatic bacteria were also identified from the samples. The environmental heterotrophic bacterial counts are included in the tables. Although not statistically significant, total bacterial counts tended to be lower at the wild and day hike sites. No correlation could be made from temperature or elevation for either coliform or total bacterial counts.

Discussion

In this study, areas frequented by cattle or pack animals had the greatest degree of fecal contamination into the wilderness watershed. We are not surprised at the finding of coliforms below cattle-grazing areas. In most of these areas, moderate amounts of cattle manure were observed during field collections. In some respects, finding coliforms below grazing areas serves as a positive control for the study. One might expect coliforms in watershed with high densities of cattle.[4] However, finding coliforms in areas frequented by pack animals is significant. NP and USDA Forest Service wilderness have strict requirements on management of livestock in wilderness areas. It is not possible to exclude a human contribution to this finding, as high-volume pack animals areas are also used by humans. However, the fact that very few backpacker-only sites had coliforms would support the conclusion that microbial contamination in pack animal areas is a result of pack animal manure. In a prior study, we examined Sierra water for coliform bacteria.[15] However, in that study, samples were taken from water primarily from sites used by both pack animals and humans and we were unable to fully determine the source. An additional study did not differentiate among areas used only by day hikers that did not see stock

Table 1 Wild sites: rare human/stock watershed impact

Wilderness area	Place	Elevation (m)	Temperature (°C)	Coliforms (CFU/100 mL)	Other bacteria (CFU/100 mL)
Yosemite	Johnston Pass Creek	2,780	13	None	2,100
	Raymond Pass Creek	2,943	11	None	900
	Florence Creek	2,819	7.5	None	300
	Upper Yosemite Creek—Side Creek	2,501	11.5	None	6,400
	Hoffmann Creek	2,560	12	None	2,600
	Upper Middle Dana-Gibbs Creek	3,016	10	None	300
	Springs, Tioga-Gaylor Lake trail	3,109	8.0	None	None
Kings Canyon	Bago Springs Creek	2,840	8.0	None	3,900
	Spring, north of Glen Pass John Muir Trail	3,353	7.0	None	100
	Creek above Rae Lake Ranger Station	3,231	5.0	None	2,500
	Creek Draining Lake 10,315	2,768	12.5	None	4,100
	Lake 11,540 above Darwin Bench	3,517	9.5	None	1,100
	Creek at McClure Ranger Station	2,926	9.5	None	1,500

CFU = colony-forming unit.

Table 2 Day hike–only sites

Wilderness area	Place	Elevation (m)	Temperature (°C)	Coliforms (CFU/100 mL)	Other bacteria (CFU/100 mL)
Yosemite	Budd Creek	2,622	10	None	4,600
	Gaylor Lake	3,150	13	None	450
	Upper Gaylor Creek	3,155	12	None	600
	Lower Gaylor Creek	2,835	17	None	650
	Granite Lake	3,176	16	None	200
	Middle Fork Tuolumne River, Headwaters	2,438	10.5	None	3,400
	Dana Fork of Tuolumne River	2,941	10	None	2,200
Kings Canyon	Bull Frog Lake	3,231	11.5	None	800
	Creek in Meadow below Taboose Pass	3,353	11	None	2,800
Emigrant	Blue Lake Creek	3,048	12	None	1,100
Carson	Murray Creek	2,149	9.0	None	2,000
Hall area	Green Treble Lake—lower	3,010	9.0	None	400

CFU = colony-forming unit.

traffic but did find that samples from cattle and pack animal sites had significantly higher levels of coliforms compared to wild or backpack sites.[16] This current study added sites that were used by human day hikers only and confirms the data from a prior year on the other risk categories. Pack animal sites are also used by backpackers; however, the low prevalence of coliforms in most of those areas used exclusively by humans in the absence of pack animals would suggest that pack animals are most likely the source in the combined use pack animal areas.

Pack animals produce high volumes of manure, which is deposited directly onto the surface of trails, soil, or meadows.[17] Manure deposited on the ground can be swept into streams during summer rains or spring snow runoff.[4] During the field operations of the study, pack animals were observed on several occasions to be defecating directly into bodies of freshwater. Fecal contamination as indicated by the finding of coliforms would place the watershed at risk for harboring microbes capable of causing human disease. Some of these infections are a potential threat to humans. This includes certain pathogenic strains of *E coli*, *Salmonella*, *Campylobacter*, *Aeromonas*, and protozoa such as *Giardia*, all of which have animal reservoirs. The organism *Yersenia enterocolitica* has been previously cultured

Table 3 Backpacking sites

Wilderness area	Place	Elevation (m)	Temperature (°C)	Coliforms (CFU/100 mL)	Other bacteria (CFU/100 mL)
Yosemite	Yosemite Creek	2,278	19	None	10,300
	Booth Lake	3,001	15	None	1,600
	Townsley Lake	3,154	4.5	None	400
	Vogelsang Lake	3,147	8	100	2,200
	Grant Lake	2,819	20	None	3,300
	Ten Lakes #2	2,813	14	None	4,500
	Ten Lakes #3	2,750	15	None	6,400
	Ten Lakes #4	2,727	16	400	4,300
	East Ten Lakes	2,865	19	None	3,600
Kings Canyon	East Creek at confluence of Bubbs Creek	2,494	15	None	3,500
	Charlotte Creek	2,219	11	None	5,200
	Charlotte Lake near Ranger Station	3,165	15	None	1,800
	Upper Rae Lake	3,213	12.5	None	3,500
	60 Lakes Drainage Creek	2,926	13	None	2,500
	South Fork Kings River at Upper Paradise	2,134	12.5	None	600
	Bench Lake	3,219	11.5	None	800
	Darwin Canyon Creek	3,475	11	200	7,400
	Goddard Canyon	2,576	11.5	None	4,500

CFU = colony-forming unit.

Table 4 Stock areas (horses and pack animals)

Wilderness area	Place	Elevation (m)	Temperature (°C)	Coliforms (CFU/100 mL)	Other bacteria (CFU/100 mL)
Yosemite	Tuolumne River (Lyell Canyon)	2,804	16	200	3,000
	Rafferty Creek	2,673	8.0	100	3,200
	Fletcher Lake	3,095	10	None	400
	Fletcher Creek	3,060	14	None	1,450
	Merced Lake	2,195	12.5	200	1,200
	Sunrise High Sierra Camp Drainage Creek	2,608	17	200	2,100
	Cathedral Lake	2,837	14	100	1,800
	Dog Lake	2,804	13	100	850
Kings Canyon	Bubbs Creek at Confluence Kings River	1,560	12.2	None	2,200
	Bubbs Creek at Junction Meadow	2,469	14	200	4,700
	Bubbs Creek at Vidette Meadow	2,896	10.5	None	6,000
	Arrow Lake	3,154	12	None	1,400
	Arrow-Dollar Creek Trail crossing	3,145	12	100	2,700
	Dollar Lake	3,115	12.5	300	7,400
	Rae Lake (middle)	3,211	16	200	2,900
	South Fork Kings River at Lower Paradise		13	300	2,800
	Woods Lake	3,265	13.5	100	1,400
	Copper Creek	1,555	13	None	3,000
Carson	Silver King Creek	2,316	10	100	1,100
Muir	South Fork San Joaquin River	2,390	15	200	20,000

CFU = colony-forming unit.

in high alpine areas of the Sierra and may have a natural reservoir in small mammals and birds.[18] Pack animals entering the High Sierra have been subject to analysis and *Giardia* found in their manure.[19]

Escherichia coli and other coliform bacteria can survive in aquatic environments for long periods of time depending on the nutriment availability, pH, and water temperature. The number of years that *coliforms* can survive in aquatic environments has been debated.[20] A study of Lake Michigan shore water showed that *E coli* may sustain itself indefinitely in appropriate environmental situations.[21] In addition to *Giardia*, cattle are noted to carry *E coli* strain O157:H7 at a rate of 1% to 30%, placing persons who drink untreated water below established cow pastures at risk for a very serious disease.[6] Studies on this strain have also shown it to survive in cold water.[6,22] In addition, many non-O157 *E coli* are capable of inducing serious disease in humans.[23]

Finally, we wish to comment on the noncoliform bacteria found in the study. Aquatic bacteria are part of a normal ecosystem of lakes and streams.[24] Indeed, if bacteria were absent, the normal food chain from frogs to fish, as well as the ecological balance, would be in jeopardy. A prior study identified many species, including *Achromobacter* species, *Pasteurella haemolytica*, *Rahnella aquatilis*, *Ralstonia paucula*, *Serratia odorifera*, *Serratia plymuthica*, *Yersinia intermedia*, *Yersinia*

Table 5 Cattle risk watersheds

Wilderness area	Place	Elevation (m)	Temperature (°C)	Coliforms (CFU/100 mL)	Other bacteria (CFU/100 mL)
Carson	Upper Clark Fork River	2,072	13	400	10,200
	Lower Clark Fork River	2,316	12	600	12,600
	Disaster Creek	2,366	12	550	11,000
	Arnot Creek	2,000	13	100	4,600
	Woods Creek	1,976	14	100	5,200
Emigrant	Kennedy Creek	2,244	14	200	8,600
Hoover	Buckeye Creek	2,377	9	450	4,700
	Molydunite Creek	2,773	14	200	12,000
	South Fork Walker River (Burt Canyon)	2,719	14.5	200	11,000

CFU = colony-forming unit.

kristensenii, *Yersinia frederiksenii*, *Pseudomonas* species, etc.[16] That study of wilderness water suggested a correlation between total bacterial counts and usage by backpackers, which was not found in the current study.

Recommendations

Hikers and backpackers should be extremely cautious with water in areas used by cattle. If water needs to be taken from lakes or streams to drink, it should be subject to maximal disinfection techniques. In areas where pack animals have been present, water should also be treated. In Sierra Nevada wilderness areas, water from alpine sidestreams that is free from domesticated animal activity has a very low risk of harboring pathogenic organisms and a minimal risk of illness if drunk untreated.

Limitations

Coliforms were used as an indicator of fecal pollution, and specific pathogenic microorganisms were not analyzed. Although samples were taken during times of the greatest use by humans and domesticated animals, these represent single point in time samples: additional samples at different times may have increased positive findings. Data in this report are applicable only to Sierra Nevada wilderness areas and not to areas with human habitation. The data may not be extrapolated to European or other international mountain areas. Finally, backpacker use was not quantified in terms of persons/night.

Conclusion

Alpine wilderness water below cattle-grazing tracts or areas used by pack animals is at risk for containing coliform organisms. Water from wild, day hike, or back areas showed far less risk for coliforms.

Declaration of Interests

The author states that he has no conflicts of interest.

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