

IMPACTS OF CATTLE ON THE WATER QUALITY OF
TINAJAS WITHIN CAPITOL REEF NATIONAL PARK, UTAH

Capitol Reef National Park (CARE) is located on the Colorado Plateau in south-central Utah (Fig. 1). The park was established in 1971, in part, to protect the scientific value of the Waterpocket Fold, an immense monocline composed of numerous sandstone strata. Within the Navajo sandstone strata of the Fold are steep drainages containing waterpockets or tinajas which occur in a series down the drainage. These tinajas are natural depressions formed by water and wind erosion. They collect runoff and range in size from small ephemeral pools (few m^3) to large perennial pools ($> 1000 \text{ m}^3$) supporting stands of riparian and emergent vegetation including willow, cattails, and sedges. Tinajas within a drainage are connected by subsurface flow through the porous sandstone and by overland flow during times of high runoff.

The tinaja drainages are located in the southern portion of the park where the slope of the Fold is the greatest ($>70\%$). This is an arid landscape where the mean annual precipitation is only 13 cm, mostly occurring during late summer thunderstorms. Therefore, the tinajas and their surrounding vegetation are a critical source of water and shade for wildlife and hikers.

When CARE was established, livestock grazing was allowed to continue with a phase-out planned to begin in 1981. However, due to the controversy this phase-out generated, Congress in 1983 directed the National Park Service (NPS) to study the effects of livestock grazing on park resources. Water resources were identified as being susceptible to degradation from cattle use.

Therefore, in 1986 this study was initiated to assess the impact of cattle grazing on tinajas.

Until 1988 the two tinaja drainages used in this study were within an active grazing allotment (Waterpocket) with 200 AUM's (30-40 cattle) grazed from November through April of each year. However, in the spring of 1988, the NPS purchased 70% of the AUM's within CARE, including all within the Waterpocket allotment. Based upon this grazing history, the following three time periods were defined for this study:

1. Grazed: December 1986 through May 1988.
2. Transition: 0 - 12 months after grazing was discontinued.
3. Ungrazed: 13 - 30 months after grazing was discontinued.

During the grazed period, cattle frequented the tinajas for shade and water. The tinajas low in each drainage were accessible to cattle while those high in each drainage were inaccessible due to the slickrock and steep terrain. This arrangement allowed us to compare the water quality of the lower, accessible tinajas to that of the higher, inaccessible tinajas during various times periods. The purchase of the AUM's allowed us to compare the water quality of the tinajas accessible to cattle during grazing and after grazing was discontinued. Therefore, the hypotheses to be tested in this study were as follows:

HO1: Fecal coliform bacteria numbers in tinajas accessible to cattle will not differ from numbers in tinajas

inaccessible to cattle during any of the time periods.

HO2: During the period of cattle grazing (i.e., through April 1988), fecal coliform bacteria numbers will not differ between the grazing and non-grazing seasons in tinajas accessible to cattle.

HO3: Fecal coliform bacteria numbers in tinajas accessible to cattle will not change after grazing in the area is discontinued.

MATERIALS AND METHODS

Two tinaja drainage systems (Cottonwood and Willow), located within the Waterpocket Fold in the southern portion of CARE, were selected for this study (Fig. 2). These drainages were adjacent to each other, within the same grazing allotment, and of approximately equal size (1.1 km²). Within each drainage an upper tinaja inaccessible to cattle (#2) and a lower tinaja accessible to cattle (#5) were selected for monitoring.

Between December, 1986 and September, 1990, water and sediment samples were collected at two week intervals from the upper and lower tinaja within each drainage. Two sampling sites were established at each tinaja and a water and sediment sample was collected in a sterile Whirl-pak plastic bag from each site.

Sediment samples were obtained by stirring the substrate and pulling the bag through the clouded water. Samples were kept cool, transported to the park laboratory, and processed for fecal coliform bacteria within 6 hrs of collection. The direct membrane filter method (EPA 1978) was used to determine the

number of fecal coliform bacteria in the samples. This process involved filtering a volume of the sample through a 0.45um filter, placing the filter in a petri dish on an absorbent pad saturated with M-FC agar, incubating the dish at 44.5 C for 24 + 1 hour, and counting the number of blue colonies (i.e., fecal coliform bacteria) that appear. This number was converted to number per 100 ml of sample.

Cattle and wildlife use of the tinajas was measured by the amount of feces and tracks of each found within 2 m of the sampled tinajas. Fresh and old feces were categorized as being absent, sparse (1-3 piles within 2 m of water), common (1-5 piles within 1 m of water or 1-3 piles in water), abundant (6-10 piles within 1 m of water or 4-6 piles in water), and ubiquitous (>10 piles within 1 m of water or >6 piles in water). Tracks were categorized similarly. The degree of urine odor was also assessed and categorized as being absent, scarcely noticeable, apparent, strong, and overpowering.

Precipitation was measured near the top and bottom of each drainage using a plastic raingage. Measurements were made each time the tinajas were sampled. After recording the reading, the gages were emptied and resupplied with a few ml of baby oil to prevent evaporation.

Due to non-normality of the coliform bacteria data based upon Wilk-Shapiro tests, non-parametric statistics were used for the analyses. Wilcoxon signed rank tests (non-parametric paired t-tests) were used to assess differences in the number of

bacteria in tinajas accessible and inaccessible to cattle during each of the three periods. Rank sum tests (non-parametric two-sample tests) were done to assess if coliform numbers in tinajas accessible to cattle differed during the grazing and non-grazing seasons during the grazed period. Kruskal-Wallis tests (non-parametric analysis of variance) were used to test if numbers of coliforms within each tinaja differed by time period. P-values are reported to allow the reader to evaluate the significance of the differences. Simple linear regression analyses were used to determine the relationship between the number of coliforms in a sample and other variables that were measured (i.e., feces, tracks, urine odor, and precipitation).

RESULTS

H01

Our data rejected this hypothesis. In the Willow drainage, the number of coliform bacteria was significantly greater in water and sediment in tinaja #5 than in tinaja #2 during the grazed period (Table 1). Because the number of coliforms in #5 decreased after grazing was discontinued in the Waterpocket Allotment (Fig. 3), there was no longer a difference between #2 and #5 in the transition or ungrazed periods (Table 1). Results in the Cottonwood drainage differed from these, being inconsistent between the water and sediment samples. The number of coliforms in water was significantly greater in #5 than in #2 in both the grazed and transition periods. However, again, there was no difference in the ungrazed period (Table 1). The number

of coliforms in the sediment samples was not significantly different in any of the three periods, although they were nearly so in the grazed and transition periods (Table 1). For both water and sediment, #5 had a higher frequency than #2 of being contaminated with coliforms in the grazed period; however, this difference had diminished by the transition and ungrazed periods (Fig. 4).

HO2

Our data supported this hypothesis. In both the Willow and Cottonwood drainages, the number of fecal coliform bacteria in the accessible tinaja did not differ between the grazing and non-grazing seasons for water or sediment (Willow: $p=0.6497$ and $p=0.8197$; Cottonwood: $p=0.4279$ and $p=0.4452$, respectively).

HO3

For both Willow #5 and Cottonwood #5, our data rejected this hypothesis for sediment samples but accepted it for the water samples. Although the number of coliforms decreased over time in both the water and sediment samples, there was no difference in the number of coliforms in water among the three time periods for Willow #5 or Cottonwood #5 ($p=.0574$ and $.4502$, respectively); the decrease was significant for the sediment samples ($p=.0026$ and $.0233$, respectively). Although not statistically significant, the average number of coliforms in water samples from Willow #5 decreased from over 2300 in the grazed period to 81 in the

Table 1. Results of Wilcoxon signed rank tests comparing coliform bacteria numbers in tinajas accessible to cattle and inaccessible to cattle in the Willow and

Cottonwood drainages during the three time periods.

1. WILLOW DRAINAGE

P E R I O D

Sample Type	Grazed	Transition	Ungrazed
Water	0.0025	0.9326	0.0687
Sediment	0.0005	0.2361	0.6241

2. COTTONWOOD DRAINAGE

P E R I O D

Sample type	Grazed	Transition	Ungrazed
Water	0.0052	0.0208	0.5067
Sediment	0.0591	0.0580	0.5936

ungrazed period (Fig. 3).

Linear Regression Analyses

The results of the linear regressions revealed that the

number of coliforms present was related more to the abundance of fresh cattle feces for both water and sediment ($r^2 = 89$ and 79 , respectively) than to old cattle feces, wildlife feces, tracks, or urine odor. The average number of coliforms present in a sample increased significantly from absent/sparse feces to common/abundant feces (Fig. 5). The trend in frequency of cattle feces contamination of accessible tinajas during the three time periods exhibits the same decrease from grazed through ungrazed as shown for the number of coliforms over time (Fig. 6).

DISCUSSION

The results of our study are consistent with others which have shown that cattle increase the number of fecal coliform bacteria in an aquatic system (Teidemann et al. 1987, Gary et al. 1983, Doran and Linn 1979) and that elevated counts may remain high for several months after cattle are removed (Clemm 1977). Our results differed somewhat between the Willow and Cottonwood drainages. Both Willow #5 and Cottonwood #5 exhibited decreases in the numbers of coliforms in water and sediment from the grazed to the ungrazed periods, however, these decreases were not significant in all cases. Also, in both drainages, the number of coliforms in the accessible tinaja was always greater than in the inaccessible tinaja during the grazed period; this difference in numbers between the accessible and inaccessible tinajas diminished through the transition and ungrazed periods, but again, this difference was not always significant.

Numbers of coliforms were typically higher in Willow #5 than

in Cottonwood #5 even though the latter had a higher frequency of cattle feces contamination (76% vs. 50%). This is likely attributable to the smaller volume of Willow #5 (30 m³) which would tend to concentrate the coliforms compared to Cottonwood #5 (414 m³) which would dilute them.

In our study sediment samples generally had more coliforms than water samples. Sediments serve as a reservoir for fecal coliforms (Kunkle 1970, Van Donsel and Gelfreich 1971, Stephenson and Rychert 1982, Tiedemann et al 1987). Numbers of coliforms in sediment are 2 to 760 times greater than in surface waters (Stephenson and Rychert 1982). Disturbance of the sediment releases coliforms into the water; therefore, even after cattle are removed from an area, sediments can be a significant source or reservoir for fecal bacteria (Stephenson and Rychert 1982, Kunkle 1970, and Goldreich 1970). Although we were unable to show this due because collection of coliform data was not timed according to precipitation events, we observed that numbers of coliforms were typically highest after a rainstorm. As water moved down the drainage and into each tinaja, bottom sediments were disturbed, suspending coliforms into the water column. To show this with data, some of our sampling should have corresponded with precipitation events.

In addition to sediments, animal feces are a reservoir for coliform bacteria and could readily be flushed into a tinaja from precipitation. A fecal deposit protects the bacteria within allowing them to survive for more than a year in a bovine feces

(Clemm 1977). Buckhouse and Gifford (1975) found that bacteria within a fecal deposit were able to survive intense sunlight and heat for at least a summer. Therefore, it seems that fecal deposits left by cattle would be capable of providing a long-term continuous source of coliforms to the tinajas. The ability for bacteria to survive in sediments and feces explains why in our study, numbers of coliforms present in the non-grazing season did not differ from numbers present in the grazing season. However, after one year survival of coliforms outside the host declines; thus, one year after grazing was discontinued numbers of coliforms in accessible tinajas no longer differed from numbers in inaccessible tinajas in the Willow drainage.

Fecal coliform bacteria is an indicator of pathogens that may be present in water. They are usually more abundant than the pathogens, easier to isolate and much safer to work with. If fecal coliforms are present in certain amounts, then there is a high probability that pathogenic organisms (e.g. Salmonella) are also present (Thelin and Gifford 1983). Geldreich (1970) found that when fecal coliforms exceeded 2000/100ml, Salmonella would also be present almost 100% of the time. Therefore, the number of coliforms in water and sediment samples in the tinajas during the grazing season posed a health hazard to backcountry visitors who used the tinajas as a source of drinking water. Since grazing has been discontinued, coliforms levels have remained low. However, monitoring of coliforms in the tinajas is continuing in light of the projected increase of visitor use in

the southern portion of the park. The proximity of the cottonwood and willow drainages to potential new developments makes them susceptible to degradation by human impacts.