Livestock Grazing and Riparian Habitat Water Quality: An Examination of Oak Woodland Springs in the Sierra Foothills of California[1]

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Abstract: *Studies throughout the western United States have shown that livestock can degrade riparian vegetation and stream channels and produce sediment, pathogen, and nutrient loading. This study at the Sierra Foothill Research and Extension Center is the first to focus on effects of livestock grazing on hardwood rangeland springs and associated riparian resources. Cattle grazing treatments at three intensities were applied in 1- to 2.5-ha pastures, which included a spring and ephemeral creek. Over a 5-year period we monitored nitrate, orthophosphate, dissolved oxygen, temperature, and pH. Results show no significant differences in measured parameters among treatments. Sites were the source of some significant differences. This study indicates that moderate livestock grazing intensities do not detrimentally affect water quality at springs or ephemeral creeks in the oak woodlands of California.*

Riparian systems, including springs, seasonal and perennial streams, and shoreline vegetation, comprise an important and unique component in oak (Quercus spp.) woodland habitat and are crucial considerations in land management (Ewing and others 1988, Platts and others 1987). California's Mediterranean climate, with a summer drought period of 5-8 months, results in hardwood rangelands dominated by introduced annual grasses, varying amounts of native perennial grasses, and native oak species. Hardwood rangelands provide 75 percent of the forage used by the State's range livestock industry, in addition to furnishing many species with a source of water and habitat (Ewing and others 1988). Thus riparian patches provide critical sources of water for humans, wildlife, and livestock, and unique habitat and diversity of plant and animal species.

Western riparian zones in general are suggested to be the most productive habitats in North America (Johnson and others 1977). However, development of these fertile environments, such as in the Central Valley of California, has resulted in massive conversion or degradation of these systems (Franzreb 1987). Spring systems have historically been developed to provide water for domestic uses.

It has been suggested that livestock grazing is a major cause of riparian habitat disturbance (Fleischner 1994, Kauffman and Krueger 1984). Cattle seek riparian habitat for shade, cool temperatures, water, and abundant forage supplies. Livestock may directly affect the physical condition of riparian areas as well as directly or indirectly degrade water quality. Physical disturbance parameters include streamside vegetation, channel morphology, and the soil structure (Kauffman and Krueger 1984, Platts 1981, Platts and Nelson 1989). Water quality degradation includes chemical changes such as nutrient loading and physical changes such as increased flow and turbidity (Stednick 1991). At the watershed level, nonpoint source pollution may be observed as diffuse changes in the water quality and runoff quantity.

Livestock may compact soil, decreasing infiltration and increasing overland flow which may result in erosion and sedimentation. Wood and others (1989) found that mean infiltration rates were significantly greater on treatments excluded from livestock grazing. Wood also found infiltration rates and quality

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of runoff water decreased, in an insignificant trend, from grazed treatments as the seasons progressed from late spring to fall. Sediment production from livestock grazing treatments was significantly greater than that from treatments with no livestock (Wood and others 1989).

The EPA recognizes sediment, pathogens, nitrogen and phosphorus, biochemical oxygen demand, and turbidity as possible nonpoint source pollutants originating from cattle (Mulkey 1977). Water quality changes from heavy metals, temperature changes, pesticides, and other potential pollutants that might stem from grazing are not considered significant by the agency. However, other sources indicate that temperature changes (such as those resulting from vegetation removal) may be important, particularly in allowing the environment to become more conducive to pathogen growth (Hall and Amy 1990). Temperature may also affect fish habitat (Clark 1992).

Nutrients are particularly important as they increase the biological oxygen demand in the stream waters. Nitrogen and phosphorus are two nutrients which commonly limit growth of microorganisms (Fedkiw 1991). Their increased loading may result in blooms of algae and microorganisms. This may lead to eutrophication of the waters when the population dies out and their degradation uses up the available oxygen in the system (Clark 1992).

Moderate livestock grazing does not appear to produce a significantly higher nutrient loading (Larsen and George 1995). The authors concluded that nitrogen and phosphorus loading associated with moderate grazing was very low and was typical of natural streams. In fact, many studies have not been able to demonstrate any significant degradation in quality of runnoff water (Johnson and others 1977, Coltharp and Darling 1973). However, Wood and others (1989) did find that total nitrogen concentrations were greater from the grazed treatments than from treatments without grazing. The study also found concentrations of total phosphorus similar in all treatments.

Many pathogens in cattle, such as *Cryptosporidium parvum* and *Giardia duodenalis*, may be transferred into municipal water supplies. These pathogens cause gastrointestinal problems in humans (Atwill 1995). Studies concerning contamination of water supplies have not been able to pinpoint the exact sources (Atwill 1995). Johnson and others (1977) found that bacterial counts increased in grazed pastures; however, they dropped to levels similar to those in the ungrazed pasture a few weeks or months after cattle were removed.

This idea of short pulses of pathogens in runoff was supported by Hall and Amy (1990). Their study revealed that bacterial levels increase with precipitation events, particularly in the presence of cattle. The influx of nutrients necessary for growth of microorganisms into the stream system may be dependent on overland water flow. Thus the influence of cattle could be seen months after they had been removed from pastures, when precipitation mobilized an influx of bacteria, nitrogen and phosphorus into the runoff (Hall and Amy 1990).

In their review, Larsen and George (1995) concluded that a large increase in bacteria was observed only where the cattle were concentrated and that very little bacterial contamination was associated with dispersed livestock herds. Another study by Buckhouse and Gifford (1976) demonstrated no significant differences in the average fecal indicator bacteria existed between grazed and ungrazed treatments. Such differences are likely to be related to variability of individual study sites and the scientist's definition of grazing intensities, as well as the inability of fecal indicators to account for all pathogen species (Buckhouse and Gifford 1976).

This study tested cattle grazing effects on spring and creek water quality. Different grazing intensities were applied and pH, temperature, conductivity, total dissolved solids, nitrate, orthophosphate, and turbidity were sampled at springs and the associated creek in the hardwood rangeland system. The results reported here are part of a larger study to evaluate grazing effects on hardwood rangeland wetland ecosystems.

Site Description

Nine study sites each containing an undeveloped spring and ephemeral creek were selected at the University of California Sierra Foothill Research and Extension Center in three different watersheds. The Center is located on the eastern side of the Sierra Foothills near Browns Valley, California, in Yuba County, covers 2300 ha, and varies between 90 and 600 m in elevation. The watersheds are dominated by blue oak/foothill pine savannas with an understory of introduced annuals. The Center has been owned and operated by the University of California for almost 30 years (Raguse and others 1990).

The 1- to 2.5-ha sites were selected on the basis of (1) the presence of an undeveloped spring and associated creek (2) similar livestock grazing history, and (3) practicality of fencing.

Methods

Beginning in 1992 three grazing treatments were applied randomly to sites within the three watersheds: (1) no grazing; (2) light-intensity grazing, leaving a target value of 1000–1200 kg/ha of residual dry matter (RDM); and (3) moderate/heavy-intensity grazing, leaving 600–750 kg/ha of RDM.

The water sampling methods used the Hach™ DREL2000 Water Testing Kit to measure temperature, pH, conductivity, dissolved oxygen, total hardness, calcium hardness, alkalinity, total dissolved solids, nitrates, orthophosphates, potassium, iron, sulfates, silica, chlorides, and recently (1994) turbidity. In the fourth year, 1995, we sampled temperature, pH, conductivity, total dissolved solids, dissolved oxygen, nitrates, and orthophosphates.

The pastures were grazed for short periods, based upon the seasonal growth of annual grasslands in California, to produced desired RDM. Water samples were taken within a few days after cattle removal for each grazing period. The grazing treatments were applied approximately every 3 months.

These parameters were statistically examined using repeated measures analysis of variance (Norusis 1993). The parameters of interest, nutrients, dissolved oxygen, conductivity, pH, and so on were first tested for significance by treatment, site, and sampling date. Because we were most interested in identifying treatment effects, two-way interactions of site-date, treatment-date, and treatment-site were analyzed to determined the sources of the observed differences. Mean comparison models at $P < 0.05$ were used to determine significance (Norusis 1993).

Rhizon Soil Moisture Samplers (Meijboom and van Noordwijk 1992) were used to take ground water samples at the spring heads. Conductivity, pH, total dissolved solids, temperature, and nitrate were recorded for all water samples. These results were compared to those recorded for the samples taken from the springs in order to determine the origin of our samples. The differences of the means of the sample measurements were tested against the hypothesis that the difference was zero. A *t*-test was used to determine significant differences between ground water and surface water for each site using the STATA statistical package (Daniel 1995).

Results and Discussion

This 5-year study is now on its 4th year; results are preliminary but very consistent. The means over the 4 years by treatment are displayed in *table 1*. The first year of the study (1992) was a baseline year, and a means comparison test revealed significant differences in water quality parameters among sites before treatments were applied. These differences in conductivity, total dissolved solids, total hardness, calcium hardness, and alkalinity simply continued regardless of treatment. Thus the significant results from this study are related to site differences. The graph of the conductivity (*fig. 1*) has a similar shape to those of total dissolved solids, total hardness, calcium hardness, and alkalinity.

Table 1—Summary of 5-year means by grazing treatment

	Heavy	SD[1]	Light	SD[1]	No graze	SD[1]
Spring						
Nitrate[2]	1.17	1.02	1.78	1.15	1.92	1.08
Phosphate[2]	0.10	0.05	0.13	0.08	0.15	0.09
pH	6.85	0.64	6.81	0.57	6.79	0.56
Conductivity[3]	0.52	0.22	0.50	0.22	0.30	0.05
Dissolved oxygen[2]	4.85	1.62	7.02	10.96	5.32	1.90
Temperature	17.42	4.29	17.62	3.75	17.77	3.43
Turbidity[4]	8.0	13.4	4.8	4.7	6.4	4.6
Creek						
Nitrate[2]	1.23	0.67	1.25	0.87	1.56	0.94
Phosphate[2]	0.12	0.14	0.12	0.07	0.11	0.09
pH	7.40	0.77	7.67	0.68	7.52	0.79
Conductivity[3]	0.53	0.18	0.50	0.22	0.30	0.05
Dissolved oxygen[2]	7.51	1.45	7.28	1.51	10.65	16.93
Temperature	17.62	5.16	17.24	5.46	16.66	4.74
Turbidity[4]	7.3	12.4	5.9	4.4	10.6	11.0

[1]S D = standard deviation
[2]NO_3-N, phosphate, and dissolved oxygen, measured in mg/l, $n = 27$
[3]Conductivity measured in mS/cm, $n = 27$
[4]Turbidity measured in NTU (Nephelometric Turbidity Unit), $n = 7$ *(started 4th year)

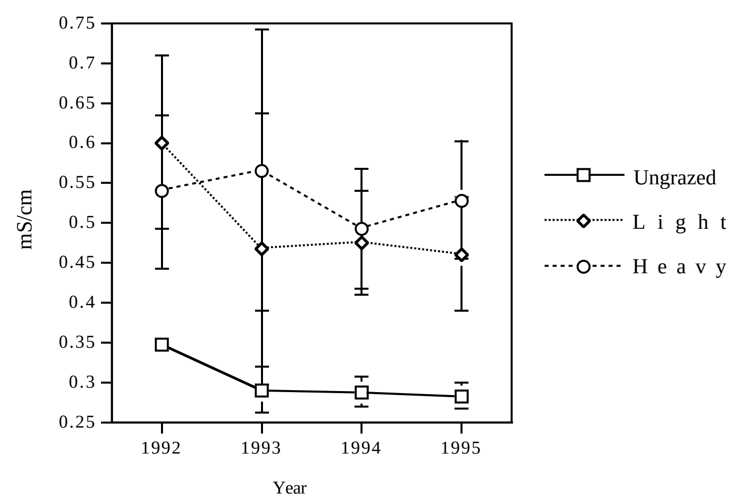

Figure 1—Data are yearly averages from three spring sites in each treatment. Ungrazed treatment sites had lower conductivity values even in the baseline year. Grazed treatments showed no significant differences in conductivity. Error bars represent ±1 standard error of the mean.

Over the 4 years there was a slight but insignificant increase in dissolved oxygen and orthophosphate at each site and a slight increase in nitrate at the ungrazed site. One contrary finding was on the heavily grazed Forbes watershed site. A significantly lower nitrate concentration was found for year 4. This site is the only one dominated by *Typhus* spp., and this may be one of many factors producing this result.

The graph of nitrate (*fig.* 2) shows the lack of differences between treatments by year. Phosphorus is also similar. It may be possible that the nutrients become more diluted with increased flows during storms, and because our sampling is point-in-time specific, this question will be examined in future studies where continuous concentration and flow data will be collected and loading calculated.

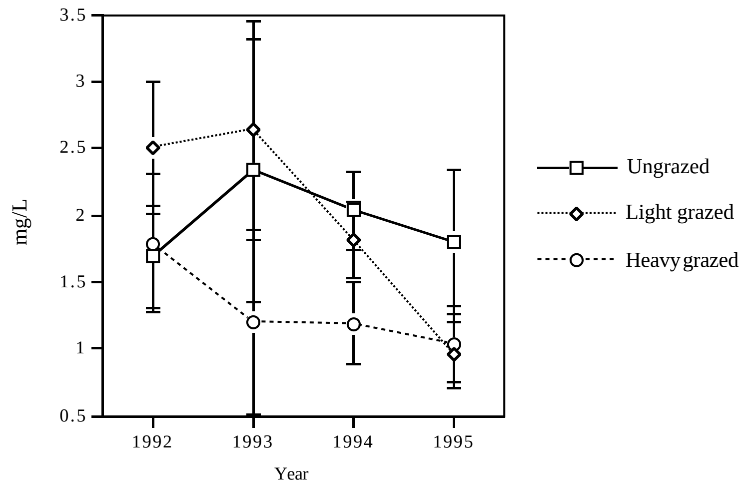

Figure 2—Data are yearly averages from three spring sites in each treatment. No significant differences in NO_3-N concentrations exist between treatments or over time ($P < 0.05$). Error bars represent ±1 standard error of the mean.

Turbidity measurements were added late in the study, but a smaller scale examination of conditions before, during, and after grazing on the Schubert and Forbes sites showed a slight increase in turbidity while cattle were on site and just after they were removed (*fig.* 3). Turbidity can be correlated to the amount of suspended sediment in the water column. However, this is a rough estimate of sediment which may be influenced by other water coloring factors, and the difference is not large enough to be significant. We intend to further examine this issue, by developing better methods to measure sediment load and better sampling practices.

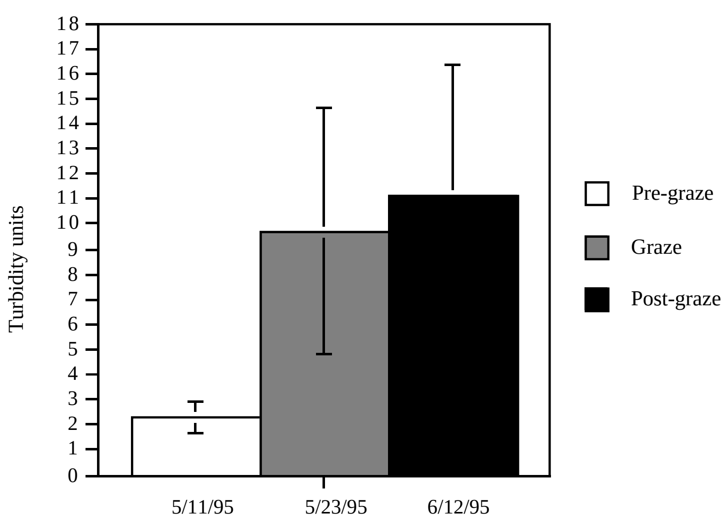

Figure 3—Turbidity results from two of three watersheds sampled before grazing, during a grazing period, and a week post-grazing ($n = 6$). Error bars represent ±1 standard error of the mean.

Temperature and pH are standard water quality parameters that influence most of the water quality measurements. Temperature and pH tell us about general conditions which can affect the biota of the waters. The ungrazed Forbes site had a lower average temperature than that of the other sites. This site has an overstory of blue oaks which may be responsible for the result. Other temperature measurements showed no obvious differences. The pH at the creek was consistently higher (more basic) than the spring. This could be a result of the flow of the water from a reduced environment in the soil to mixing with the atmosphere.

The Rhizon Soil Water Samplers were used to collect groundwater samples. The samples were taken from 10 cm below the ground surface at the origin of the spring. The results are summarized in *table 2*. The difference between the groundwater and spring samples is not statistically significant for conductivity, total dissolved solids, pH, and nitrate. Temperature was the only significant parameter; however, this is no surprise as the soil may have heterogeneous temperatures because of geothermal heating and different latent heat absorption and conductance properties, compared to the atmosphere.

Table 2—*t*-test values for Rhizon Soil Water Samplers.

Sample	Mean	SD[1]	*P*-value	Significant
Spring pH	7.30	0.33		
Rhizon pH	7.32	0.28	0.82	no
Spring nitrate[2]	1.31	2.31		
Rhizon nitrate[2]	1.15	4.63	0.45	no
Spring conductivity[3]	0.45	0.20		
Rhizon conductivity[3]	0.46	0.22	0.37	no
Spring temperature[4]	20.49	1.17		
Rhizon temperature[4]	23.29	1.07	0.00	yes

[1]Standard deviation
[2]Nitrate measured in mg/L
[3]Conductivity measured in mS/cm
[4]Temperature measured in °C

Conclusions

The study indicates that moderate livestock grazing intensities do not detrimentally affect water quality of springs, ephemeral creeks, or the localized ground water feeding the springs. Site characteristics have greater influence on water chemistry. The treatments applied had negligible effects on the water quality over time, and no cumulative differences were observed between the spring and creek at each site.

Creek samples had slightly higher, but not significant, pH, and dissolved oxygen values than the springs. This demonstrates a possibility of surface runoff containing nonpoint source pollution or organic acids present in the creek channel.

The observed water chemistry and the suggested origins of nonpoint source pollution agree with those of Mulder and others (1995), in their study of acid rain. Mulder worked to derive the origin of water flow in three water catchments in Norway to examine acid rain pollution. The conclusion was that low-flow water originated from ground water, while high-flow water originated from surface and subsurface flow. Only the high-flow conditions produced the nonpoint source pollution. Our findings demonstrate the lack of pollutants in the low-flow springs.

Thus surface and subsurface runoff after heavy rains is the likely source of nonpoint source pollution. In a system with low levels of erosion, such as at the Sierra Foothill Research and Extension Center, effects of cattle grazing do not become apparent in water quality of springs or ephemeral creeks. If nonpoint source pollution occurs in runoff, then it must collect in the downstream rivers. The greatest input of nonpoint source pollutants would theoretically occur as a flushing effect of the first rainstorms of the year.

Studies such as ours have obvious constraints of time, space, and money. Whole watersheds were not available for the study; thus small pastures were used. In order to simulate year-long grazing, a high-intensity short-duration management scheme was used to manage cattle to reach desired upland RDM levels. There may be some difficulty extrapolating to the larger watershed scales, however, the RDM levels were managed to simulate year-round grazing.

Despite these difficulties, our results are supported by the literature. The differences in nutrients (nitrate and orthophosphate) between treatments were not significant. Site characteristics are apparently a greater influence on water quality than our heavy grazing treatment. We are aware of cases in which grazing animals apparently caused environmental degradation and decreased water quality. However, our study did not show any detrimental effect on water quality. Unfortunately, we did not sample microorganisms in this study. However, the lack of changes in temperature, nutrients, and dissolved oxygen does support the idea that there were probably no major effects on microorganisms.

Finally, this study has produced many new ideas which need to be addressed in order to better understand the effects of grazing management on water quality at a watershed level. For example, high-flow streams are a more likely site of pollution than springs, so greater attention must be given to the surface and subsurface waters which flow into these streams. We plan to further evaluate the flow of nutrients, pathogens, and interill erosion from a boundary-layer perspective, as well as identify natural removal processes such as wetland biofiltration.

Greater attention must also be given to the spring sites as highly productive patches in a dryer oak woodland matrix. We would like to examine these patches as habitat and forage supply for birds and other wildlife. We would also like to use invertebrate bioassay techniques to study the general health of these systems.

On a watershed scale we have begun to develop paired watershed studies. Flow and pollutants can be monitored on a large scale, and management techniques and other utilization on the smaller scale may be related to the landscape observations.

Acknowledgments

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