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Impact of livestock management on water quality and streambank structure in a semi-arid, African ecosystem

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ABSTRACT

Natural resource management may change local and regional ecosystems, especially in drought-prone environments. Livestock are commonly kept as a source of capital in agriculturally dominated communities in Southern Africa, but the mis-management of available forage and water resources has led to significant land and water degradation. In Northwest Zimbabwe, to reverse trends in environmental degradation a community-based conservation program was established that uses intensive Holistic Management Planned Grazing (HMPG) to restore lost habitat and re-establish natural vegetation. We examined riparian ecosystem structure and water quality to compare the environmental impact of this management to nearby communal lands during a drought. The results demonstrate that concentrating livestock on ephemeral stream standing pools results in reduced water quality and altered riparian ecosystem structure. These results were not significantly different from what was observed when wildlife utilized similar water resources without livestock influence. When water is scarce, as during extreme droughts, livestock usage of surface water resources must be weighted against community water needs. The long-term regional benefits of HMPG may prevail over short-term reductions in local water quality but more research is needed to assess all the consequences of such management.

1. Introduction

Surface water resources and their associated riparian zones are extremely important components of semi-arid environments, providing valuable habitat and ecosystem services for Southern African communities. A disproportionate number of species utilize this region of the landscape due to its high productivity, the availability of shade and the accessibility of water (Bonkoungou, 2007; Fleischner, 1994; Kauffman and Krueger, 1984). Riparian vegetation prevents soil erosion and traps sediment in runoff, reduces water temperatures and provides habitat (Belsky et al., 1999; Gereta et al., 2004). Rural African communities often rely upon this ecozone for crop production, livestock grazing, potable water and supplemental protein from fishing. The greatest changes in vegetation composition and productivity due to livestock grazing have been reported to occur around water sources (Andrews, 1988; Lange, 1969). Riparian vegetation is usually grazed more heavily than upland zones resulting in the reduction or elimination of species, the physical alteration of streambanks or channels, or the lowering of the water table (Armour et al., 1991). Effective livestock management is important for reducing these potential negative consequences.

Livestock are crucial components of the social and economic systems in semi-arid communities in Africa (Deshler, 1965; Turner, 1993). A lot of attention has been paid to the environmental impacts of livestock management, particularly on vegetation richness, standing biomass, and soil microbial communities (Anderson and Hoffman, 2007; Kieft, 1994). Grazing has been shown to affect the hydrological properties of a watershed, particularly the rate of infiltration and surface runoff during precipitation events by trampling and removing vegetation and compacting soil (Little et al., 1987; Savadogo et al., 2007). However, few studies have focused on the direct effects of grazing on riparian ecosystems and water quality in semi-arid environments.

Historically, range management theory was centered on equilibrium models based on carrying capacity, stocking rate and ecological succession, but have had limited success in the more arid African ecosystems (de Leeuw and Tothill, 1993; Ellis and Swift, 1988). This is because arid environments are rarely in equilibrium, exhibiting significant spatial and temporal ecological heterogeneity, with unpredictable climates (Naimir-Fuller, 2000; Tobler et al.,

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2003; Walker, 1993). Forecasting ecosystem responses to livestock management is difficult and many large-scale livestock operations in African have been afflicted by bush encroachment, soil erosion and disease (Okigbo, 1985).

More intensive livestock grazing has the potential to increase rangeland productivity, biodiversity, and vegetation cover compared to traditional grazing systems (McNaughton, 1993). However, the sustainability of such systems depends on the rate of vegetation removal and soil erosion (Bailey, 2004). Depending on the management of a particular rangeland, multiple stable plant communities are possible and ecological thresholds may exist between states (Briske et al., 2005). Well-managed, intensive grazing may help to stimulate new shoot growth, preventing the oxidation of above-ground biomass. Active herding of livestock, such as in a pastoral system as opposed to free-range management, avoids straining local ecosystems by consistently moving livestock. This mobility promotes vegetative recovery and re-growth and reduces strain on water resources (Child et al., 1984). By mimicking the grazing pressures that naturally exist with wildlife in grasslands, herding is believed to increase the economic output of arid environments without having negative, long-range ecological consequences (Skarpe, 2000). Although herd size is one measure of land productivity, livelihoods models encourage a balanced measure of human, social, natural, physical and financial capital to ascertain the success and sustainability of a livelihood system, including asset accumulation, household wealth, and ecological resilience, such as rangeland biodiversity and soil structure (Lyons et al. 2000; Paine and Lautze, 2002).

The general application of inappropriate management techniques in arid environments has led to a decline in natural resources (Turner, 1993; Walker and Salt, 2006). Population growth and overstocking have led to overgrazing and subsequent land degradation in many arid African regions, resulting in altered vegetation composition, reduced vegetative cover, lost soil structure, habitat, and forage (Mekuria et al., 2007; Naimir-Fuller, 2000; Scones, 1992). In the past overgrazing and land degradation in Zimbabwe was primarily attributed to increasing livestock density (Whitlow 1988; Scones 1992). Competition for forage resources and communal grazing lands has increased the time livestock spend grazing a single pasture and has reduced the time left for re-growth of vegetation (Scones, 1992; Skarpe, 1992; Whitlow, 1988).

The recent growth of the human population in the Hwange community has exacerbated environmental change. In order to protect their natural resources, local leaders formed a community-based conservation management program. In 1992, the Africa Centre for Holistic Management (ACHM) was established to manage livestock using Holistic Management Planned Grazing and to develop and spread sustainable agricultural throughout the Hwange community. By utilizing Holistic Management Planned Grazing (HMPG) the ACHM attempts to avoid overgrazing any one particular area while improving soil structure (Savory and Butterfield, 1999). Many parts of Southern Africa have responded successfully to such management on a short-term basis. However, for long-term success, a thorough evaluation of the ecological implications, particularly concerning water and riparian habitat, is needed.

Livestock management may alter the local environment, but the degree and direction of change depend on the duration of grazing, the length and number of previous grazing periods and the season. Overgrazing is the result of prolonged grazing without adequate recovery of the vegetation and is not necessarily a function of livestock density as often assumed. Higher livestock densities may be beneficial in actively herded systems but without proper management, overgrazing may result in the deterioration of streambanks and surface water quality (Blackburn, 1984; Gary et al., 1983; Kauffman et al., 1983; Ohmart and Anderson, 1982; Owens et al., 1989; Rauzi and Hanson, 1966). Livestock tend to heavily graze vegetation near water sources and the subsequent disruption of the soil surface and reduced plant cover increase surface runoff and soil erosion (Blackburn, 1984; Ohmart and Anderson, 1982; Trimble and Mendel, 1995). Additionally, livestock tend to deposit a greater amount of waste close to water sources than they create in other areas of the range (Gary et al., 1983; Perciasepe, 1997). Haynes and Williams (1993) found a higher density of dung and soil nitrate near water points as a result of increased grazing intensity. Maintaining the integrity of water resources is critical to the Hwange community as they depend on seasonal surface water sources to supplement their water needs.

The purpose of this study was to determine if livestock management affects streambank structure and water quality in the Hwange area. We intended to test the hypothesis that the more active herding of livestock along streams using HMPG would lead to decreased degradation of streambank structure and water quality. However, although the research was planned to take place in June–July following the rainy season, a drought occurred prior to research implementation. Therefore, the research was modified to test this hypothesis on small standing pools remaining from streams, rather than actively flowing water.

Two categories of management were investigated: one where 75 head or more of livestock, comprised of cattle and goats, were actively herded to a stream for water each day; the other where less than 25 head of free-roaming livestock casually grazed along the streambanks of a water source each day. Because of the drought, the Holistic Management Planned Grazing strategy was adjusted by the ACHM so as to utilize the few remaining water sources by returning the herd of 75+ livestock to the same standing pools prior to and throughout the research period. Water quality and streambank structure on pools subjected to these two management practices were compared to a stream excluded from livestock usage but that experienced extensive usage by herds of wild mammals (elephants, buffalo, kudu). Streambank structure was quantified by measuring the proportion of bare soil, vegetation, plant litter and animal waste along streams. Ammonia and dissolved oxygen were used as indicators of biological contamination in water resources while salinity, conductivity, suspended solids, and orthophosphate were used as measures of soil erosion (Linsley et al., 1992).

2. Methods

2.1. Location

Three locations were sampled in the Hwange region of Northwest Zimbabwe: the Dimbangombe River (25°52′E, 18°10′S), the Tsetsegombe River (25°55′E, 18°13′S), and the Matetsi River (18°14′E, 26°2′S) (Fig. 1). The vegetation of this region is a mixture of woodland and grassland, heavily dominated by Poaceae and Fabaceae plants (Werger and Coetzee, 1978). Historically, mean annual precipitation is approximately 600 mm with 90% falling in the months of November–March (NOAA, 1991). This study was conducted from June to August of 2005, following a severe drought. Droughts are frequent occurrences in this region and these results may represent the most extreme conditions that are experienced in Southern Africa. The Dimbangombe River originates in Dimbangombe Ranch, a communal area managed by the ACHM. This river was purposely excluded from livestock but was frequented by herds of wildlife prior to and throughout the research period and therefore was designated the "wildlife" treatment. The level of usage by wildlife was not measured but herds of kudu, elephant and buffalo were frequently observed at the river. The Tsetsegombe

Fig. 1. Hwange region of Northwest Zimbabwe where tributaries to the Zambezi were sampled. Triangles represent sample site locations.

River originates in the Matetsi Safari Area and merges with the Dimbangombe River in the southern portion of Dimbangombe Ranch. During 2005, more than 75 cattle and goats visited the Tsetsegombe River each day prior to and during the research period, and this river was designated the "high livestock" treatment. The Matetsi River is a large river in the Hwange Communal Lands that flows into the Zambezi River. In the heart of the communal lands, the Matetsi River is excluded from wildlife as no roaming wildlife move through the densely populated region. The river is used as a water source for people and for small groups of free-roaming livestock. This river was therefore designated the "low livestock" treatment.

2.2. Sample sites

During the wet season, when there is sufficient precipitation, water flows continuously from the Dimbangombe to the Matetsi, which then flows to the Zambezi River. During prolonged drought, however, these tributaries cease flowing and form independent pools of water. Within each river, three sample locations were chosen such that no location was within 100 m of another location. Because 2005 was an extremely dry year, sample sites were limited to the locations with the largest pools of standing water to ensure water availability during the entire sampling period. In general, one large (surface area $> 300\ m^2$), one medium ($100–300\ m^2$) and one small ($< 100\ m^2$) pool was used from each river to minimize variations in location topography and pool size between the three treatment groups. Vegetation surrounding the riparian zones was not assessed, but due to the close proximity of the sampling sites differences between their vegetation were minimal. Water and riparian vegetation data were collected over the course of two months (June and July). Rainfall did not occur during the study period.

2.3. Riparian ecosystem assessment

Three-, ten-meter transects marked off at 10-cm intervals on a length of rope were used to assess ecosystem structure on both banks of each pool. Transects were positioned roughly parallel with the pool at 2, 4 and 10 m distances from the bank. At each of the 10-cm intervals, the groundcover was determined as bare soil, animal waste, plant litter, or vegetation. The presence of vegetation was determined by basal groundcover as any part of the living plant intercepting the point. Plant litter was determined as any component of dead plant material covering the ground at the point. The proportion of groundcover in each category was determined for all three transects on each side of the stream (Allen-Diez and Jackson, 2000; Paine and Ribic, 2002).

2.4. Water chemistry assessment

At each sample site, two 250 mL samples of water were collected from the deepest part of the pool across two-month sampling period. A YSI 85 temperature and elevation compensated meter was used to make direct measurements of dissolved oxygen, electrical conductivity (hereafter referred to as conductivity), and salinity concentrations (Yellow Springs Instruments, Yellow Springs, OH). The concentration of total orthophosphate (referred to hereafter as phosphate) was determined using the ascorbic acid method directly after collection (Edwards et al., 1965). Within 12 h of collection, samples were processed for nitrogen–ammonia using the salicylate method (Reardon et al., 1966). Finally, total suspended solids, also known as non-filterable residue, were measured using the photometric method (Krawczyk and Gonglewski, 1959), and pH was measured using phenol red with a 10 mL sample of water. The concentration of all reaction products was determined by colorimetry using a Hach 850 colorimeter (Hach Inc., Loveland, CO).

2.5. Data analysis

A Kruskal–Wallis with tied ranks, non-parametric multiple comparisons test was used to determine significant differences between mean values among management treatments. Such a test was employed because most of the data were not normally distributed, even following transformations. To limit experimental error, a Dunn's test was used as a post hoc test to compare individual treatment values using an alpha = 0.05. All data were entered into Systat version 10 for statistical analysis (Systat Software Inc., San Jose, CA).

3. Results

3.1. Riparian ecosystem structure

There were significant differences between the 'high livestock' treatment group and 'low livestock' group for three of the four riparian structure characteristics measured (Fig. 2). The percent of ground covered by plant litter was not significantly different between treatment groups ($H_c = 0.724$, df = 2, $p = 0.70$). However, there was a difference in the percentage of ground covered by living vegetation ($H_c = 10.65$, df = 2, $p < 0.01$), by animal waste ($H_c = 17.61$, df = 2, $p < 0.01$) and by bare soil ($H_c = 21.43$, df = 2, $p < 0.01$). Comparing the two levels of livestock intensity, basal vegetation cover was higher for the 'low livestock' treatment group

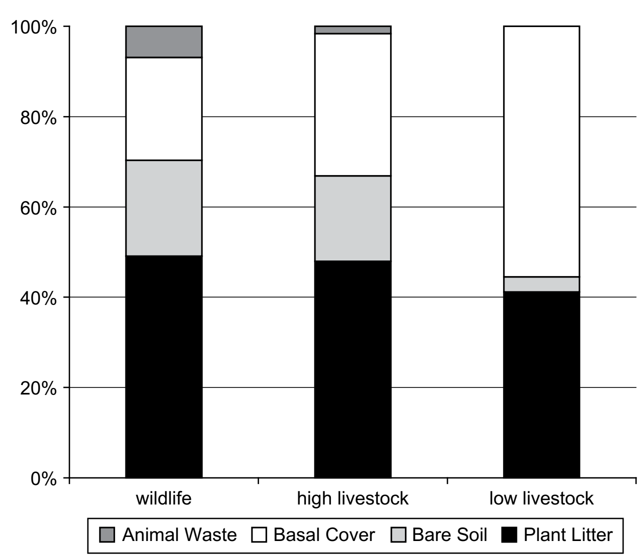

Fig. 2. Mean percent of riparian ground covered by basal vegetation, plant litter, animal waste or bare soil as measured by six 10 m transects at three sampling sites along each treatment stream at 2, 4 and 10 m from stream edge.

($q_3 = 2.75$, $p < 0.05$) while the proportion of bare soil was lower for that group ($q_3 = 5.78$, $p < 0.001$). The proportion of ground covered by animal waste was lower for the 'low livestock' treatment group, but this difference was not significant ($q_3 = 1.19$, NS). It should be noted that no animal waste was recorded in the riparian zone of the 'low livestock' treatment group. The only difference observed between the 'wildlife' treatment and the 'high livestock' treatment was in the proportion of ground covered by animal waste ($q_3 = -3.08$, $p < 0.01$), which was higher in the 'wildlife' treatment group.

3.2. Water chemistry

Significant difference between the 'high livestock' and 'low livestock' treatment groups was observed for five water chemistry characteristics (Fig. 3). There were significant differences between salinity ($H_c = 153$, df = 2, $p < 0.001$), conductivity ($H_c = 153$, df = 2, $p < 0.001$), and phosphate ($H_c = 153$, df = 2, $p < 0.001$) across the treatment groups. Salinity ($q_3 = 5.94$, $p < 0.001$), conductivity ($q_3 = 4.03$, $p < 0.001$) and phosphate ($q_3 = 4.54$, $p < 0.001$) were each significantly lower in the 'low livestock' than in the 'high livestock' treatment group. Suspended solids in the 'low livestock' treatment group were also lower than the 'high livestock' group, but this difference was not statistically significant ($H_c = 2.07$, df = 2, $p = 0.35$). The 'wildlife' treatment group showed no significant difference from the 'high livestock' group in terms of salinity, conductivity, phosphate or suspended solids.

While not statistically different, ammonia concentrations were lower in the 'low livestock' treatment group than in either the 'high livestock' or 'wildlife' groups (Fig. 4). Dissolved oxygen concentrations were significantly higher ($q_3 = 3.89$, $p < 0.001$) in the 'low livestock' treatment group than in either the 'high livestock' or 'wildlife' groups, as were pH levels ($q_3 = 5.12$, $p < 0.001$) (Fig. 5).

4. Discussion

The Hwange region in Northwest Zimbabwe faces two major resource problems: decreasing water quality and quantity, and decreasing availability of land for grazing and cultivation. The ACHM was created to restore land that had been degraded by poor management and improve habitat for threatened wildlife by utilizing livestock in an active management process that monitors rangeland responses and uses this feedback to adjust grazing patterns and duration. One of the consequences of this program was the reduction of pressure on forage and water sources in settled areas by concentrating livestock on communally designated rangeland. The treatments in this study were designed to compare the Holistically Managed Planned Grazing with low intensity, continuously grazed, passive management and to assess the impact of these management differences on water quality and riparian ecosystems.

4.1. Riparian vegetation

Riparian vegetation is an extremely valuable provider of ecosystem services. The high productivity of vegetation in riparian zones provides a reliable source of forage that encourages soil water retention compared to the adjacent landscape. Riparian trees provide shade, lowering the relative temperature of riparian areas. Holistic Management Planned Grazing used by the ACHM limits the amount of time livestock spend in the riparian zone. Without such management, livestock would spend more time grazing and resting in the cool shade of the riparian zone (Belsky et al. 1999). However, due to the drought at the time of the study,

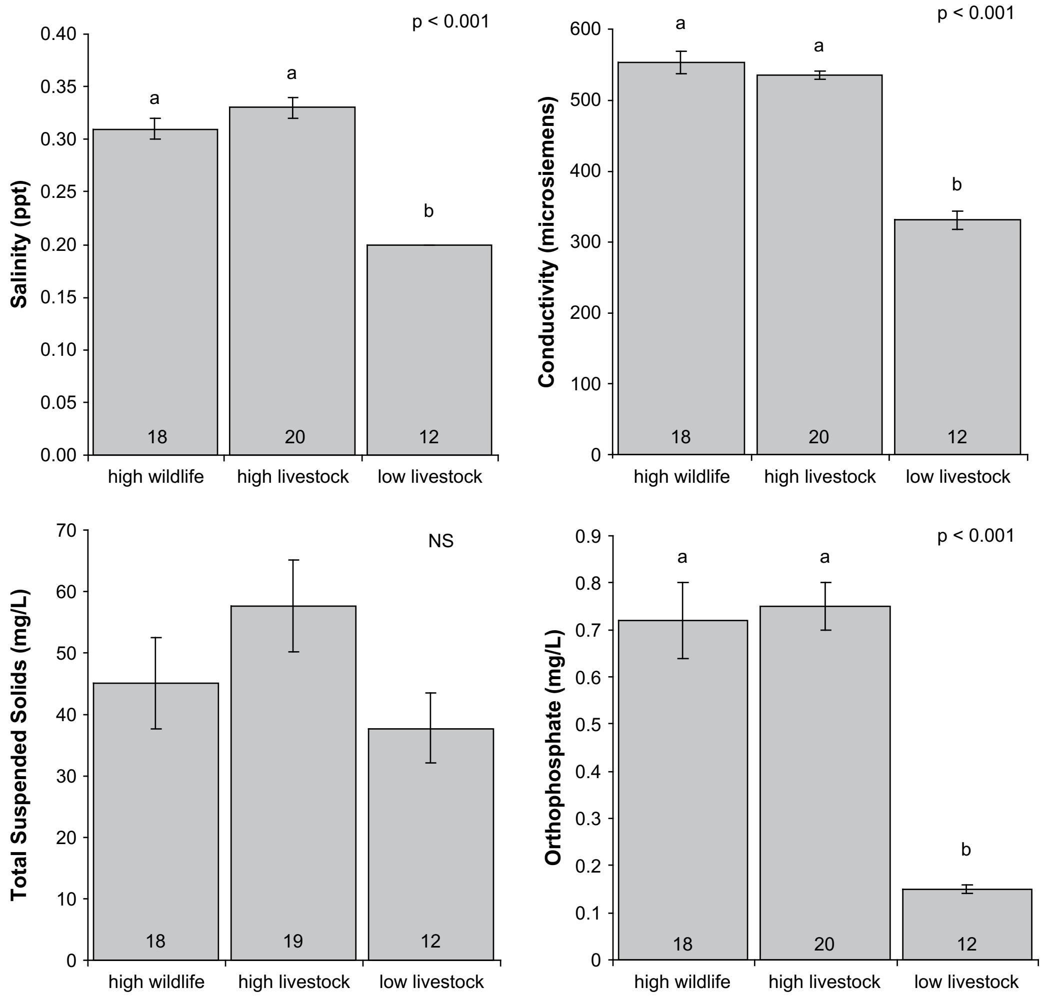

Fig. 3. Mean (±SE) of four measures of water quality representing soil erosion from three management treatments. Samples were obtained from each of three sample sites per treatment over a two-month period during the dry season. Upper right-hand corner values represent Kruskal–Wallis one-way ANOVA results and individual letters represent Dunn's test for significant differences ($p < 0.05$). Values at the base of each bar are sample sizes.

the ACHM had to alter its grazing plan to allow livestock daily visits to the remaining pools in the riparian zone.

The managed herds left less animal waste in the riparian zone than the wildlife. While no waste was observed in the unmanaged herd, this is to be expected since there were fewer animals spread out over greater distances. The riparian zones in the 'high livestock' treatment had less vegetative cover and more exposed soil (Fig. 2). The increase in exposed soil was due to a greater amount of vegetation removed by livestock, increasing the potential for soil erosion (Trimble and Mendel, 1995; Wohl and Carline, 1996). With an increase in exposed soil, we may infer that there is greater potential for soil erosion and in most circumstances, vegetation removed by grazing leads to increased runoff and soil erosion (Trimble and Mendel, 1995; Wohl and Carline, 1996). However, a greater amount of plant litter was observed in the 'high livestock' treatment. The close contact with the ground of plant litter may be more important factor influencing erosion control than basal vegetation cover. Thus, the actual amount of erosion will depend on the recovery of riparian zone vegetation in the subsequent wet season.

Past studies have demonstrated that cattle may increase streambank erosion (Buckhouse et al., 1981; Kauffman et al., 1983; Trimble and Mendel, 1995) and that improper management of rangeland may lead to the degradation of soil structure, vegetation composition and riparian habitat (Kauffman and Krueger, 1984). This is important as 81% of the vegetation removed by cattle originates in a riparian zone despite the fact that riparian zones make up only 2% of semi-arid rangelands (Kauffman and Krueger, 1984). For rural communities such as Hwange, riparian ecosystems provide grazing, water, soil erosion control and terrestrial and aquatic habitat—a variety of important services that must be conserved. The ACHM might consider reassessing its plan for riparian grazing management during drought, if further studies show that intensive riparian use during drought results in long-term negative consequences in terms of erosion, soil degradation, plant diversity and biomass production.

4.2. Water chemistry

Semi-arid environments often experience seasonal precipitation followed by extended dry periods. During dry periods, water quality becomes an increasingly important issue for both ecosystems and public health. Reductions in water quality due to sedimentation, eutrophication, nitrogen loading, and hypoxia may severely reduce the survival of fish, increase the transmission of disease, or decrease the potability of water sources (Carpenter et al., 1998). As the availability of surface water diminishes, evaporation further concentrates impurities in water resources.

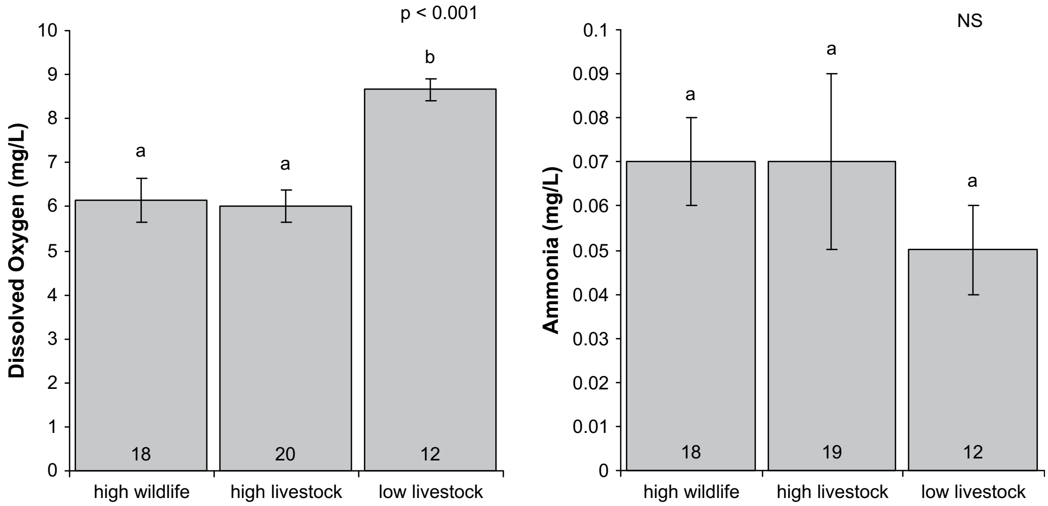

Fig. 4. Mean (±SE) of two measures of animal waste contamination in water samples from three management treatments. Samples were obtained from each of three sample sites per treatment over a two-month period during the dry season. Upper right-hand corner values represent Kruskal–Wallis one-way ANOVA results and individual letters represent Dunn's test for significant differences ($p < 0.05$). Values at the base of each bar are sample sizes.

The pattern of rainfall found in semi-arid environments increases the occurrence of erosion from exposed soil. There are pronounced wet and dry seasons and during the wet season, precipitation falls heavily in short time periods. During these storm events, there is little infiltration and this leads to increased runoff (Agnew and Anderson, 1992). Very little precipitation fell during the wet season prior to this research and conditions reflected a severe drought. Because we did not make any measurements in the wet season, no direct measures of soil loss or bank collapse were possible. We have extrapolated that there was greater runoff and erosion in the high livestock treatment based on the aqueous phosphorous, salts and anions. Phosphate and other soluble ions are dissolved in runoff from the exposed soil surface, supporting the theory that the more heavily utilized riparian zones were more eroded (Fig. 4). The high variability in bare soil around the two heavily utilized water sources is likely the result of some of the larger water sources being utilized more frequently (due to the availability of water) than others.

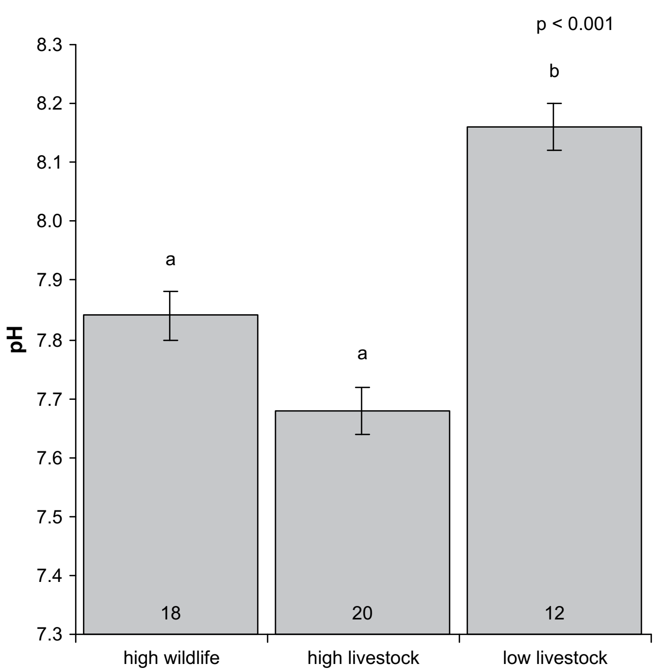

Fig. 5. Mean (±SE) pH of water samples drawn during the dry season from three management treatments. Samples were obtained from each of three sample sites per treatment over a two-month period during the dry season. Upper right-hand corner values represent Kruskal–Wallis one-way ANOVA results and individual letters represent Dunn's test for significant differences ($p < 0.05$). Values at the base of each bar are sample sizes.

Although there were clear statistical differences between treatments, biological significance still needs to be explored. Even minor additions of animal waste to the soil surface can severely impact the biological quality of water sources (Collins and Rutherford, 2004). It is not unusual for some arid, ephemeral rivers to have salinity concentrations approaching brackish water conditions of 20 ppt or higher (Gereta and Wolanski, 1999), and so the statistical difference observed between the treatments would not be expected to have much of a biological effect. While salinity can be important, such as in shifting the primary production and macroinvertebrate community structure in arid lake communities, the salinity differences in our data were not large enough to be of consequence (Wollheim and Lovvorn, 1995). The conductivity of surface water nine months post-flood in one arid river was as high as 475 μS/cm (Dent and Grimm, 1999), which was surpassed in the heavily used treatments suggesting that livestock may artificially increase dissolved solutes by pushing in streambanks or disturbing streambed sediment (Fig. 2). Fish can be sensitive to changes in pH but observed differences would not be expected to have biological significance (Kann and Smith, 1999); As far as the impact of water quality on animal performance, Socha et al. (2003) recommended that livestock do not consume water that exceeded 0.7 mg/L phosphorus, a value that was regularly surpassed in these same two treatments. However, a pH of 8.5, the recommended pH cutoff for livestock (Socha et al., 2003), was never exceeded (Fig. 5).

Like many rural communities in Southern Africa, Hwange livelihoods depend on the availability and quality of fresh water. Reductions in water quality because of upstream erosion are likely to affect animal performance, public health and wildlife (Nilsson and Renöfält, 2008). Eroded sediment carries minerals, organic molecules and microorganisms into water sources, thus reducing ecosystem health. Reduced vegetation cover and increased soil exposure by grazing have already been shown to increase surface runoff (Ohmart and Anderson, 1982; Stout et al., 2000), sediment yields (Nichols, 2006), and reduce fish habitat (Belsky et al., 1999; Karr and Schlosser, 1978; Lyons et al., 2000). Water users in communities downstream of the grazing region may experience changes in water quality following the return of rains as these pools of poor quality water are flushed downstream. Surface water sources supplement bore holes in the Hwange region as important sources of water for human use and reduced quality may be not be acceptable for consumption. The fish are an important source of protein in the local diet and aquatic habitats need to be protected to prevent declines in abundance (Kadye and Marshall, 2006).

Non-point sources of pollution are a common public health concern in semi-arid rangelands and have been attributed to improper grazing management (USEPA, 1995; USGAO, 1988). Increases in ammonia and decreases in dissolved oxygen suggest that many of the water sources examined in this study are contaminated with animal waste (Fig. 3). Livestock have been shown to significantly increase the likelihood of nutrient and biological contamination of water sources (Bohn and Buckhouse, 1985; Meiman and Kunkle, 1967; Morrison and Fair, 1966) Waste deposited along the streambanks during the dry season may be carried in runoff or in high flows following heavy precipitation (Crowther et al., 2002; Hooda et al., 2000; Hunter et al., 1999). Thus, in regions where seasonal fluctuations in stream flow may inundate exposed streambanks covered in dung, animal waste may continue to contaminate streams long after being deposited (Buckhouse and Gifford, 1976).

5. Conclusion

HMPG is one of a number of newer grazing management systems that more closely simulate natural herbivore behavior and have been shown to improve riparian habitats and water quality over systems that often led to land degradation (Burton and Kozel, 1996; Clary and Webster, 1989; Elmore and Kauffman, 1994). The continued productivity and potential sustainability of these approaches demonstrate that successful land management does not have to utilize traditional methods of grazing management, but rather benefits from a more holistic perspective on ecosystem sustainability (Savory and Butterfield, 1999).

Semi-arid ecosystems are some of the most productive environments in the world in terms of terrestrial biomass (Tow and Lazenby, 2001). Using livestock to simulate the herbivores that graze in these ecosystems can be a sustainable use of resources (Savory and Butterfield, 1999). In many regions, pastoralism and communal land use are blamed for environmental degradation (Reid et al., 2004). Such contentions led Hardin (1968) to formulate his theory on the tragedy of the commons. In Zimbabwe, there is evidence of human-induced land degradation and landscape change including soil erosion from overgrazing and deforestation (Jones, 1987). Such is the case in the Sinamatella region of Hwange National Park where historical land use indicates that some of the most severely eroded lands were formerly occupied by human settlements (Tafangenyasha and Campbell, 1998). The growth of the rural population and their expansion into formerly designated grazing lands have placed increasing pressure on natural resources that highlights the need to identify sustainable methods for intensive management of natural resources in rural areas (Wolmer et al., 2002).

There is also evidence that grazing can have a detrimental effect on riparian ecosystems if livestock are not managed properly (Belsky et al., 1999). This study showed that during a drought, intensively managed livestock had a negative impact on water quality and riparian ecosystem structure of the pools in the stream studied. But this snapshot does not provide the entire picture, and long-term analysis of the sustainability of such management on a larger scale is still needed to understand the intra- and inter-annual fluctuations. A multi-year longitudinal study involving repetitions of each treatment group on multiple streams would be necessary to understand how representative the results from this study are for the Hwange ecozone and its varied climatic conditions. This would also be necessary to elucidate the similarities and differences and between the impact of Holistic Management Planned Grazing and wildlife utilization of the streams in the area, as well as the potential public and ecosystem health consequences of the three treatments studied.

HMPG can be an effective tool to improve range condition by simulating the behavior of natural herds of wildlife and the negative consequences for water quality and riparian ecosystems may be acceptable to local communities if there are sufficient benefits from such management. For instance, by prohibiting livestock from accessing within-village water resources, there is less chance of direct, local contamination and subsequent transmission of waterborne diseases within the community. Further research is needed to address whether pooling livestock actually increases the total livestock capacity for the Hwange region or simply concentrates its impact on the environment away from human settlements. By setting aside large tracks of land for communal grazing, these lands may also be developed for other activities such as ecotourism. Assessing the environmental consequences of changing local resource management in Zimbabwe will help to shape future management strategies.

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