Grazing effects on grassland ecosystems

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Abstract.—In this study, we used a modified version of a meta-analysis (compilation and analysis of the literature in which an individual area is subjected to the disturbance and its response is noted) to analyze grazing effects on grassland ecosystems. Prior efforts have focused on one aspect of ecosystem behavior such as productivity or species diversity. In this analysis, we examined several components of ecosystem function that are seldom explored including measures of nutrient cycling and soil compaction. In general, cattle grazing appears to decrease production measures, increase soil compaction, and have mixed impacts on nutrient cycling rates. In studies that examined nutrients, cattle grazing tended to increase amounts of available phosphorus and nitrogen while decreasing the amounts of other nutrients. We located several studies of sheep grazing and found that their impacts are not much different from those of cattle.

INTRODUCTION

To understand ecosystem function with respect to abiotic and biotic disturbances, two different methodologies have been followed. First, an empirical method has been used in which an individual area is subjected to the disturbance and its response is noted. A more recent technique (a meta-analysis) involves compilation and analysis of the literature in which the former type of study was done (Fernandez-Duque and Valeggia 1994). In this study, we used a modified version of this second procedure to analyze grazing effects on grassland ecosystems.

Prior efforts have focused on one aspect of ecosystem behavior such as productivity (Lacey and Van Poollen 1981; Coughenour 1991; Painter and Belsky 1993) or species diversity (Milchunas and Lauenroth 1993; Fleischner 1994). In this analysis, we examined several components of ecosystem function that are seldom explored including measures of nutrient cycling and soil compaction.

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It is critical that many components be examined because they may provide insight into ecosystem health trends sooner than can be determined by looking at only one type of ecosystem function. For example, species diversity is often a poor indicator of ecosystem response to grazing because by the time there is any observable effect on species diversity, significant ecosystem damage may have occurred (Milchunas and Lauenroth 1993). One way to examine this is to consider the classical species response curves in relation to a resource. In these Gaussian curves, as resource quantity is reduced below optimum, the abundance of a species decreases, as seen in figure 17.1B of McNaughton (1993). But, as occurs with these types of responses, resource quantity can decrease dramatically before the species disappears from the system; even if that species has a narrow resource response curve. The processes associated with a resource (e.g., PAR, nutrients, etc.) would also be affected. Thus, species loss is preceded by the changed processes, rather than causing the changed processes.

There are, however, numerous examples that point to change in ecosystem processes due to species loss (Martinez 1995). For example, food web structure may depend upon one or more species, without which system structure and function collapse. Examining changes in species diversity as a result of changes in ecosystem processes does not negate the alternative view. Both opinions must be examined to understand the effects of disturbance on ecosystems (Jones and Lawton 1995). From this dual perspective, we can examine the ecosystem-level impacts of herbivory.

METHODS

We examined recent papers for discussion of the response of multiple ecosystem processes to grazing. Grazing included that by ungulates (primarily domesticated), insects and birds, or large-scale clipping or mowing experiments. A large number of journals were searched including *Journal of Range Management*, *Ecology*, *Journal of Wildlife Management*, *BioScience*, *Journal of Ecology*, *Journal of Applied Ecology*, *Functional Ecology*, *Oecologia*, *Oikos and Ecological Applications*. Journals were chosen based upon the likelihood that they would report large-scale studies. We did not include single-species response papers, instead we focused on recent papers to avoid reanalyzing those that may have been included in other summary analyses.

Each paper was examined for evidence of the following parameters: stocking rate (as defined by Heitschmidt and Taylor 1991), evidence of soil compaction, nutrient cycling, primary and secondary production, and effects on community structure. The grazing system (Heitschmidt and Stuth 1991) and location of the study were also noted. Standard meta-analysis procedures (Fernandez-Duque and Valeggia 1994) could not be used since the data in each of the categories varied. For example, data on grazing impacts on nutrient cycling varied from narrative evaluations (more digestible forage) to the size of soil pools of a nutrient. Therefore, what we present here is a narrative review of trends among these different factors.

The nomenclature we use is common in domestic grazing management. The abundance of animals is stocking density; grazing pressure is the numbers of animals per unit plant production; stocking rate is the number of animals per unit land area per unit time (Coughenour 1991). A grazing system includes defined periods of grazing or deferment in one or more pastures (Heitschmidt and Stuth 1991).

RESULTS

Seventeen studies are described in table 1. These, along with the 16 reviews described previously (Wallace and Dyer 1995), indicate that few studies examined multiple parameters. In general, cattle grazing appears to decrease production measures, increase soil compaction, and have mixed impacts on nutrient cycling rates. In studies that examined nutrients, cattle grazing tended to increase amounts of available phosphorus and nitrogen while decreasing the amounts of other nutrients. Other large herbivores were not studied to the same extent as cattle. We located several studies of sheep grazing and found that their impacts are not much different from those of cattle. Interestingly, stocking rates of sheep tend to be higher than those of cattle.

Few studies have examined the impact of wildlife grazing or insect herbivory on ecosystems. In one study, insects increased nutrient cycling rates more than ungulate herbivores (Brown 1994).

Out of the 34 studies we examined (Wallace and Dyer 1995), only 12 observed more than one parameter response to herbivory. Approximately half of these examined plant production and species composition, but did not examine nutrient levels, soil compaction, or below-ground biomass. Useful longevity indicators, such as root biomass and soil C, decreased in studies by Dormaar et al. (1994) and Mitchell et al. (1994). However, other soil nutrients, particularly measures of soil N, increased in response to grazing (Mitchell et al. 1994; Dormaar et al. 1994; Brown 1994; Wallace and Dyer 1995). Available phosphorus and calcium were increased by grazing in one study (Westenskow et al. 1994).

DISCUSSION

Herbivory impact on ecosystems is a controversial topic with long-lived debates focusing on issues such as plant compensation for herbivory

Table 1. Impacts of grazing systems on ecosystem level parameters. If the herbivore species is not named explicitly, then cattle were grazed. Cattle were grazed with other species in those systems marked as various herbivore species. Where responses are preceded by a sign (+ or -), the response is the process seen in a grazed area relative to an ungrazed area. Where no sign is present, the response is the absolute value measured in the treatment.

Name/Date	System	Location	Stocking rate	Soil compaction	Nutrient cycling	Production Plant	Production Animal	Community structure
Wallace & Dyer 1995	Various	Various	Various	Increased	Generally decreased	Less	More	Reduction in grass cover
Fleischner 1994	Various	Various	Various					Reduction in overall diversity
Anderson & Radford 1994	Continous	England	Various			-28.8% Cover		
Mitchell et al. 1994	Continous ducks	Texas	Heavy Light		Increase soil N	Rhizome biomass -23.7% -5.1%		Increase in species richness
Brown 1994	Insect herbivory	Minnesota			+8.9% soil N +56.5% soil NO3 +18.7%plant N uptake			Increase in species richness
Lacey & Van Poollen 1981	Various	Various	Moderate			-68%		
Brown & Stuth 1993	Continous	Texas	.217 AUY/ha .435 AUY/ha .571 AUY/ha			No overall reduction		
Dyer & Wallace (In review)	Various	Various	Various			+47% Monocots +17% Dicots		
Bullock et al. 1994	Put & take sheep	England	Heavy Light			Increase in dicot abundance		
Pickup 1994	Continous	Australia	660 cattle/ 170 km2			-11.6% Forage Index[1]		
Vickery et al. 1994	Continous	England	186.7 LUD/ha cattle 262.8 LUD/ha sheep		Protein 15.4% 14.8%	g/m2 68.5 51.7		
Smith & Rushton 1994	Rest/ rotation	England	100 ewes/ 16.2 ha sheep			Biomass -34.7%		Increased species richness
Pfeiffer & Steuter 1994	Continous bison	Nebraska	1 AUM/ha/yr			Biomass (unburned) -15.1% grass +1.6% forb		

Table 1. Cont'd.

Name/Date	System	Location	Stocking rate	Soil compaction	Nutrient cycling	Production Plant	Production Animal	Community structure
Volesky et al. 1994		Oklahoma	6.7 head/ha			kg/ha	kg/ha/day	
	Frontal					1390	281	
	continous					1400	6	
	rotational					1510	321	
Westenskow et al. 1994	Continous elk	Oregon			+51% Ca,P	kg/ha -37.8%		
Austin et al. 1994	Continous	Utah	5.3 horses/ 0.1 ha			-50.0%		
	delayed (horse)					+165.4%		
	deer					+5.3%		
	deer & horse					+178.4%		
Dormaar et al. 1994	Continous	Alberta	Moderate	-5.5%	-14.4% C -15.5% N -16.4% NO_3 +30.9% NH_4 +22.5% P	-16.4% Roots		Increase in species richness
Papolizio et al. 1994	Continous	Colorado	621 AUM					-9.3% species *number*

[1] *Forage Index for Pickup (1994) describes the relative attractiveness of each species for grazing multiplied by its abundance and summing over all species for a site.*

(Belsky 1986; McNaughton 1986; Dyer et al. 1993) and livestock herbivory on public lands (Gillis 1991; Wilcove 1994). We do not propose to reopen these arguments, but instead to examine how to answer questions associated with them. Since many of the proponents and opponents of livestock grazing profess a strong desire to protect the ecosystem (still loosely defined in ecological circles [Allen and Hoekstra 1992]), it is incumbent upon scientists focusing on this topic to provide policy makers with information concerning grazing impacts on ecosystem processes.

PRODUCTIVITY

Many of these processes have different temporal scales. Productivity is strongly controlled by climate and greatly influences the rate of herbivory (McNaughton et al. 1990; Cebrián and Duarte 1994). Productivity also has a strong seasonal component and can be analyzed on a shorter daily time-step. However, given the variance in productivity among these different time scales, it may be a poor predictor of the longevity of grazing management protocols. Production and other ecosystem parameters have been noted to pulse in other systems (Odum et al. 1995) and should be expected to do so in grazing systems.

COMMUNITY STRUCTURE AND BIODIVERSITY

Many authors have also examined plant community structure under the supposition that species will integrate a number of other processes and can indicate long-term ecosystem health (Tracy and Brussard 1994; Brown 1995). However, this view has been strongly questioned. Milchunas and Lauenroth (1993) examined over 300 grazing studies that analyzed plant community responses and found that species composition showed few strong correlations with critical ecosystem parameters such as net primary production, consumption, or evolutionary grazing history. In a strongly worded statement they proposed that, "Current management of much of the world's grazing lands based on species composition criteria may lead to erroneous conclusions concerning the long-term ability of a system to sustain productivity." Scarnecchia (1994) also stated that we would have greater power in analyzing grazing systems using a combination of variables rather than relying on single-variable analyses.

COLLECTION AND USE OF COMPLEX DATA SETS

How do we interpret multiple variable studies? Do we give one variable more weight than another? This is one of the critical issues in linking species-and ecosystem-level processes (Jones and Lawton 1995). Several key elements are missing that are necessary to accomplish an overall interpretation in the data set we have accumulated.

First, some uniformity of methodology and units is needed. Meta-analysis procedures are a powerful technique to draw conclusions from large, disparate data sets. However, this power is diminished if the variables analyzed do not have an associated variance (Fernandez-Duque and Valeggia 1994). Therefore, narrative evaluations should be avoided and quantification of parameters should be done using similar methods among studies. For example, sometimes plant productivity estimates include estimates of the amount of material removed, but more often they do not. True estimates of primary production in grazed environments require some quantification of removal rates.

Second, many variables that provide an estimate of longevity of the grazing system are difficult to measure and are therefore usually not measured. We found only two studies in our data set that explicitly addressed root biomass (Dormaar et al. 1994; Mitchell et al. 1994). Root and soil carbon are long-term, slowly-cycling parameters that can indicate trends in system aggradation or degradation. Few if any studies examined below-ground herbivory despite early requests in the literature for such data collection (Dyer 1979). In addition, few studies explicitly examined the rates of secondary productivity in systems (McNaughton et al. 1990), although this is critical to examining energy flow patterns. For example, invertebrates are more efficient at converting plant biomass to herbivore biomass than are vertebrate grazers (McNaughton et al. 1990; Brown 1994), which leads to a more efficient flow of energy, nutrients, and information. This may be a scale-related phenomenon in which small-scale herbivores with short life spans have a greater impact on the nutrient regime of grazed systems than herbivores that operate at larger scales and have longer life spans. This spatial scale would most certainly be expected to interact with a temporal scale, particularly in pulsed systems (Odum et al. 1995).

Finally, the grazing systems used in each study must be explicitly described. This includes a uniform quantification of grazing intensity with appropriate use of control plots and careful monitoring of herbivory timing. With this level of quantification, some of the objections of those concerned about grazing (e.g., Painter and Belsky 1993; Wilcove 1994) can be addressed.

Our data set illustrates many of the problems described above and gives mixed results in terms of how herbivores affect ecosystems. In many systems, plant production measures are lower in grazed areas than in ungrazed (table 1). Given the caveats listed above, until we understand where each of these systems is in the two-dimensional space relating productivity to herbivory (Risser 1993), interpretations concerning the effects of grazing as a whole are impossible. Increases in species richness were noted for several systems; decreases were noted in others. In some systems, greater richness was attributed to the increase in numbers of unpalatable forbs and to the increase in bare ground on which they could germinate (Anderson and Radford 1994; Bullock et al., 1994). However, exactly the opposite was found in other systems (Austin et al., 1994; Smith and Rushton 1994).

Given the inconsistencies in the approaches to collecting and analyzing data, we feel that we can not develop global conclusions from the information compiled. However, it is critical to note that grazing intensity in each system must be matched to the capability of the system to sustain that use level. We hope that the problems illustrated in this exercise will encourage others to collect data needed by managers to make decisions about the sustainability of their own system. Additionally, we hope that managers realize that what is sustainable in one system, will not necessarily be so in others. We are concerned that given the negative response of the longevity measures of soil C, etc., some of the systems we have examined appear to be grazed at levels that may be unsustainable over the long-term. This adds a strong sense of urgency to our endeavors.

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