The Organisation and Human Use of *Terai* Riverine Grasslands in the Royal Chitwan National Park, Nepal

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Abstract
I studied the landscape dynamics, organisation, and productivity of a tall-grass and riverine forest mosaic in the eastern portion of Chitwan National Park, Nepal. Aerial photograph interpretation, relevé sampling, experimental plots, models, and foraging studies were done. A model of landscape dynamics showed that fluvial action controlled landscape organisation. Ten grasslands and three forest associations were identified on edaphic and successional gradients. Above-ground net primary production appears to be among the highest in the world. Large herbivore consumption was estimated at 6% of above-ground production. Humans legally harvested 11,132 tonnes of grass worth NRs 10 million in 1987. Experimental testing of the effects of mechanical disturbance, staggered burning, and cutting to maintain, create, or restore habitat and provide for compatible human use is suggested. An adaptive management approach is proposed to engage managers and scientists in using scientific methodology to gain reliable management information.

Introduction

Little work has been done to describe the ecology and productivity of *Terai* riverine grasslands. Grasslands have been classified locally in dry regions of the subcontinent (see Yadava and Singh 1977 for a review), but the 1973 broad classification of Dabadghao and Shankarnarayan (DS) remains the commonly cited system for *Terai* riverine grasslands. The DS *Saccharum-Phragmites-Imperata* grassland type, however, is generalised for all of north India (Yadava and Singh 1977) and is not very useful for research or management of specific locales. Moreover, little is known about the floristic and successional relationships of these grasslands and the processes affecting pattern and productivity, particularly fire and wild ungulate herbivory (Lehmkuhl 1989, 1994).

The interactive effects of grazing and fire on grass production and quality have significant impacts on energy and nutrient cycling (McNaughton *et al.* 1982), and ecosystem productivity (Van Dyne *et al.* 1980). Fire is an important influence on grasslands worldwide (Daubenmire 1968; Vogle 1974), and particularly in south Asia where the climax vegetation is said to be forest (Puri 1960; Wharton 1968). Fires in Chitwan's recent past have been wholly anthropogenic, and nearly always started early in the dry season during late January or early February (Bolton 1975). Early season fires generally stimulate production, which is considered beneficial to important ungulates, but late season fires usually depress production (see reviews by Daubenmire 1968; and Vogle 1974). Little research has been done on the effects of fire on community dynamics and wildlife (Lehmkuhl 1989).

Grazing influences the composition, quality, and quantity of above-ground biomass. Grazing will usually reduce the standing crop of biomass (Heady 1975; Crawley 1983), and often reduces total annual productivity (Jameson 1963;

Younger 1972). However, some research has suggested that grass productivity is sometimes higher with moderate grazing than with lower or higher intensities of grazing (McNaughton 1979; Dyer *et al.* 1982). Regrowth after grazing is also of higher quality than ungrazed forage (Christensen 1977; McNaughton 1985). The result is a higher grazing capacity. South Asia has received little attention in the study of large ungulate herbivory (Lehmkuhl 1989).

Grassland productivity research on the subcontinent (reviews by Yadava and Singh 1977; Coupland 1979; Misra 1979) has overlooked *Terai* grasslands. Reported production estimates for four north Indian grasslands of the shorter (<2m) and dryer *Dicanthium-Cenchrus-Lasiurus* and *Sehima-Dicanthium* types were higher than estimates for 48 of the 52 temperate and tropical grasslands reported by Coupland (1979). Based on *Terai* grassland heights of four to seven metres and their occurrence on the most productive soils in Nepal (Carson *et al.* 1986), the *Phragmites-Saccharum-Imperata Terai* grasslands are potentially the most productive in the world.

Management of the grasslands for compatible human use, primarily grass cutting, is a major concern of the Park managers. The contribution of grass products from the Park to the local village and household economies has been estimated at NR 10 million (Mishra 1982b). Strategies to manage thatch grass inside the Park and to increase fodder supplies outside the Park are necessary to reduce conflicts with villagers (Mishra 1982b, 1984; Sharma 1986). Such strategies require good information on human use and attitudes (Lehmkuhl *et al.* 1988).

Research Objectives

This paper summarises my research in Chitwan National Park from 1985 to 1987, and describes potential adaptive management work that could be done to manage *Terai* grassland for conservation and compatible human use. The objectives of my work were to: (1) understand the landscape and disturbance ecology of Chitwan's riverine grasslands; (2) quantify the productivity of natural grasslands and village pastures, and the effects of fire and herbivory on production; and (3) quantify human use. Detailed accounts of the research can be found in Lehmkuhl (1989, 1992, 1994) and Lehmkuhl *et al.* (1988).

Methods

Location

The study area encompassed 2,300 ha along the north-central boundary of Chitwan National Park near the village of Sauraha—the largest area of grassland and riverine forest in the Park. The research area extended nine kilometres west from Itcharny to the Dumaria area, and about three kilometres south from the south bank of the Rapti River to the edge of the sal forest.

Organisation and Classification

Approximately two-thirds of the study area was sampled with 188 relevé plots (Mueller-Dombois and Ellenberg 1974) to study community organisation (Lehmkuhl 1989, 1994). Plot locations were mapped on aerial photographs in a 250 m x 250 m grid pattern. Minimum plot sizes (Mueller-Dombois and

Ellenberg 1974) were selected to include at least 90% of the total number of observed species in *S. spontaneum* and *N. porphyrocoma* swards (8.5 m x 8.5 m), and in the understorey of riverine and sal forest (11 m x 11 m) (Lehmkuhl 1989, 1994). All herbs, shrubs, and tree regeneration within sample plots were listed and cover/abundance was rated on the Domin-Krajina cover-abundance scale. Soil information was obtained from soil survey maps prepared by Carson *et al.* (1986). Sample plot classification and ordination was performed with the TWINSPAN and DECORANA programs (Hill 1979a,b).

Landscape Dynamics

Black and white aerial photographs from 1964 and 1981 were used to quantify landscape patterns, then model landscape dynamics (Lehmkuhl 1989). Landscape dynamics over historical time and projected into the future were estimated with a linear compartment model (Swartzman and Kaluzny 1987). The model was intended as a preliminary exploration of landscape dynamics because some model assumptions may not be valid for this highly dynamic system.

Productivity

Three experimental sites were selected in stands dominated by *I. cylindrica*, *S. spontaneum*, and *N. porphyrocoma* to estimate biomass production and the effects of fire and wild ungulate herbivory on annual production (Lehmkuhl 1989). The *N. porphyrocoma* site was meant to be representative of a "mixed tall grass" (MTG) type. Grazing treatments were grazed and ungrazed. Ungrazed plots for the two replicates were fenced with five-strand electric fence powered by a 12-volt car battery. Burn treatments were early burn (early February), late burn (mid-May), and no-burn. Each treatment combination was replicated twice with 20 m x 20 m plots in a randomised split-block design. The split-block arrangement was used for convenience in fencing, to save scarce fencing materials, and to reduce costs, while providing statistically valid results.

Primary Consumption

Primary consumption by rhinoceros and domestic elephants, the dominant ungulate herbivores, was estimated by multiplying the number of animals or grass cutting permits by the per capita harvest (Lehmkuhl 1989). Population estimates of rhinoceros were calculated using 1975 census estimates (Laurie 1978) as an initial population size, and a minimum 2.6% annual increase as estimated by Dinerstein (1985). Rhinoceros per capita grass intake was estimated from defecation rates and forage quality data from Laurie (1978) and Gyawali (1986) using the formula of Milner and Hughes (1968).

Elephant consumption rates were estimated by a year-long field study (Lehmkuhl 1989). The weight and species of fodder cut for night feeding and the amount consumed overnight were measured. Grazing intake was estimated by a bite-count technique.

Legal harvest rates of thatch and canes by grass cutters were estimated from a field study and attitudes toward the Park were gathered in a closed-questionnaire survey (Lehmkuhl *et al.* 1988). The weight of fodder illegally cut during the hot season of February through May was estimated roughly for the *S. spontaneum* cover type.

Village Pasture Production and Harvest

Annual production was quantified on a village pasture near the Park boundary, and the effects of different clipping frequencies inside a 22 m x 22 m exclosure were determined experimentally (Lehmkuhl 1992). Standing biomass was clipped at 5-weekly intervals from 0.5 sq.m plots inside the exclosure and outside the exclosure using the caged-plot method with moveable barbed wire exclosures. An experiment was done inside the exclosure to study the effects of four frequencies of cutting on production. Effects of defoliation every 11, 22, 45, and 90 days were compared to an undefoliated control. Six replicate 0.5 sq.m plots of each treatment were arranged in a randomised block design.

Results

Landscape Dynamics

The river was the focus of landscape dynamics: erosion, deposition, and channel meandering destroyed, created, and modified habitats constantly. During the 17-year period between photograph years, the river channel area increased 56% (Table 1). Floodplain sandbars increased 215% inside the Park, and 121% outside the Park. The landscape was not stable, or a 'shifting mosaic', with constant properties. Analysis of the photographs and model simulations indicated that three subsystems of landscape change existed in the dynamics (Figure 1) (Lehmkuhl 1989).

One subsystem consisted of the river channel and lands outside the Park that are influenced by river action. About 45 ha of agricultural and 52 ha of forest land within the study area were eroded into the river during the 17-year period, an average of 5.7 ha per year. The net loss of outside-Park lands was only 22 ha, because some of the lost upland remained in floodplain habitats outside the Park.

The floodplain and upland habitat inside the Park was the main landscape subsystem. This subsystem displayed dynamics different to those outside the Park, because the river channel was primarily cutting outside lands and depositing on the Park side of the river. *Saccharum spontaneum* floodplain habitat increased 73% after 1964 to become the most abundant vegetation type. Model simulations show that *S. spontaneum* habitat area will double over the next 50 years and dominate the landscape if current trends continue. The increase in *S. spontaneum* habitat was a consequence of faster creation of floodplain habitat than succession to mixed tall grass habitat.

The third landscape subsystem consisted of reclaimed agricultural land succeeding to natural vegetation. About 540 ha of wet paddy fields succeeded primarily to a stable mosaic of *N. porphyrocoma*, *T. arundinacea*, and *I. cylindrica*. Another 309 ha of dry fields reverted to savanna and woodland in mosaic with *I. cylindrica*. *Imperata cylindrica* dominated these lands in nearly pure swards after they were reclaimed; but after 25 years nearly all would have disappeared under tall grass. It was estimated that 66% of the area would revert to tall grass within 10 years.

Table 1: Area and percentages of grassland and forest habitat types identified from aerial photographs taken in 1964 and 1981 of the Sauraha area of Chitwan National Park, Nepal

	1964		1981		Change	
	Area ha	%	Area ha	%	ha	%
Non-Park Land						
Outside-Park Lands	97	3.2	0	0.0	-97	NA
Non-Park Floodplain	50	1.6	110	3.6	60	122
Non-Park *Saccharum spontaneum*	76	2.5	91	3.0	16	21
Park Land						
River Channel	157	5.2	245	8.1	88	56
Floodplain	52	1.7	165	5.4	112	215
Saccharum spontaneum	362	12.0	435	14.4	73	20
Mixed Tall Grass	546	18.1	393	13.0	-153	-28
MTG-*Imperata cylindrica* Mosaic	0	0.0	51	1.7	51	NA
Themeda-Imperata Mixture	133	4.4	459	15.2	326	244
Bombax-Tall Grass Savanna	207	6.9	509	16.8	301	145
Riverine Forest	405	13.4	473	15.6	68	17
Sal Woodland	6	0.2	6	0.2	0	0
Sal Forest	88	2.9	88	2.9	0	0
Reclaimed Agricultural Land						
Agriculture (treeless)	537	17.7	0	0.0	-537	-100
Agriculture (woodland)	309	10.2	0	0.0	-309	-100
Total	**3,025**		**3,025**			

Community Organisation

Ten grassland associations, with six phases, and three forest associations were identified (Lehmkuhl 1989, 1994). Types were classified on an edaphic and successional gradient indicated by the amount of shrub cover (Figure 2). *Themeda* and *Narenga* dominated types occurred on the wettest sites with the smallest shrub cover, and appeared to be relatively stable over time. The majority of types with *S. spontaneum* and *S. bengalense*, but also some with *N. porphyrocoma*, were considered stages in the succession to riverine forest.

Fluvial action was the controlling force of community organisation at the landscape level. At the lower among-habitats level of organisation, gradient analysis suggested that soil moisture and development, and fire were the primary factors underlying community organisation and succession. Succession was a complex function of species life-history characteristics (e.g., seed dispersal, competitive ability) and population processes, changes in soil moisture regimes, and increasing soil fertility over time. Large mammalian

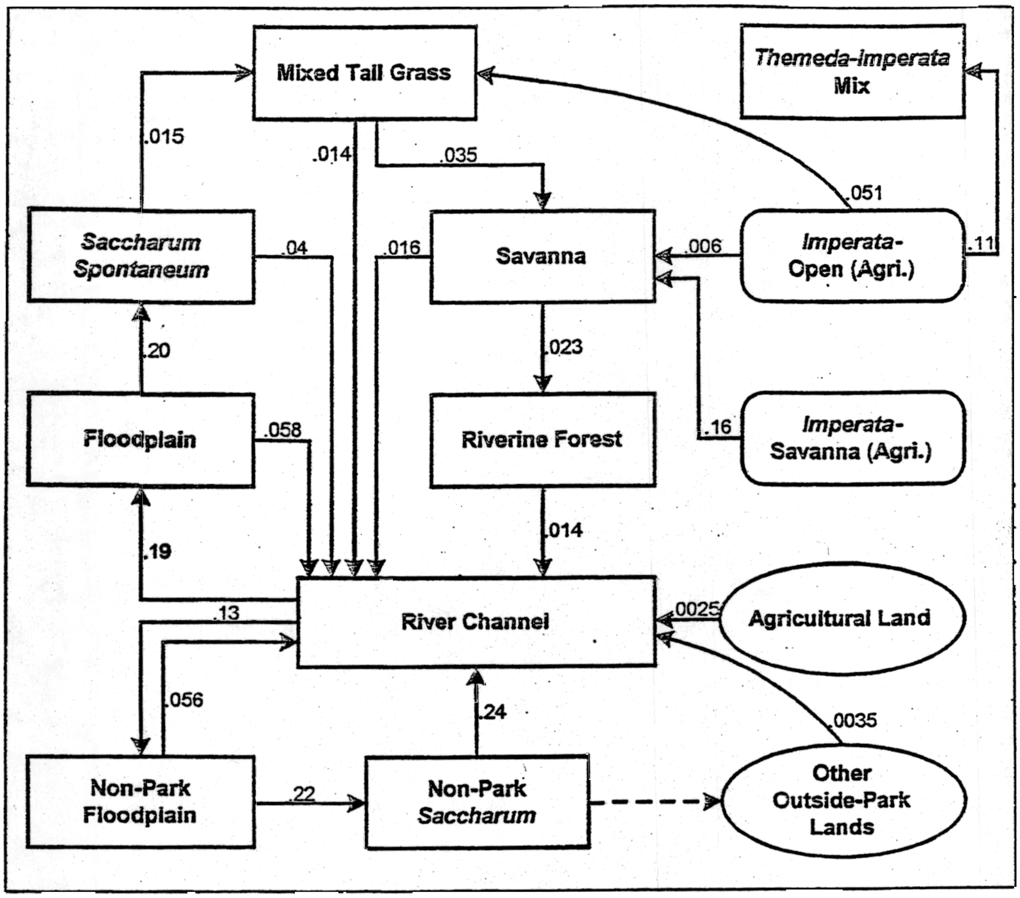

Figure 1. **A model of landscape dynamics for natural upland and floodplain grassland and forest communities in Chitwan National Park, Nepal. Numbers are the instantaneous rates of area transfer estimated from aerial photographs taken in 1964 and 1981. The rates indicate relative changes in area from one type to one or more differing types over time.**

herbivore feeding and fodder cutting for domestic elephants were secondary factors. Herbivores were probably most important as agents of site disturbance and plant dispersal, and thus regulators of community organisation, rather than as consumers, as only 6-10% of aerial net primary productivity was consumed by large mammalian herbivores.

Productivity and Consumption

Park grasslands

Fire and grazing had significant effects on the standing biomass of *I. cylindrica*. Early burning without grazing produced the greatest biomass (1.2 kg per sq.m). Late-burn production was 81% of early-burn production and unburned production was 38% of early burn production. Grazing removed the greatest biomass from the late-burn plots, probably because burned plots were surrounded by older and less palatable forage. Grazing after late-burning was strong for at least 15 weeks. Grazing after early burning removed an estimated 141g per sq.m, 12% of annual above-ground production. Humans harvested

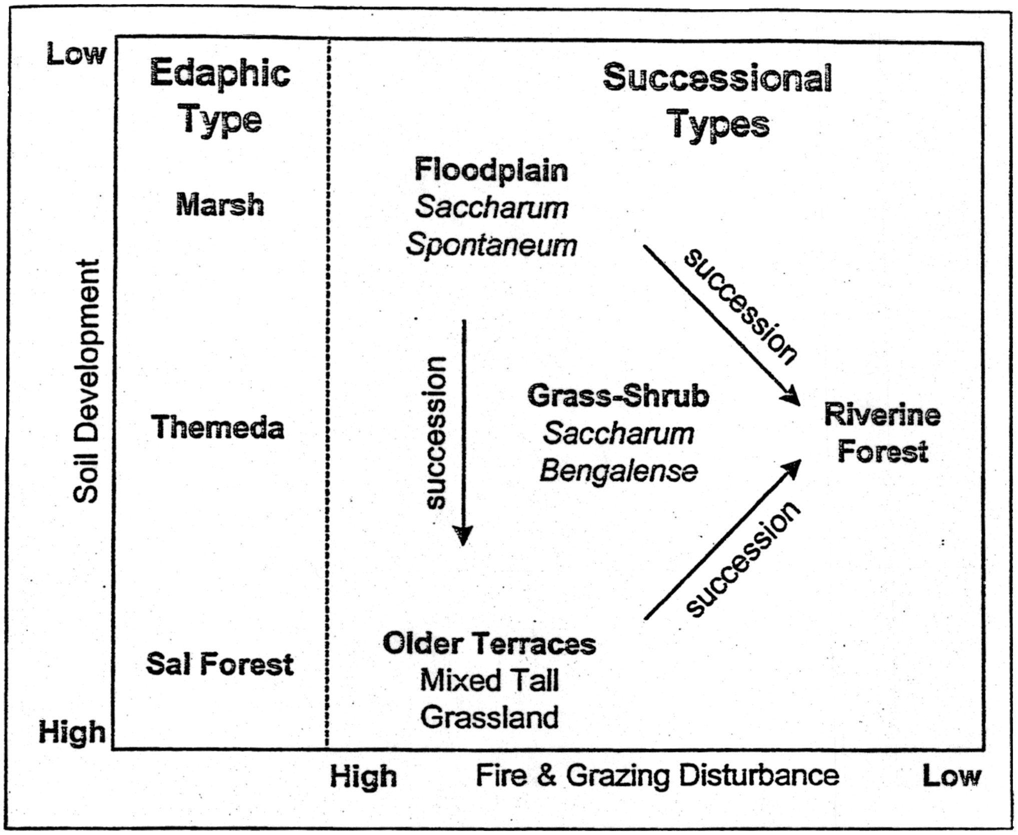

Figure 2. **Generalised riverine grassland and forest types determined from field sampling in Chitwan National Park, Nepal, and the hypothesised edaphic and disturbance gradients influencing grassland and riverine forest composition.**

nearly all of the remaining biomass during the January grass cutting season. Heavy grazing after early burning lasted for about 10 weeks, when forage apparently became unpalatable. *Imperata cylindrica* probably compensated fully for grazing by producing biomass equal to ungrazed production. Model simulations indicated little change in *I. cylindrica* biomass availability over the 20 years from 1987.

No significant grazing effects on production were found with *N. porphyrocoma*. Grazing was not evident on burned or unburned plots. Early burning resulted in the highest above-ground production (1.6 kg per sq.m), followed by unburned production (60%), and late-burn production (42%). Large herbivore consumption was estimated by model simulations as 4% of production. Humans harvested 26% of the above-ground production during the grass cutting season. Model simulations indicated a 28% decrease in mixed tall grass biomass over the 20 years from 1987 as a result of succession and erosion.

Problems were experienced with the *S. spontaneum* experimental plots. Villagers and elephant handlers surreptitiously cut grass from the plots, and ruined the treatment design. However, data were collected over the year to assess production in response to burning as well as possible. Late burning appeared to decrease production to 22% of the early and unburned production (1.65 kg per sq.m). Model simulations indicated that rhinoceros and domestic elephants consumed 10% of annual production, and humans harvested 5%. The model of landscape dynamics showed a 15% increase in *S. spontaneum* biomass over the 20 years from 1987.

The above-ground net primary production of Chitwan's grasslands appears to be among the highest in the world. Tall grass production was surpassed by only five of 70 grasslands reported in the literature. Large herbivore grassland consumption in the study area averaged 6% of above-ground production. The literature reports less than 10% consumption for most natural grazing systems, except the Serengeti.

Village pastures

The grazed pasture composition was dominated by *Chrysopogon asciculatus* (45%), *Cynodon dactylon* (19%), and *I. cylindrica* (19%). The ungrazed pasture was quickly dominated by *I. cylindrica* after one year of protection from grazing.

Above-ground production of the pasture, also considered a surrogate for Park grazing lawns, was 872 g per sq.m. Grazed production was 39% less than the ungrazed production of 1,410 g per sq.m inside the exclosure. Consumption by livestock outside the exclosure was 100% of annual production.

Experimental defoliation every 11 days reduced production by about 29%, but defoliation every 90 days reduced production by only about 4%. Production models were fitted for three cutting schedules to estimate grass production for a stall-feeding program. Production was most rapid between April and September for all cutting schedules. Annual yield was an estimated 9,400 kg/ha, 10,440 kg/ha, and 12,970 kg/ha for the 2-week, 7-week, and 13-week cutting schedules (Figure 3).

Human consumption

About 60,000 grass cutting permits were sold, and there were about 216,000 visitor-days during 1985 and 1986. The harvest of thatch grass and canes for house construction was 6,406 tonnes and 4,726 tonnes, with monetary values of NRs 4.6 million and NRs 5.4 million (1986 values). Subtraction of labour and permit costs yielded a net value to the economy of NRs 5.5 million. Benefits accrued to the individual village family were NRs 2,500. Seventy-five percent of the villagers interviewed were dependent on grass products from the Park for their subsistence needs.

Domestic elephant consumption

An average daily fodder ration of 58 kg DW (dry weight; 153 kg wet weight) was cut for each elephant, of which they consumed 25 kg DW. Eighty percent of the fodder was the floodplain grass *S. spontaneum*. Six percent was tree fodder, mainly the limbs of young *B. ceiba* trees. Elephants were grazed for at least four hours each day, during which time they consumed an average 20 kg DW fodder for a total daily consumption estimated at 45 kg DW (135 kg WW). Intake increased during the summer, leveled during the fall through December, then increased through the remainder of the dry season.

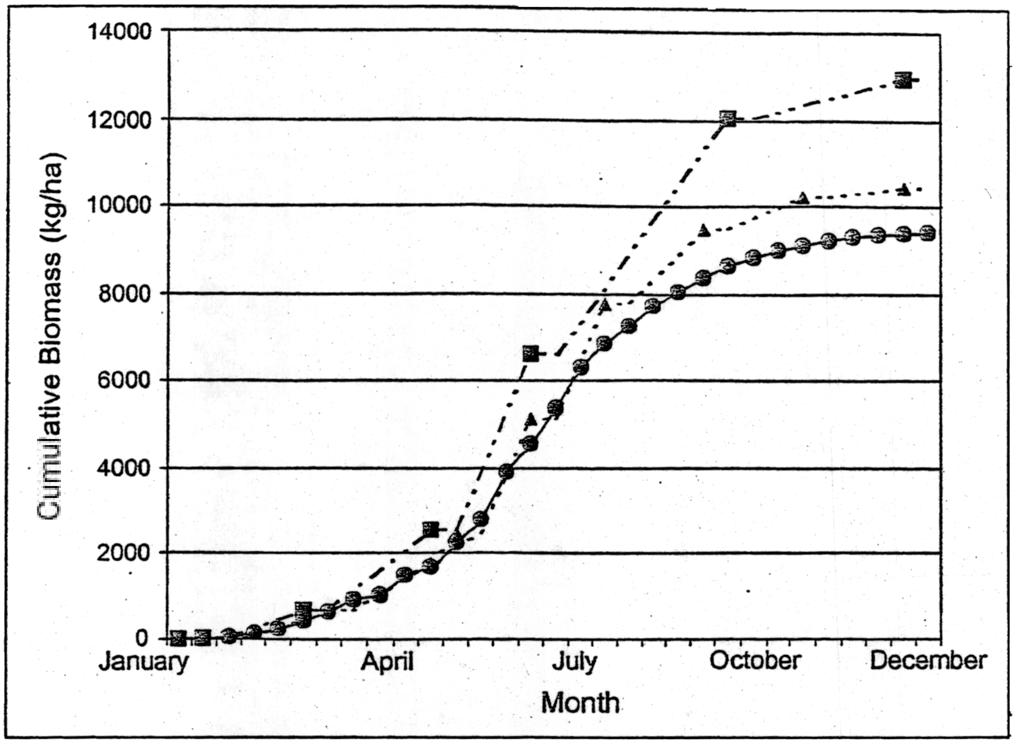

Figure 3. **Cumulative yield of a native mixed-species pasture in lowland central Nepal from 2-week, 7-week, and 13-week cutting schedules. Lines are model estimates, and points are original data on above-ground production from an experimental defoliation experiment during 1986 and 87.**

Conclusions

Disturbance and Succession

The increase in the *S. spontaneum* type is good for Park management. *Saccharum spontaneum* grassland is perhaps one of the highest quality habitats in the Park in terms of forage quality and use by wild herbivores (Mishra 1982a; Dhungel 1985). It is essential rhinoceros habitat (Laurie 1978), the major source of elephant fodder (80%), and is used heavily by deer species (Mishra 1982a). The Park may be able to play a larger role in the local economy by providing *S. spontaneum* for paper fibre via grass cutting permits. Such a programme would have to be carefully planned and managed, however, to avoid jeopardising wildlife conservation and other natural values.

Imperata cylindrica biomass will decrease only very slightly. Demand is extremely high for this grass, and will continue to rise as the local population and households increase. Judicious grassland management would not endanger, but could enhance, wildlife or plant conservation values and increase total *I. cylindrica* biomass at little cost. A programme to break up mechanically extensive tall grass stands that were formerly *I. cylindrica* into a patchwork of tall grass and *I. cylindrica* might benefit wildlife by increasing landscape diversity and thatch supplies, allow for better fire control and management by breaking up extensive stands of inflammable tall grass, and provide better opportunities for wildlife viewing.

Fire Management

Staggered burning of grasslands in small patches could provide fresh, high-quality forage for a longer time during the dry season than at present. Laurie (1978) and Dinerstein (1979) have suggested this practice to increase the carrying capacity for large mammalian herbivores in Nepalese reserves. Roy (1986) described a successful patch burning programme in Manas Wildlife Sanctuary in Assam. Rodgers (1986) provided a good review of fire management for wildlife habitat management in south Asia.

The results of my fire experiments indicated that staggered burning may foster the formation of pasture-like grazing lawns by concentrating grazing pressure on limited areas. Grazing lawns would produce high-quality forage year-round, may decrease crop depredation by attracting wild herbivores away from agriculture, and would increase herbivore carrying capacity. Patch size would be critical for success; a patch too large would be hard for herbivores to crop fast enough to keep the grass short, and a patch too small might be overgrazed and not provide adequate benefits to warrant management.

Patch burning would also increase cover for wildlife. Oliver (1980) concluded that widespread burning was one of the factors contributing to the decline of the endangered *Sus salvanius* (likely extinct in Chitwan) and *Caprolagus hispidus*. Roy (1986) claimed that his patch burning programme has been instrumental in increasing the population of *S. salvanius* in Manas, and managing high quality habitat for other species. Patch burning would also provide the essential spring nesting habitat for grassland birds in unburned sites that is now missing with widespread, uncontrolled fire (Rodgers 1986).

Pasture Management

Studies on the village pasture provide a base of data from which management studies and plans can be formulated. Although ungrazed pastures produced over 30% more forage than grazed pasture, the quality of ungrazed forage was lower (E. Dinerstein, unpublished data), and the carrying capacity would likely be lower. There would be some threshold to manage where production and quality are optimised. This is just one point to consider to increase livestock production around the Park. A complete analysis of grazing management that considers forage production, forage quality, introducing forage crops, stall feeding, tree plantation intercropping, and grass responses to grazing is beyond the scope of present studies, but is recommended for proper management.

Adaptive Management

Adaptive management marries scientific research principles with management objectives and practices to gain reliable information for managers (Holling 1984). The process is simple: define management objectives; design management treatments and their implementation using scientific principles of treatment randomisation, replication, and controls; monitor or measure the effects of treatments; analyse the results using statistically sound methods; and, finally, assess whether the outcome met the management objective, and adjust management if necessary. The approach is ideal for testing new grassland management treatments where results are uncertain, for example, the effects of patch burning or mechanical treatments on productivity and ungulate use.

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