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Potential herblayer production and grazing effects in anthropogenic savanna-grasslands in the moist tropical forests of the Western Ghats of India

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Abstract

The moist tropical forests of the Western Ghats of India are pockmarked with savanna-grasslands created and managed by local agricultural communities. A sample of such savanna-grasslands with differing growing conditions was studied in terms of peak above-ground biomass, monthly growth, and cumulative production under different clipping treatments. The herblayer was found to be dominated by perennial C4 grasses, with *Eulalia trispicata*, *Arundinella metzii* and *Themeda triandra* being common to all sites. Peak biomass ranged between 3.3–5.9 t/ha at sites most favourable for grass production. Across these sites, peak biomass was found to be inversely related to the number of rainy days during the growing season, suggesting that growth may be light-limited. This hypothesis is supported by the observation that growth is most rapid immediately after the easing of the monsoon. Single clips early in the growing season had no negative or a slightly positive effect on production, but mid-season single clips or continuous frequent clipping reduced production by as much as 40%. The results suggest that, while indiscriminate grazing may certainly be deleterious, it is possible to obtain sustained high yields from forest lands managed for grass production without totally excluding grazing.

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Introduction

The "natural" range of savannas and grasslands is considered to be in areas with annual rainfall in the 800–2000 mm range and a long (more than 6 month) dry season (Long and Jones 1992). These conditions prevail in most of the savanna-grasslands[1] in Africa, Southern America, tropical Australia, and parts of Asia, including west-central India. Not surprisingly, these regions have been the focus of most savanna-grassland ecosystem research, whether purely ecological in nature (*e.g.* Long *et al.* 1992), or dealing with questions of resource management in the primarily pastoral economies that have co-evolved with this biome (*e.g.* Young and Solbrig 1993).

The highly seasonal climates of peninsular India and south-east Asia enable the occurrence of regular fires that in turn prevent the formation of a closed forest canopy. Patches of tree savannas and even pure grasslands are thus found to be distributed throughout areas with much higher annual rainfall, where the climatic climax (soil conditions permitting) would be dense tropical evergreen, semi-evergreen, or moist-deciduous forest (Kayll 1974; Stott 1990). Many, possibly most, of these patches have been created and maintained by agri-pastoral communities over millennia. Yet, these savanna-grasslands have rarely been the subject of rigorous empirical research. Ecologists have generally ignored such heavily disturbed, "unnatural" vegetation, focusing instead on the "natural" climax vegetation, *i.e.* forests. State resource managers, *i.e.* foresters, have condemned savanna-grasslands as both "unproductive" compared with

[1]Strictly speaking, pure grasslands contain no trees, whereas savannas do. We shall use the term savanna-grassland to include both vegetation types, noting that, in the moist tropical forest region studied here, patches of pure grasslands are typically less than a few hectares and invariably surrounded by many trees.

forests and "unsustainable" at the current levels of (over)grazing. These claims, based upon sketchy empirical work, have become a justification for denying local communities access to grazing in state-controlled forest lands. Thus, understanding the production ecology of these savanna-grasslands is of interest from an ecological point of view and is critical to formulating policies for rural ecodevelopment.

As a step toward such an understanding, we conducted a study in the Western Ghats of India during June–December 1990, as part of a larger interdisciplinary research project to understand the impacts and determinants of human use of forest lands (Lélé 1993). Taking an explicitly applied perspective, we focused on 2 questions: (i) whether the use of moist tropical forest lands for grass is inherently unproductive; and (ii) whether grazing by livestock might be causing declines in their productivity. Hence, we looked at only above-ground production — the socially useful part of total production. Our specific objectives were to:

- establish preliminary estimates of "potential" above-ground herblayer production, including its seasonality and variation across the region of interest; and
- understand effects of grazing on within-season production.

Characteristics of the study region

The Western Ghats is a range of mountains in peninsular India running approximately parallel to its west coast and home to the largest tracts of moist tropical forests in the country. Uttara Kannada district in Karnataka state (see Figure 1) has the biggest share, with an estimated forest cover of 5000–6500 km^2 (Reddy *et al.* 1986; Gadgil *et al.* 1987). The district straddles the Ghats, which are at their lowest here (<600 m) and are about 20–25 km inland. East of the crestline of the Ghats are rolling hills with forested slopes and shallow valleys with cultivation. This region, locally known as the *Malnaad*, covers most of Siddapur, Sirsi, and Yellapur *talukas* (sub-districts); it formed the focus of our study.

The rocks of the Malnaad region consist mainly of "Dharwar" (chlorite-) schists, granitic gneisses and charnockites from the Archaen complex (Kamath 1985, pp. 22–24; Bourgeon 1989). The soils have been categorised as red sandy or sandy-clay loams (Kamath 1985, p. 304), or more specifically (Bourgeon 1989) as mainly Ferrallitics (French soil taxonomy) or Alfisols and Inceptisols (USDA soil taxonomy). They are generally acidic in nature (pH range 4.8–6.3).

Rainfall, brought by the south-west monsoon, shows the dramatic effect of the rain-shadow created by the Ghats, as total annual precipitation drops from over 5000 mm at the crestline to less than 1700 mm 40 km east (Figure 2a). The rainfall is also highly seasonal, with more than 90% occurring in June–November. Mean monthly temperatures range from 20–27°C. The net result is an effective dry season of almost 8 months (Figure 2b).

Corresponding broadly to the climatic variation, the "natural" vegetation varies from moist-evergreen forest at the crestline to semi-evergreen (or moist-deciduous) and dry-deciduous forest as one moves eastward (Pascal 1986). The vegetation is in various successional stages within these broad types, and also has patches of monoculture forest plantations, heavily pruned leaf-manure forests, and grasslands. While some of the grassy patches (especially those on hilltops) may have an edaphic origin (Yadav *et al.* 1970), the majority of the savanna-grasslands are anthropogenic, resulting from centuries of tree pruning, shrub removal, and burning. The savanna-grasslands are exposed to varying levels of grazing, and some are temporarily fenced off and harvested by hand at the end of the growing season. These management practices have co-evolved with the local agrarian system, which is a combination of areca-spice orchards and paddy fields (Mani 1985; Lélé 1993). Productivity depends critically on the continuous input of organic matter and nutrients in the form of livestock dung (along with leafy matter), and on the availability of draught animal power for ploughing. Milk is an important additional benefit. Livestock, almost all cattle and buffalo, are thus an integral part of the agrarian system.

One may thus divide the factors affecting herblayer production in savanna-grasslands used by local communities into 2 broad categories: (i) "exogenous" factors such as rainfall, temperature, topography and soils, over which human beings have little or no control; and (ii) "endogenous" factors such as the intensity, timing and frequency of grazing, harvesting and fire, and the extent of tree canopy cover, over which the local

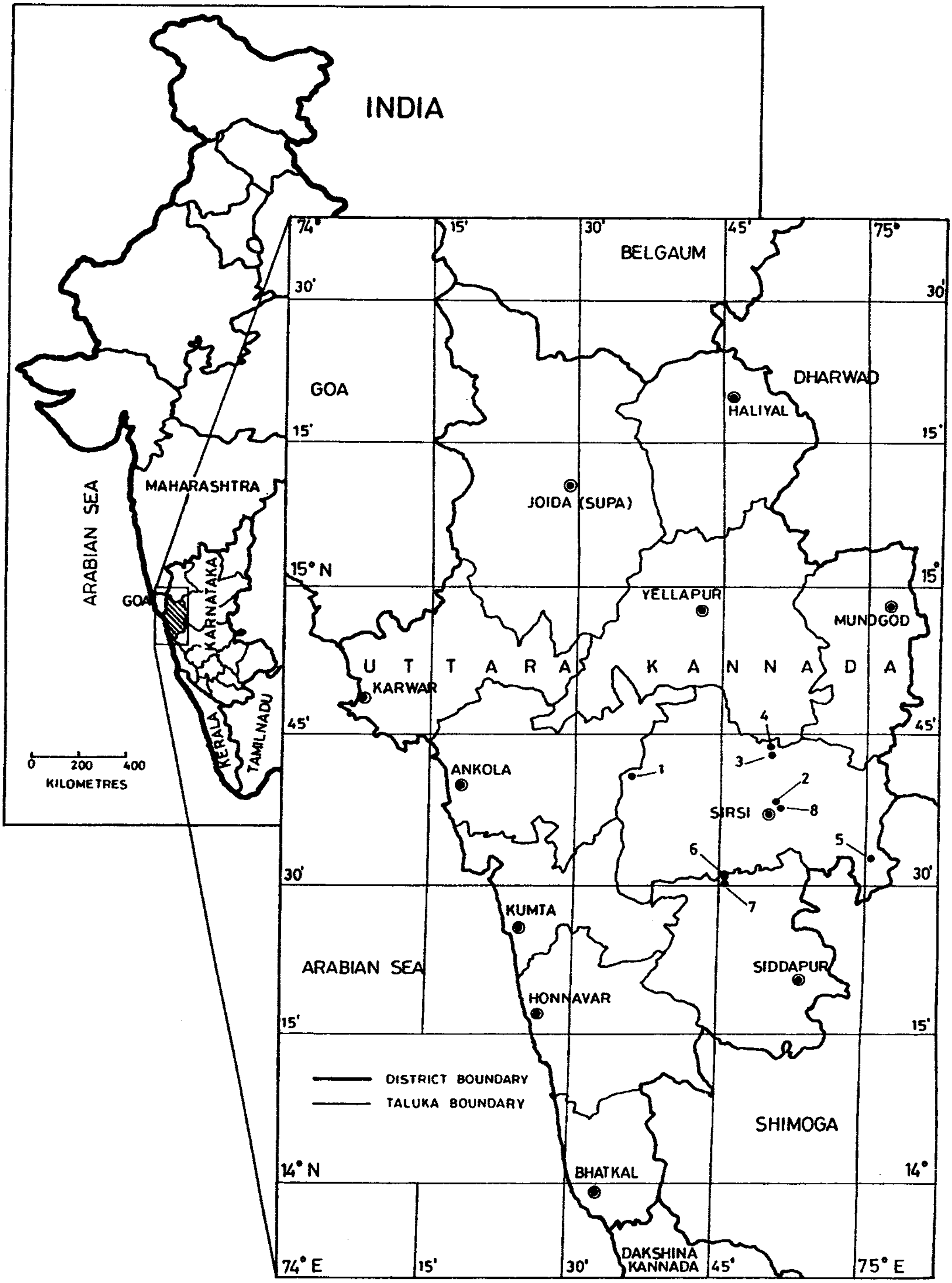

Figure 1. The location of Uttara Kannada district and the study sites in it (1 = MT-BENA, 2 = CH-BENA, 3 = AP-BENA, 4 = MH-BENA, 5 = BV-BENA, 6 = KS-BETTA, 7 = TK-BETTA and 8 = CH-BETTA).

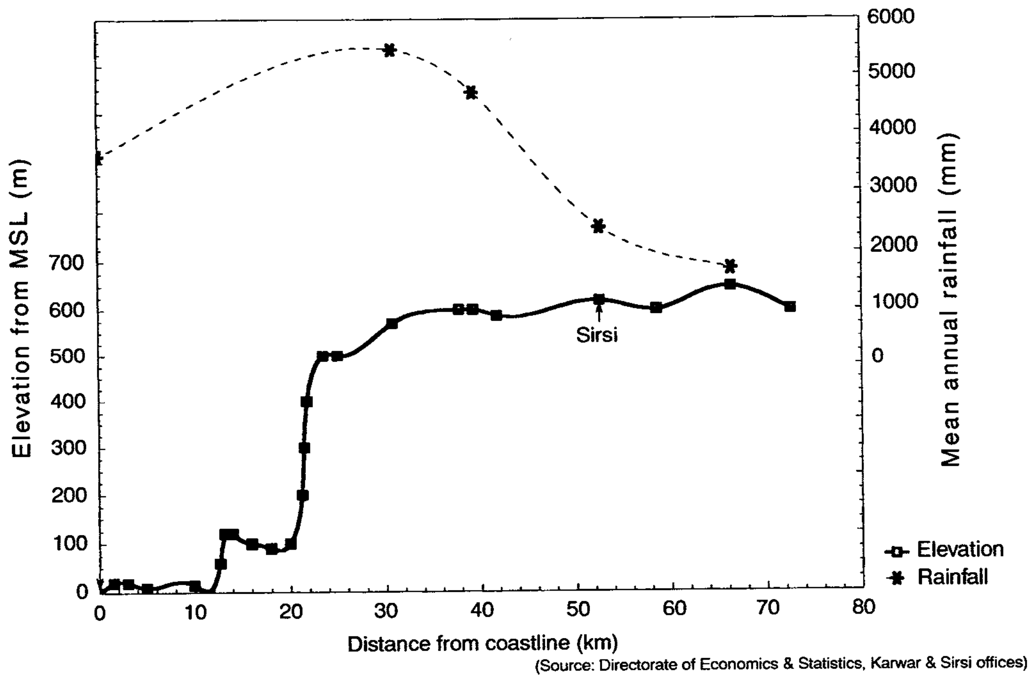

Figure 2(a). Spatial variation in rainfall and topography along a transect between Kumta and Sirsi.

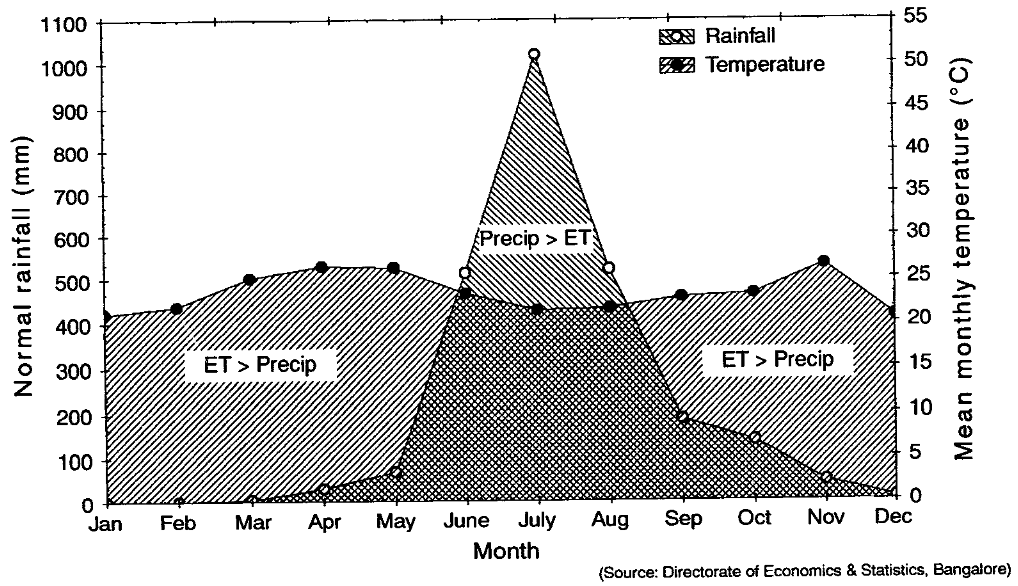

Figure 2(b). Climatic diagram for Sirsi, using normal rainfall and mean monthly temperatures (100-year records). ET is assumed to be 20 mm for each 10°C.

population exerts substantial control. Exogenous factors are highly correlated. The direction of maximum change in average annual rainfall in the Malnaad (approximately 25° north of east), is also the direction in which terrain becomes flatter and soils generally become less stony (or less skeletal) and deeper. Endogenous factors also do not vary randomly: lands used extensively by villagers are simultaneously subject to heavy grazing, lower or no tree canopy, and regular fire. These correlations affected the research design.

Overall approach

In order to understand the effects of exogenous variables, we looked at "potential" production, defined as production under maximally favourable management, *i.e.* endogenous, conditions. These conditions, identified from traditional local knowledge and known modern results, were: zero tree canopy, annual application of late dry season fire, and zero grazing during the growing season. Such "pure" grasslands are locally called *bena* lands, and are almost treeless patches carved out of forests decades or centuries ago. Given the correlations amongst the exogenous variables, partitioning the effects of all variables was not possible. Instead, we confined the measurement of "potential" production to a set of bena sites approximately along the west-to-east rainfall-slope-soil gradient. This was compared with production in sites with sub-optimal growing conditions, *i.e.* tree savannas, locally termed *bettas*, with varying tree cover, fire and grazing regimes.

For understanding grazing effects, we limited our study to 2 typical systems in the region: early light grazing (followed by fencing till the end of the growing season); and continuous light/heavy grazing. Clipping experiments were conducted to explore the effects of each regime of defoliation on production at some of the bena and betta sites.

Net above-ground herblayer (AGHB) production was measured in terms of the dry biomass weight; palatable fractions and nutrient concentrations could not be measured due to practical limitations. Further, peak standing biomass (including standing dead) was used as a proxy for net AGHB production in "control", *i.e.* unclipped/ungrazed quadrats. The problems generally associated with using peak standing biomass as a measure of net AGHB production (Long *et al.* 1992) and our ways of minimising them or reasons for ignoring them are as follows. Firstly, measurements of live biomass only will miss out the biomass that died before measurement, so we included standing dead in our measurements. Secondly, using peak biomass means one misses out growth that may occur after the so-called peak, *i.e.* during subsequent growing seasons (Kamnalrut and Evenson 1992) or corresponding to different species. In our study region, however, the sharply uni-modal distribution of rainfall and lower species diversity (than say in African savannas) results in only one growing season per year and a more coherent growth pattern. Finally, monthly sampling may result in one missing the exact peak in the standing biomass. In a growing season of 7 months, however, a monthly sampling strategy seemed reasonable.

Specific sites and methods

Sites

A total of 8 sites were chosen and the herblayer sampled in different ways. Their locations are shown in Figure 1, and the site features and measurements taken are summarised in Table 1. Five sites (MT-, CH-, AP-, MH-, and BV-BENA) were benas, sharing the following characteristics:

(a) zero or almost zero tree canopy cover;
(b) slope generally less than 5°;
(c) well-drained sandy-clay loam or sandy-loam soil; and
(d) a consistent management history for at least a decade of: (i) full protection from grazing during the growing season (except BV-BENA where some grazing occurred during June–July); (ii) open grazing during the rest of the year; and (iii) annual or biennial fire at the end of the dry season.

Three other sites (KS-, TK-, and CH-BETTA) chosen as representative of sub-optimal endogenous conditions were bettas, characterised by higher tree densities (100–300 trees/ha), somewhat higher slopes (5–20°), and varying historical levels of grazing and fire. KS- and TK-BETTA had lower tree densities than CH-BETTA and a history of moderate grazing. CH-BETTA had been exposed to heavy grazing in the previous decade.

Although some sites were fenced off by the landowners, we attempted to erect barbed wire

Table 1. Site characteristics and types of measurements and experiments conducted.

Site code	Vegetation type[1]	Annual rainfall[2] (mm)	Slope	Soil texture	Historical disturbance regime[3]	Whether exclosure set up	Measurements/ treatments
MT-BENA	grassland (0)	5000	5–30°	sandy-loam (stony)	regular P & B	no	peak biomass
CH-BENA	grassland (0)	2500	5°	sandy-clay loam	regular P & B	no	peak biomass
AP-BENA	grassland (0)	2100	5°	sandy-clay loam	regular P & B	yes	monthly & peak biomass, single-clip
MH-BENA	grassland (0)	2100	0–5°	sandy-clay loam	regular P & B	yes	monthly & peak biomass, single-clip
BV-BENA	grassland (0)	1500	5°	sandy-clay loam	regular P & B	no	peak biomass
KS-BETTA	savanna (100)	4300	10–20°	sandy-loam	no P, irregular B	yes	monthly & peak biomass, single-clip
TK-BETTA	savanna (100)	4300	20°	sandy-loam	recent P, irregular B	yes	monthly & peak biomass, single-clip
CH-BETTA	savanna-woodland (300)	2500	5°	sandy-clay loam	no P & heavy grazing, irregular B	yes	monthly and peak biomass, single-clip, repeated clip[4]

[1]Figures in brackets are approximate tree densities per ha, with "trees" being single-stemmed woody plants with girth at breast height > 20 cm.
[2]At nearest available recording station.
[3]P = protected from grazing during each growing season; B = burning during dry season.
[4]Includes two treatments: continuous clipping throughout the season; and partial closure after mid-August.

exclosures to prevent our quadrats being disturbed by stray cattle or persons. However, logistics and landowners permitted the erection of exclosures at only 5 of the 8 sites (Table 1), including 2 benas and 3 bettas. At these sites, monthly clipping was carried out for estimating the monthly growth curve, peak standing biomass and response to light grazing. The CH-BETTA site was adjacent to our field station, and was well fenced, so additional clipping treatments were performed there.

The 3 "unexclosed" sites (MT-BENA, CH-BENA and BV-BENA) had been fenced off by their owners (historically and in 1990), but were either too remote for repeated visits or unavailable for repeated clipping. Only peak biomass was estimated at these sites through a single harvest.

Peak ungrazed biomass

At most of the exclosed sites, 10 m × 10 m or larger barbed wire exclosures were constructed in May 1990, and a block of 4.5 m × 3.5 m was marked inside it, resulting in a 9 × 7 matrix of quadrats (each 0.5 m × 0.5 m) and leaving 1–2 m wide buffer strips on each side. Each strip of 9 quadrats was sequentially assigned for 1 month's clipping in the 7-month period of June–December. At CH-BETTA, a larger exclosure allowed us to lay 24 quadrats for each month in blocks of 3 under varying levels of tree canopy. Thus, each month's set of quadrats contained vegetative growth that had not been grazed or clipped from the beginning of the growing season till the date of harvest of that set, giving us month-wise standing biomass values under no grazing or clipping, *i.e.* the control. The maximum among these values was taken as the peak standing biomass of the control.

At the unexclosed sites, standing biomass was harvested on a day during the week that local people said was the time of peak above-ground biomass. Nine quadrats of 0.5 m × 0.5 m were harvested in a stratified random manner, 3 each from the top, middle and bottom of the slope at the site. Since all 3 sites had their own fencing (being benas maintained for fodder), these measurements also correspond to the ungrazed treatment, *i.e.* the control. The likely error in assuming this estimate to be the peak ungrazed biomass is discussed later.

Grazing treatments

To simulate the effect of light grazing with varying timing, we used the month-wise harvested strips in the exclosures. Reharvesting all these strips (originally clipped in different months) at the end of the growing season (December) gives the amount of regrowth after the first clip. The sum of the biomass obtained from a quadrat in the first clip and in the re-harvest is an estimate of the cumulative production in that quadrat over the growing season under a "single-clip" treatment in the corresponding month.

To examine the effect of heavy and frequent grazing, 2 treatments were implemented at CH-BETTA. The first treatment, simulating "continuous heavy grazing", consisted of clipping of twenty-four 0.5 m × 0.5 m quadrats at 15-day intervals from June to December. The second treatment was an attempt to simulate a local practice of "partial closure", *viz.* allowing heavy grazing in the grasslands until the end of the initial heavy rainfall period and then protecting the grasslands till the end of the growing season. This treatment was thus identical to the continuous heavy grazing treatment through mid-August, after which clipping was stopped completely till the final harvest in December.

To summarise, we had estimates of peak ungrazed biomass from all 8 (5 bena/grassland and 3 betta/savanna) sites, monthly ungrazed biomass for the 5 exclosed sites (2 bena and 3 betta sites), cumulative production under single-clipping treatments (6 treatments corresponding to clips in the different months during June–November) at the same 5 sites, and repeated grazing treatments (continuous heavy grazing and partial closure) at one exclosed betta site (Table 1).

General methods

In each quadrat, the vegetation was clipped to ground level. Fresh weights were recorded, distinguishing monocots, dicots and dead (monocot + dicot, but excluding tree leaflitter). Full samples (or well mixed 10% subsamples) were oven-dried at 40°C to constant weight. At the exclosed sites, the major species that *together* appeared to contribute more than 75% of the peak standing biomass were identified, and specimens collected, dried and identified by taxonomists. Rainfall data were collected from the nearest recording stations.

Results

Peak AGHB biomass and its variation

The estimates of peak herblayer biomass for the 8 sites are given in Table 2. Peak biomass in the

Table 2. Summary of results of clipping experiments.

Location code	Mean (± s.e.) peak biomass of control (t/ha DM) & date[1]	Dominant species[2] (at time of attaining peak biomass)	Single-clip treatments: Minimum and maximum cumulative biomass obtained (avg. ± s.e. [dry t/ha], date of clip, and difference from control[3])		Multiple clipping treatments: Cumulative biomass from all clips (avg. ± s.e. [dry t/ha] and difference from control)	
			Minimum	Maximum	Continuous	Partial closure
MT-BENA	3.36 ± 0.21 (8 Nov)	n.i.	—[5]	—	—	—
CH-BENA	4.45 ± 0.23 (26 Oct)	*E. trispicata, A. metzii, T. triandra*	—	—	—	—
AP-BENA	4.13 ± 0.39 (29 Oct)	*E. trispicata, A. metzii, T. triandra, H. contortus*	2.24±0.18*** (28 Aug)	3.33±0.41 (28 Jun)	—	—
MH-BENA	5.23 ± 0.35 (28 Nov)	*E. trispicata, A. metzii, T. triandra, H. contortus*, "Kestrada hullu"	3.23±0.13*** (28 Sep)	5.43±0.12 (28 Jun)	—	—
BV-BENA	5.89 ± 0.27 (6 Nov)	n.i.	—	—	—	—
KS-BETTA	1.02 ± 0.08 (22 Oct)	*I. indicum, A. metzii, T. triandra*	0.95±0.07[4] (21 Sep)	1.60±0.23* (19 Jun)	—	—
TK-BETTA	1.58 ± 0.09 (22 Oct)	*E. trispicata, A. metzii, T. triandra*	1.20±0.12 (20 Aug)	1.65±0.18 (19 Jun)	—	—
CH-BETTA	1.63 ± 0.09 (15 Nov)	*E. trispicata, A. metzii, T. triandra*	1.16±0.06*** (16 Aug)	1.69±0.09 (15 Oct)	1.01±0.08 ***	0.97±0.03 ***

[1]Date of clip which yielded maximum AGHB (except in case of MT-BENA, CH-BENA, and BV-BENA: see text).
[2]Full names are: *Arundinella metzii, Eulalia trispicata, Heteropogon contortus, Ischaemum indicum* and *Themeda triandra*. "Kestrada hullu" is a local name for a species that could not be identified. "n.i." indicates sites where species identification could not be carried out.
[3]Significance estimated using post-hoc multiple comparison tests (HSD test for unequal N).
[4]Significantly different from cumulative production values for June & July clips (P < 0.01), although not from control.
[5]Treatment not conducted for these sites.

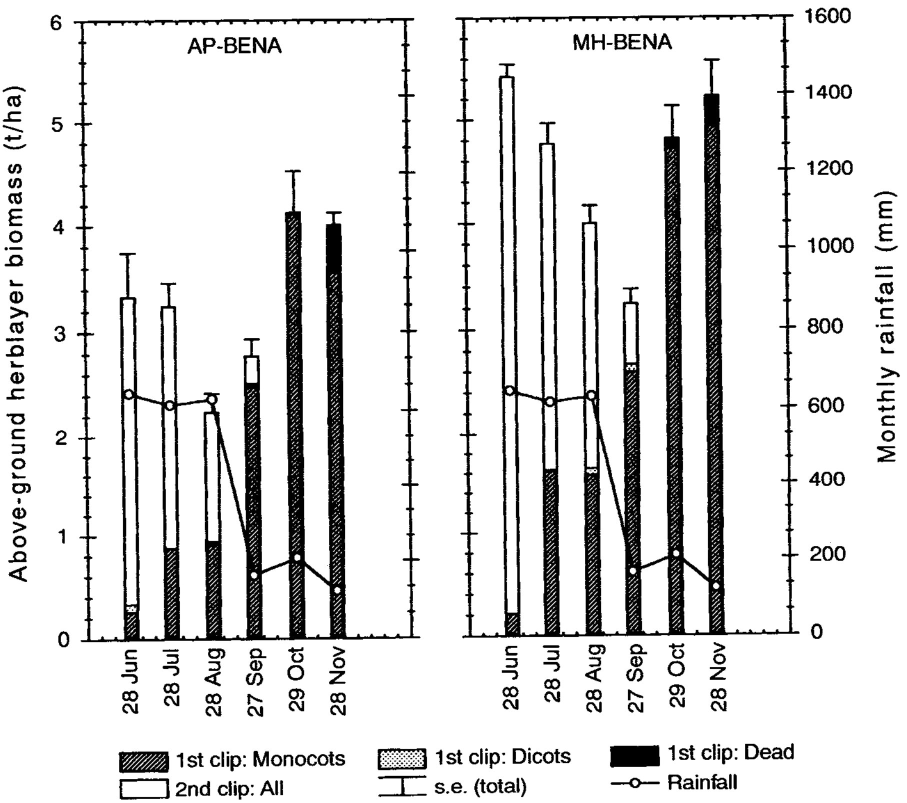

Figure 3. Seasonal growth patterns and single-clip effects in 2 exclosed bena sites, along with monthly rainfall during the study period.

optimally managed benas ranged from 3.3–5.9 t/ha/yr. On the other hand, peak biomass in the shaded and historically grazed bettas was much lower at 1.0–1.6 t/ha/yr. Spatial variation at any given site was not high, the CV of peak biomass being in all cases less than 15%. The difference in average peak biomass between the bena and the betta sites was thus highly significant ($P < 0.002$ in a t-test).

The monthly growth patterns for 2 benas and 3 bettas are given in Figures 3 and 4, respectively. There appear to be two distinct growth episodes, with the second one (September–November) contributing the most to peak biomass. This episode coincides with a reduction in the intensity of the monsoon — and a corresponding increase in light availability — at each site, as can be seen from the graph of monthly rainfall overlaid on each growth curve.

The growth patterns also enable us to limit the uncertainty introduced due to sampling only once a month at the exclosed sites. In all cases, the peak in live biomass appears to have occurred some time between late October and late November. Allowing time for the biomass to reach its peak and then decay to the lower value of late November, the error in timing of our harvest is likely to be less than 15 days. In this period, extrapolating from the earlier (Sept–Oct) rate of growth, and noting that the rate must slow down as biomass peaks, the additional growth would have been insignificant (less than 0.2 t/ha). At the 3 unexclosed sites, where only single samples were taken, the sampling was done between 26 October–8 November, tallying well with the period of peak biomass occurrence at 4 of the 5 exclosed sites, including both benas.

The wide range in biomass production amongst the benas, from 3–6 t/ha/yr, indicates the significant effect of exogenous conditions on "potential" production. We plotted peak biomass observed at these sites against the number of

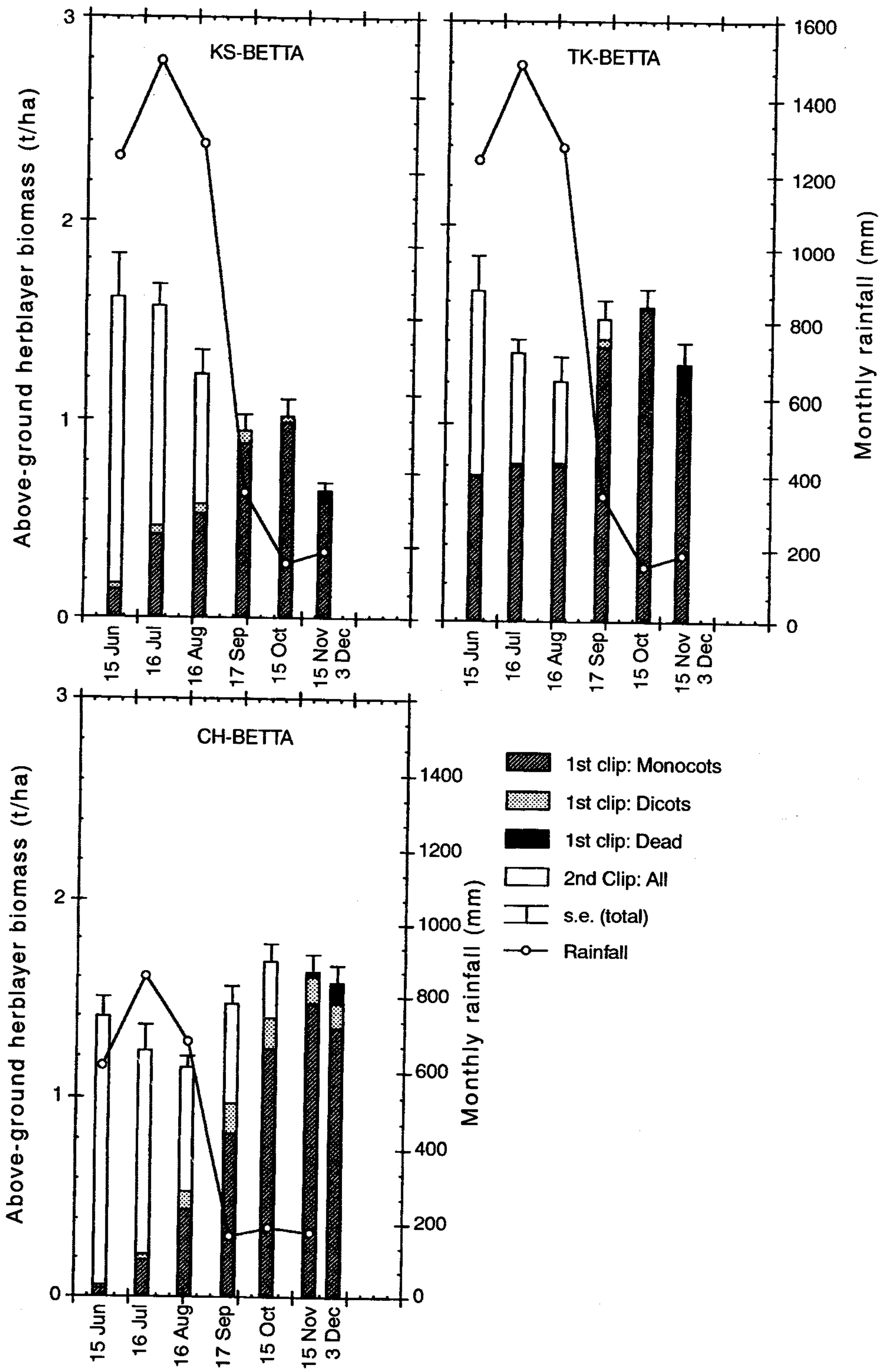

Figure 4. Seasonal growth patterns and single-clip effects in 3 exclosed betta sites, along with monthly rainfall during the study period.

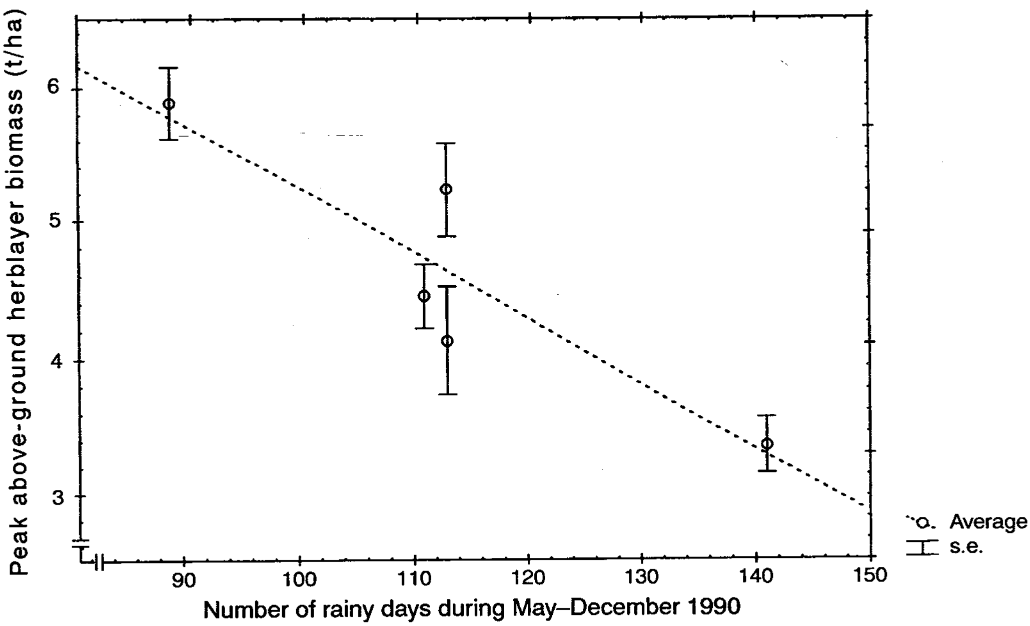

Figure 5. Relationship between peak AGHB estimates and rainfall across the study region. Mean AGHB = 10.05–0.048* (Number of rainy days) + error term; P (slope) <0.05.

rainy days recorded during May–December that year at the nearest recording stations (Figure 5). Peak biomass was negatively related to the number of rainy days, with the linear regression having a Pearson's adjusted $r^2 = 0.74$ and a slope different from 0 ($P < 0.05$). The relationship with rainfall was essentially similar, although not linear.

Species composition

Perennial C4 grasses comprised more than 90% of the peak AGHB at all sites. The dominant species, listed in Table 2 (col. 3), included *Eulalia trispicata*, *Arundinella metzii* and *Themeda triandra*.

There is a clear, though slight, increase in the fraction of dicotyledonous biomass in the herb-layer at peak AGHB as the tree canopy cover increases: compare the dicot fraction at AP- and MH-BENA (Figure 3) with that at KS-, TK- and then at CH-BETTA (Figure 4). At every site, dicots emerged earlier, but were then suppressed by the heavy growth of the grass species.

Effect of single clipping and its timing

The regrowth and cumulative biomass values obtained at the 5 sites under the single-clip treatments are graphically presented in Figures 3 and 4, and the cumulative biomass values were compared with each other and with the peak biomass of control using ANOVA and multiple-comparison tests (HSD test for unequal N). The results are summarised in Table 2.

Single clips early in the growing season cause no significant reduction in production. Indeed, in some cases there is a possibility of a slight increase compared with the control. For KS-BETTA, this increase is significant ($P < 0.02$).

On the other hand, cumulative production is clearly negatively affected by clipping that occurs midway through the growing season. At all 5 sites, the August- or September-clip treatments showed the least cumulative production. At 3 of these sites (CH-BETTA, AP-BENA and MH-BENA), this value was significantly lower than the peak biomass of the control ($P < .001$) and the cumulative biomass from the June-clip treatment ($P < 0.05$ at least). In KS-BETTA, the cumulative biomass for the September-clip treatment was significantly lower ($P < 0.001$) than that for the June- and July-clip treatments. The same trend in average values was seen at TK-BETTA, although the differences were not statistically significant. Overall, cumulative production showed a U-shaped response to the timing of the single-clipping treatment.

Effect of continuous clipping

The results of the 2 multiple-clip treatments carried out at CH-BETTA are given in Table 2. Both continuous clipping and partial closure resulted in a virtually identical level of cumulative production, *viz.* about 1 t/ha. This was significantly less than the peak biomass of the unclipped control, which was about 1.6 t/ha. Thus, 15-day clipping resulted in a 40% decline in AGHB production at this site, even when it was suspended after mid-August.

Discussion

There are no studies of herblayer production in anthropogenic grasslands of the Karnataka Western Ghats with which to compare our results. The range of potential AGHB production observed by us (3–6 t/ha/yr) is far above the value of 0.2 t/ha assumed by Reddy *et al.* (1986) for forest lands of Uttara Kannada district as a whole, the 1.3 t/ha/yr harvested by Bhat and Gadgil (1987) from unexclosed quadrats in an open grassland just west of the crestline of the Ghats in this district, and even the 2.5 t/ha for very similar protected benas in villages in the middle of our study region estimated by Nadkarni *et al.* (1989) from farmers' oral recall. This highlights the dangers of ignoring the effects of tree canopy cover and grazing, and of using visual or oral estimation methods as against actual harvests in exclosures. All these errors tend to underestimate herblayer production, perpetuating the myth of grasslands and savannas as "unproductive" and "degraded". On the contrary, our results show that maintaining "forest" land as grassland can be a productive landuse, since the total above-ground biomass in even rain-fed upland paddy cultivation may be 3–4 t/ha (Y.G. Kanade, personal communication).

Our estimates of net AGHB production are nevertheless significantly lower than the range of 9–14 t/ha/yr reported by Kamnalrut and Evenson (1992) for an anthropogenic savanna-grassland in a moist tropical region of Thailand, and the estimate of ~12 t/ha/yr for humid grasslands in the southernmost part of the Western Ghats (Karunaichamy and Paliwal 1994). Some of the difference must be attributed to our use of peak standing live+dead biomass as a measure of net AGHB production, missing out some of the losses due to mortality (although the positive increment method used by Karunaichamy and Paliwal also misses out most mortality). However, the major reason for higher production measured in these other studies is that climatic conditions permitted grass growth throughout the year in Thailand or at least in 2 distinct seasons in Kanyakumari, as against in only one 7-month season at our site.

The dominant species tally with those reported by Dabadghao and Narayanan (1973) for this region. That 3 or 4 species together contributed more than 75% of the peak biomass at any site indicates the relative homogeneity of the herb-layer at each site. *Eulalia trispicata*, *Arundinella metzii* and *Themeda triandra* are common dominants at all sites, indicating the homogeneity across sites. Not surprisingly, these species belong to genera that are known to be fire-adapted (Sanchez 1976).

The negative correlation between peak biomass and rainy days or rainfall across the sites is an interesting and intriguing result. We were unable to locate studies in the humid tropics with regional spatial coverage such as ours; most studies focused on the effect of rainfall on production across seasons or years at a particular site. Comparing across studies is possible (see tables in Jones *et al.* 1992; Karunaichamy and Paliwal 1994) but yields little insight, because there are major differences in site conditions, species composition and methods used to estimate production. However, most studies examining inter-annual effects report a weakly positive (Kamnalrut and Evenson 1992) or strongly positive relationship (Pandey and Singh 1992a; 1992b). It is therefore unlikely that higher rainfall *per se* is causing declines in production at our sites. On the other hand, growth is certainly not being limited by soil moisture deficits at any of the sites during most of the growing season.

We hypothesise that the negative correlation with rainy days across bena sites in our region represents the light-limiting effect of prolonged cloudiness during the heavy monsoon. This inhibition would be particularly pronounced because the dominant species are C4 grasses that could otherwise have taken full advantage of the high level of insolation at this latitude. Data on insulation (or at least number of cloudy days) would have helped test this hypothesis, but were not available. Some support for the hypothesis comes from the earlier observation that the period of most rapid growth at all sites coincides with the reduction of rainfall after August. Rainfall may also have another indirect effect over the long term; the soils in the high rainfall region may be more leached and hence poorer in nutrients, constraining production. Clearly, the response of moist savanna-grasslands to environmental conditions is quite different from that observed in the heavily researched drier regions, pointing to the urgent need for further research on the former.

The effect of a single-clip treatment on biomass production follows a "U-shaped" curve with respect to the timing of the clip, with the possibility of "overcompensation" (stimulation of production as compared with the control) with early clips, and a low point in the "U" that appears to just precede the point at which the growth rate of the control is at its maximum. This response is unlike many results reported for temperate grasslands (Robards and Leigh 1967; Miller *et al.* 1990), but similar to results obtained for the semi-arid region of Mali (Turner 1992). The overcompensation was clearest at the site with lowest peak biomass of the control, a betta site with unfavourable growing conditions. If production were measured in nutritive terms, this overcompensation may become more pronounced, because the clipped plants were observed to be at an earlier growth stage than those in the unclipped quadrats in mid-November (the latter having flowered and begun to set fruit). What exact combination of soil and tree canopy conditions might enable such overcompensation, and whether clipping at some distance above ground level (arguably a more realistic simulation of cattle grazing) will lead to greater overcompensation as reported by Sundriyal *et al.* (1993) for Himalayan grasslands are issues needing further research.

The results of the continuous clipping and partial closure treatments need to be interpreted and extrapolated with caution, given the atypical nature of the site, clipping intensity and clipping frequency employed. Firstly, the CH-BETTA site had the highest historical grazing pressure and the highest tree canopy (Table 1), *i.e.* the least favourable growing conditions. Secondly, the frequency of clipping was every 2 weeks, and the clipping intensity was 100%, *i.e.* to ground level. This corresponds to a very heavy grazing regime, because, in practice, grazing by cattle and buffaloes does not result in complete defoliation. Under such extreme conditions, it is not surprising that we observed a 40% drop in production relative to the control. One may therefore hypothesise that 40% is the maximum intra-annual reduction heavy grazing can cause. This does not, however, imply that continuous grazing *as practised in the region* will result in similar reductions. Less frequent (30- and 60-day intervals) and less intense (5 cm or 15 cm above ground) clipping regimes have been shown to result in little or no decrease in cumulative production in studies with species (though not growing conditions) similar to ours (Singh and Mall 1977, *T. triandra*; Sundriyal *et al.* 1993, *E. trispicata*).

The absence of differences between the 2 repeated clipping treatments again implies that, *at the particular frequency, intensity and site used*, partial closure will not yield any gains in cumulative production over continuous heavy grazing. In practice, however, grazing is actually less intense than the clipping treatments and most savanna-grasslands have less tree canopy and more root stock (less grazing-induced denudation) than the site we used. Jumping to the conclusion that the traditional practice of partial closure is inappropriate or ineffective would therefore be imprudent; further investigation with more appropriate clipping treatments and a larger number of sites is necessary.

Although our clipping experiments have captured only intra-annual effects, an indication of whether the landuse is sustainable in the long run can be obtained by comparing the production at sites with historically consistent management with a "natural benchmark". The 5 bena sites in our study have consistent histories. They have been protected during the growing season, harvested in late November, lightly grazed during the dry season, and burnt at the end of the dry season for over 3 decades (somewhat less in the case of MH-BENA). The only available natural benchmark is the value of 6.2 t/ha/yr estimated (using the peak-biomass method) by Swamy

(1989) in naturally-occurring high-altitude grasslands in the nearby district of Chickmagalur. The peak AGHB values of 3–6 t/ha/yr at our 5 sites are quite comparable with this benchmark.

Thus, one may hypothesise that the management regime followed in the benas or pure grasslands is "sustainable", even in the long run. Indeed, a regime of this type is probably essential to obtain such high levels of herbaceous production from lands that would otherwise revert back to dense semi-evergreen or evergreen forest. On the other hand, heavy grazing, especially at and beyond mid-season, is bound to be deleterious to production. Between these extremes, however, there are a range of grazing intensities and durations that are likely to result in only a limited loss of production, and possibly even some overcompensation. Local land managers generally show an appreciation of these aspects. Their traditional practice of partial closure is partly a reflection of a belief in the harmlessness of early season grazing and partly a compromise between the need for protection and the need to make the limited stocks of stored fodder last during the period of closure.

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