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Costs of overstocking on cattle and wildlife ranches in Zimbabwe

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Abstract

In African semi-arid savannas livestock production frequently dominates human activity, but it has been claimed that wildlife ranching can be more profitable than extensive beef production. Traditional accounting methods generally exclude the biological costs of stocking effects on rangeland productivity. This paper presents a framework for evaluating overstocking effects on the financial profits (based on market prices) and economic profits (estimated from the opportunity costs of inputs and outputs) of alternative range-based animal production systems. The method was applied to 50 commercial cattle, wildlife, and mixed ranches in the Zimbabwe Midlands using 1989/90 data. Level of overstocking was estimated from positive differences between grazer stocking rate and rangeland carrying capacity, which was predicted from long-term mean annual rainfall. Since it is generally impossible to accurately quantify stocking effects on rangeland productivity, and thus to confidently evaluate overstocking costs, values ranging from Z\$0.00 to Z\$0.50 kg^{-1} ha^{-1} overstocking were used. The resulting range of costs were subtracted from financial and economic profits. Cattle ranches were significantly overstocked while mixed and wildlife ranches were not. Thus cattle ranch profits decreased more rapidly with increasing simulated overstocking cost. In other words, with increasing sensitivity to overstocking, wildlife and mixed ranches had a higher probability of remaining financially and economically profitable than did cattle ranches.

Keywords: Livestock production; Overstocking

1. Introduction

Environmental cost accounting has traditionally excluded the cost of exploiting biological capital leading to a decrease in the productive capacity of natural resources. Most economic stocking rate models have been developed from a static, short-term perspective that does not account for overstocking effects on future rangeland productivity (Torell et al., 1991). The economic efficiency of production systems which over-exploit rangelands for short-term gain are thus generally overvalued relative to those that exert less pressure on rangeland resources. This is a particularly critical deficiency in African savannas where rural people depend largely on rangeland resources for survival.

Savanna rangelands dominate 65% of Africa (Huntley and Walker, 1982), and over large areas their productive potential is low due to infre-

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quent, erratic rainfall and low soil fertility. In these semi-arid areas livestock production has historically dominated human activity, but the use of wildlife is starting to emerge as a viable production alternative.

This paper presents a framework for evaluating overstocking effects associated with different range-based animal production systems. The technique is applied to commercial cattle and wildlife ranches in the Zimbabwe Midlands using cross-sectional data from the 1989/90 production season. Since it has a long history of cattle ranching and landowners are allowed to profit from wildlife on their property, Zimbabwe presents a rare venue for conducting comparative economic studies of African range use. The Midlands Province, consisting of Zimbabwe's most productive semi-arid savannas, 78% of which is grazeable (Roth, 1990), was selected for study because it was ideal for identifying economic trade-offs between cattle and comparable wild ungulates. In areas drier than the Midlands sparser grass cover may favor browsers while in wetter areas abundant grass is likely to favor cattle.

1.1. Herbivory effects in semi-arid savannas

Extended intensive defoliation of plants frequently leads to changes in vegetation structure, species diversity and secondary productivity (Crawley, 1983). In Africa, megaherbivores such as elephants, rhinos and giraffes have historically played a major role in maintaining open savannas by defoliating or debarking woody plants (Owen-Smith, 1988). However, with the increase in domestic livestock and the concomitant eradication of megaherbivores across large tracts, grazing pressure relative to available herbaceous forage has become the dominant factor driving vegetation dynamics in many semi-arid savannas. The consequent widespread continuous defoliation of herbaceous plants in excess of regrowth has resulted in replacement of perennial grasses by annual and woody plants (Walker, 1976; Walker et al., 1981). This has frequently led to lower rangeland productivity and increased soil erosion.

Since multi-species herbivore communities tend to consume a greater range of forages than cattle alone (Taylor and Walker, 1978; Walker, 1979), it has been argued that wildlife production is ecologically the most rational land-use in such savannas (Child and Child, 1986). It has, moreover, been claimed that game ranching can produce more biomass and therefore greater profits per unit area than extensive beef ranching (Dasmann and Mossman, 1961; Clarke et al., 1985; Hopcraft, 1986). However, other studies have not corroborated this claim (Taylor and Walker, 1978; McDowell et al., 1983). The main advantages of the use of wild animals relative to conventional livestock production are now generally considered to be the higher value per unit area, multiple-use potential, and lower population densities of wildlife systems (Johnstone, 1973; Child, 1988; Cumming, 1989). Yet few studies have empirically evaluated the economic costs of stocking levels associated with alternative range-based production systems.

1.2. Carrying capacity, stocking rates and land productivity

Evaluating overstocking effects requires clear definitions of carrying capacity and overstocking. Ecological carrying capacity is the herbivore biomass that is sustained when, in the absence of external disturbances, forage production and consumption are equal (Caughley, 1979). This definition may, however, be too rigid for practical purposes because the number of herbivores is not only a function of forage availability, but also depends on the effects of herbivory on vegetation dynamics (Savory, 1988; Bartels et al., 1991). Realistically, carrying capacity can, however, be represented by a probability band the width of which is determined by rainfall variability (Bell, 1984).

The observation that overgrazing can negatively affect rangeland productivity has traditionally led to stocking recommendations below estimated carrying capacity (Stoddart et al., 1975; Holechek et al., 1989). Where stocking is excessive, the costs of associated rangeland degradation should, in theory, be borne by producers through declining land values. However, in reality, market prices for land frequently do not accurately reflect the opportunity costs of rangeland overuse for two reasons. Firstly, in semi-arid ecosystems the relationship between herbivory and range condition is complex and influenced by episodic events, such as drought (Walker, 1988; Westoby et al., 1989). The impact of overuse on rangeland productivity is thus frequently lagged or intermittent and difficult to quantify. Secondly, during rapid inflationary periods, as occurred in Zimbabwe during the study, the effect of range condition on land prices is frequently insignificant due to speculative land pricing (Rowan and Workman, 1992).

Since market prices, generally, do not effectively capture the intertemporal range use externality of falling future productivity, it can thus be argued that revenues derived from range-based production systems should be adjusted to reflect overstocking effects. Indeed, short-term profit maximization, which does not account for such intertemporal effects, has frequently been blamed for excessive stocking (Workman, 1986). It has, however, also been suggested that, if grazing impacts on range productivity are small relative to the effects on animal performance, the short-term, economic-optimum stocking rate is unlikely to exceed the rangeland degradation threshold (Torell et al., 1991; Wilson and MacLeod, 1991). The preceding discussion emphasizes that, due to varying but uncertain rangeland sensitivity to herbivory, it is impossible to precisely quantify the extent of overstocking and the economic cost of assumed overstocking levels. There is nevertheless some stocking threshold which, when exceeded, can force semi-arid savannas to change to less productive states, especially in dry periods.

2. Study description

2.1. Carrying capacity

Since area-specific carrying capacity models are rare and were unavailable for the Zimbabwe Midlands, a modification of the more general Coe, Cumming and Phillipson model (1976) was used to estimate carrying capacity. This model positively correlates large herbivore biomass with mean annual rainfall in 20 eastern and southern African locations with less than 800 mm rainfall. Similar positive correlations were identified for nineteen individual herbivore species by East (1984). The Coe, Cumming and Phillipson model may, however, over-predict biomass per unit of rainfall in nutrient-poor areas, such as the ubiquitous sandveld of Zimbabwe (Bell, 1984). Moreover, the model does not account for the negative correlation between energy requirements per unit body mass and size of mammals (Hudson, 1985). To address these limitations, Cumming (1991) derived the relationship between metabolic biomass (MM in kg ha^{-1}) and long-term mean annual rainfall (MAR in mm) using data from 15 of the 20 locations used in the Coe, Cumming and Phillipson model. The regression is presented below (standard errors of coefficients are parenthesized). The 95% confidence limits for 700 mm MAR (ca. 30-year mean annual rainfall for the Midlands) are $\pm 22\%$ of the predicted value.

$$\begin{aligned} MM &= -2.47820 + 0.01965\ MAR \\ &\quad\ (1.68835) \quad (0.00644) \\ &(r = 0.88;\ P < 0.001;\ n = 15), \end{aligned} \tag{1}$$

where: $MM = W^{0.75}$ (kg ha^{-1}), since basal metabolism for mammals is 293 $W^{0.75}$ kJ d^{-1}, W = kg of body mass (Kleiber, 1975).

Based on East's (1984) observation that wild mammal populations in Africa are usually regulated at levels close to carrying capacity, Eq. 1 should predict the ecological carrying capacity for a mixed large herbivore community. However, the study area is largely devoid of megaherbivores, while in undisturbed woodland savannas (Bell, 1984), such as those occurring in the Midlands, megaherbivores may constitute over 50% of the total herbivore biomass. Since much of the vegetation that is normally used by megaherbivores is inaccessible to other herbivores, it could be argued that the carrying capacity for herbivores that do occur may be only 50% of that predicted by Eq. 1.

Due to the uncertain power of the modified Coe, Cumming and Phillipson model for accurately predicting the carrying capacity for existing herbivore communities in the Midlands, three estimates were derived for each study ranch. These were the carrying capacity predicted by Eq.

1 using 30-year mean annual rainfall, the upper 95% confidence limit of this value, and 50% of the value to account for the lack of megaherbivores.

2.2. Stocking rate and overstocking estimates

In semi-arid savannas, grazing pressure is of greater significance than total stocking rate for evaluating herbivory impacts on rangeland productivity because vigor of the herb layer is the primary determinant of productivity (Walker, 1976). Moreover, since larger browsers use disproportionately larger shares of foliar resources (du Toit and Owen-Smith, 1989), and the density of browsers was low throughout the Midlands (representing only about 10% of total biomass of mammalian herbivores weighing 10kg or more),

Table 1
Biomass (kg), metabolic mass ($kg^{0.75}$) and proportion of grass fractions in the diets of herbivores

Species	Scientific name	Unit body mass		Grass in diet
		Biomass	Metmass	
Wild herbivores				
Elephant	*Loxodonta africana*	1725 [b]	267.7	60% [f]
White rhino	*Ceratontherium simum*	1500 [c]	241.0	100% [f]
Hippo	*Hippopotamus amphibius*	1000 [c]	177.8	80% [f]
Black rhino	*Diceros bicornis*	816 [c]	152.7	5% [f]
Giraffe	*Giraffa camelopardalis*	750 [b]	143.3	0% [f]
Buffalo	*Syncerus caffer*	450 [c]	97.7	90% [f]
Eland [a]	*Taurotragus oryx*	340 [b]	79.2	20% [f]
Zebra [a]	*Equus burchelli*	200 [b]	53.2	90% [f]
Sable [a]	*Hipotragus niger*	185 [b]	50.2	90% [g]
Wildebeest [a]	*Connochaetes taurinus*	165 [b]	46.0	100% [g]
Waterbuck	*Kobus ellipsiprymnus*	160 [c]	45.0	90% [f]
Kudu [a]	*Tragelaphus strepsiceros*	136 [b]	39.8	0% [g]
Tsessebe [a]	*Damaliscus lunatus*	110 [b]	34.0	90% [g]
Ostrich	*Struthio camelus*	68 [b]	23.7	50% [e]
Bushpig [a]	*Potamochoerus porcus*	54 [c]	19.9	75% [g]
Warthog [a]	*Phacochoerus aethiopicus*	45 [b]	17.4	80% [f]
Impala [a]	*Aepyceros melampus*	45 [b]	17.4	50% [f]
Reedbuck [a]	*Redunca arundinum*	40 [c]	15.9	95% [f]
Bushbuck [a]	*Tragelaphus scriptus*	30 [c]	12.8	5% [g]
Oribi	*Ourebia ourebia*	14 [d]	7.2	90% [f]
Steenbok [a]	*Raphicerus campestris*	10 [b]	5.6	50% [g]
Grysbok [a]	*Raphicerus melanotis*	10 [c]	5.6	10% [f]
Duiker [a]	*Sylvicarpa grimmia*	10 [b]	5.6	0% [g]
Klipspringer [a]	*Oreotragus oreotragus*	10 [c]	5.6	0% [g]
Domestic Stock				
Bulls		600 [e]	121.2	100%
Cows		400 [c]	89.4	100%
Steers (> 1 year)		300 [e]	72.1	100%
Heifers (> 1 year)		275 [e]	67.5	100%
Weaners		180 [e]	49.1	100%
Calves (< 6 month)		120 [e]	36.3	100%
Sheep/goats		35 [b]	14.4	50%

[a] Species used for safari hunting.
[b] Cumming and Taylor (1989).
[c] Coe et al. (1976).
[d] Smithers and Wilson (1979).
[e] Anecdotal information from ranchers.
[f] Walker and Hanks (1974).

there was little herbivory pressure on the woody vegetation. For these reasons, stocking rates and overstocking, relative to predicted carrying capacity, were estimated only for the grazer component of the herbivore community.

The approximate proportions of grass in domestic and wild herbivore diets are presented in Table 1. Stocking rates of the grazing fraction of herbivores (SRG_j measured in $kg^{0.75}$ ha^{-1}) were estimated for each wild herbivore species and each sex and age class of cattle using metabolic unit body mass (body mass weighted for average herd or class structure raised to the 0.75 power). The function used to derive grazer stocking rates was:

$$SRG_j = \left(N_j\ W_j^{0.75}\ G_j\right)/A, \tag{2}$$

where: N_j, W_j and G_j are the population size, unit body mass (kg) and grass fraction in the diet of species or age–sex category j, respectively, and A = ranch area (ha).

Overstocking was assumed to be the positive difference between the total grazer stocking rate and carrying capacity estimates. Overstocking by all grazer fractions (OS) was estimated using Eq. 3 while the cattle and wild herbivore contributions to overstocking (OS_C and OS_W, respectively) were calculated using Eqs. 4 and 5, respectively.

$$OS = \Sigma SRG_j - CC, \tag{3}$$

$$OS_C = (OS * SRG_C)/\Sigma SRG_j, \tag{4}$$

$$OS_W = (OS * SRG_W)/\Sigma SRG_j, \tag{5}$$

where: ΣSRG_j, SRG_C and SRG_W are the stocking rates of all grazers, of all cattle and the grazing component of wild herbivores, respectively (derived from Eq. 2), and CC is the estimated carrying capacity (CC = MM in Eq. 1).

2.3. Cost of overstocking and profit estimates

Although overstocking effects on semi-arid rangeland productivity is uncertain and varies according to the sensitivity of preferred herbaceous species to defoliation, degradation is more likely to occur when overstocking coincides with droughts because herbivory pressure on preferred plants is increased. Since the study coincided with below average rainfall, it was assumed that estimated overstocking was deleterious. This assumption was supported by anecdotal evidence that reduced livestock production and widespread brush encroachment had been correlated with similar stocking rates on Midlands cattle ranches during the 1980s.

In one study on a ranch in southern Zimbabwe, the average annual loss in cattle revenue was estimated to be Z$0.113 kg^{-1} ha^{-1} herbivores overstocked (Jansen et al., 1992). However, due to uncertainty about the herbivory tolerance of rangelands in the Midlands, it was not possible to precisely quantify the level of overstocking nor the economic cost of assumed overstocking levels. Given these limitations, a sensitivity analysis, incorporating a range of assumed overstocking costs, was used to adjust ranch profits for overstocking effects. Assumed annual productivity losses ranged in value from Z$0.00 to Z$0.50 kg^{-1} ha^{-1} grazer overstocked. The upper value was assumed to exceed the likely annual productivity loss on rangelands that are sensitive to overstocking. Moreover, the selected range of values was sufficiently broad to estimate the rates of increase in overstocking costs resulting from decreasing rangeland tolerance to herbivory.

Financial profits (based on market prices) and economic profits (based on the opportunity costs of inputs and outputs) excluding overstocking costs, were previously estimated for each ranch (Kreuter, 1992). Actual financial profits were calculated from the revenue and cost statistics of individual ranchers. Economic profits were estimated from f.o.b. prices of exportable outputs, c.i.f. prices of importable inputs, and the opportunity costs of non-tradeable inputs (labor and capital). The economic profits reported in this paper were derived using 0% capital opportunity cost, 50% Z$ overvaluation, and a cattle–revenue conversion rate of 1.25 (Kreuter, 1992).

In this paper, both economic and financial profits have been adjusted to reflect the simulated economic costs of overstocking. Such adjustments are normally included only in economic analyses in order to reflect the full opportunity cost of resource use. However, the dual adjustment used here allows comparison of the effects of internalizing simulated overstocking costs on ranch profitability, both with and without adjustments for government policy effects. This is an important consideration for determining the relative efficiency of competing range-based production systems under policy-neutral and prevailing economic conditions.

2.4. Study sample and data analyses

Of the 239 Midlands ranches, 90.8% (84% by area) derived income mainly from cattle, and 9.2% (16% by area) mainly from wildlife. The study population was restricted to independent ranches exceeding 1200 ha (70% of total number of ranches) because smaller ranches cannot sustain 240 livestock units, the likely minimum herd size for commercially viable cattle enterprises. The six agricultural areas with the highest concentration of larger ranches were selected for study. Four were dominated by *Miombo* woodland savanna with abundant wildlife while the other two consisted of mainly open, *Hyparrhenia*-dominated grasslands with low densities of wild ungulates.

Fifty ranches deriving revenue from cattle, or wildlife, or both, and ranging in size from 1424 to 132 840 ha were included in the study. In the four areas with abundant wildlife, data were obtained from most (ca. 80%) of the relevant ranches, including 15 cattle ranches, seven wildlife ranches and 13 ranches with both cattle and wildlife enterprises. In the two areas with sparse wildlife, no revenue was derived from wildlife, and 15 cattle ranches (ca. 25%) were randomly selected for study.

Cattle ranchers included in the survey derived virtually all of their income from the sale of beef cattle. Among wildlife enterprises, 84% provided revenue from the sale of safari hunting opportunities, 25% from hunting leases, and 25% from the sale of game meat. Hunting clients were 49% American, 40% European, and 6% Australian, and the hunted species included leopard (*Panthera pardus*) or sable (*Hipotragus niger*) as the main trophy species, and several other plains game species shown in Table 1.

Data were collected for the 1989/90 production season through personal interviews based on an extensive standardized survey questionnaire. The questionnaire consisted of two parts; the first related to physical and managerial information and the second was used to record estimated numbers of cattle and wild mammals, as well as revenue, cost, and capital investment statistics. Since data were obtained through personal interviews and repeated visits, non-response was negligible.

The model used to estimate the effect of simulated overstocking costs on cattle, wildlife and mixed ranch profits was a sample regression function of the form:

$$Y_i = \beta_0 + \beta_1 X_i + \epsilon_i, \qquad (6)$$

where: Y_i = financial or economic profit (Z\$ ha^{-1}) at the X_ith level of overstocking cost (Z\$ kg^{-1} ha^{-1} herbivore overstocked), β_0 = profit with zero overstocking, β_1 = the rate of change in profit with increasing rangeland sensitivity to overstocking, and ε_i = residual error.

Differences between paired regressions (e.g., cattle ranches versus wildlife ranches) were analyzed using the abridged Chow test (Gudjarati, 1988). The non-parametric Mann–Whitney test (Hollander and Wolfe, 1973) was used to test differences between the mean stocking rates of the four ranch categories.

3. Results

The results of the Midlands study are presented in two parts: (1) estimated carrying capacity and stocking rates, (2) the effects of simulated overstocking costs on ranch profits. Data for the cattle ranches in the four areas with abundant wildlife (C4) and cattle ranches in the two areas with sparse wildlife (C2) are presented separately.

3.1. Carrying capacity and stocking rate

Since stocking rates are traditionally measured in Livestock Units per hectare (1 LSU = 454 kg)

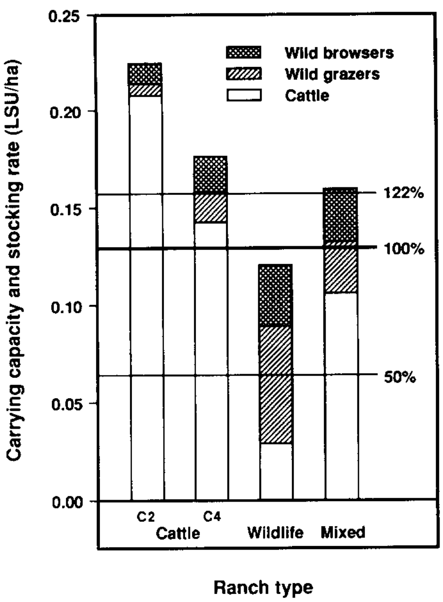

Fig. 1. Mean stocking rates of cattle and wild herbivores on cattle ranches (C2 in areas with sparse wildlife, C4 in areas with abundant wildlife), wildlife ranches and mixed ranches compared with mean predicted carrying capacity (100%), 50% of the predicted value and its upper 95% confidence limit (122%).

instead of metabolic kg, the results from Eqs. 1 and 2 were converted to LSU ha^{-1} using a factor of $454^{-0.75}$. Due to the uniformity of mean annual rainfall across the study area, predicted carrying capacities were similar for all ranches. The predicted mean carrying capacity (100%) of all ranches, 50% of the predicted mean, its upper 95% confidence limit (122%), and the mean stocking rates of cattle and wildlife are presented in Fig. 1.

Cattle ranches in areas with sparse wildlife (C2) were stocked 27% more heavily ($P < 0.05$) than cattle ranches in areas with abundant wildlife (C4), and the mean stocking rates on cattle ranches and mixed ranches were significantly greater (44% and 31%, respectively, $P < 0.05$) than on wildlife ranches. In contrast to their lower overall stocking rates, mixed and wildlife ranches were more densely populated by wild ungulates than cattle ranches mainly because wild animals generally prefer areas with less cattle-related human disturbance and some wildlife ranches were equipped with game proof fences.

C2 cattle ranches were stocked well above (69% excluding browsers, $P < 0.01$) the mean predicted carrying capacity, as were the C4 cattle ranches (21% excluding browsers, $P < 0.05$), but C2 cattle ranches were overstocked significantly more ($P < 0.01$) than C4 cattle ranches. Based on the predicted mean carrying capacity, the C2 ranch stocking rates appear to be unsustainable. There was, however, anecdotal information that such overstocking might have been a short-term phenomenon related to foot-and-mouth disease associated marketing restrictions in 1989/90. This anomaly contrasts with the general decrease in the number of commercial cattle throughout Zimbabwe during the 1980s (Child, 1988) mainly due to negative price and exchange rate policy effects on cattle revenues, and marketing constraints for cattle from foot-and-mouth affected areas (Jansen et al., 1992).

By contrast to cattle ranches, the mean grazer stocking rate of mixed ranches did not significantly exceed the predicted carrying capacity. On average, wildlife ranches were stocked below the predicted carrying capacity, and their mean grazer stocking rate may be even lower once remnant cattle herds on two ranches are removed. However, with increasing interest in wildlife ranching since 1975, wildlife populations have generally been increasing on commercial ranches in the Midlands during the 1980s (Child, 1988) and may increase even further as wildlife enterprises mature.

The mean stocking rates of all ranch categories were significantly greater ($P < 0.01$, except on wildlife ranches when browsers were excluded) than 50% of the mean carrying capacity. This implies that if Eq. 1 overpredicted actual carrying capacity for the existing herbivore community by 100% (because it may be strictly applicable only to savannas with up to 50% megaherbivores), all of the Midlands ranches were overstocked. Conversely, if the upper 95% confidence limit of predicted carrying capacity more accurately represents actual carrying capacity, then only the cattle ranches in areas with sparse wildlife were significantly overstocked ($P < 0.01$).

3.2. Effects of overstocking costs on profitability

The effects of deducting simulated overstocking costs (for stocking rates in excess 100% of predicted carrying capacity) from financial and economic profit estimates are represented by a series of linear regressions in Fig. 2. Statistical descriptions of these regressions are presented in Table 2. The intercepts in Fig. 2 represent the mean financial profits (panel a) and mean economic profits (panel b) with zero cost for overstocking. The slopes represent the rate of decline of financial and economic profits with increase in simulated productivity loss (rangeland sensitivity to overstocking).

When simulated overstocking costs were zero, both the financial and economic profits (intercepts in Fig. 2) of C2 cattle ranches were, on average, significantly greater ($P < 0.01$) than those of the other three ranch types. Moreover, wildlife ranches were financially less profitable ($P < 0.05$) than mixed ranches, and economically less profitable ($P < 0.01$) than both C2 cattle and mixed ranches. Moreover, financial profits were consistently lower ($P < 0.01$) than economic profits for all ranch types, implying that prevailing government policy interventions relating to pricing, marketing and currency exchange rates, were creating negative production incentives for ranchers (Kreuter, 1992). These differences were, however, greater for cattle ranches than the other three ranch types. In southern and western Zimbabwe, the viability of cattle ranches was similarly found to be more sensitive to government policy interventions than wildlife ranches (Jansen et al., 1992).

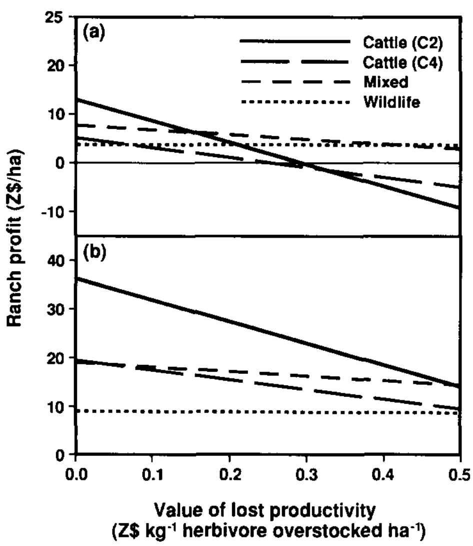

Fig. 2. The effect of simulated overstocking costs (for stocking rates in excess 100% of predicted carrying capacity) on (a) financial and (b) economic profits of cattle (C2 in areas with sparse wildlife, C4 in areas with abundant wildlife), mixed and wildlife ranches.

Table 2
Statistics of relationships between financial and economic profits and simulated rangeland productivity losses in the Zimbabwe Midlands shown in Fig. 2

Statistic	C2 cattle	C4 cattle	Mixed	Wildlife
Financial profits				
Intercept (β_0, Z\$ ha^{-1})	13.15 **	5.28 **	7.84 **	4.02 **
Slope (β_1)	−43.96 **	−19.71 **	−9.50 *	−0.67
Adjusted R^2	0.42	0.14	0.03	0.00
F statistic	119.08 **	26.23 **	4.85 *	0.04
Economic profits				
Intercept (β_0, Z\$ ha^{-1})	36.11 **	19.51 **	19.14 **	9.23 **
Slope (β_1)	−43.96 **	−19.71 **	−9.50	−0.67
Adjusted R^2	0.17	0.04	0.00	0.00
F statistic	35.14 **	7.52 **	1.51	0.03

For H_0: $\beta_0 = 0$, H_0: $\beta_1 = 0$, and F statistic: ** $P < 0.01$; * $P < 0.05$.

The slopes of corresponding regressions in the two panels of Fig. 2 are identical because the overstocking cost for each ranch was constant at a given level of simulated productivity loss. However, due to the broader range of economic profits than financial profits within each ranch category, the probability that slopes and differences between slopes were greater than zero (i.e., for H_0: $\beta_{1i} = 0$, $\beta_{1i} - \beta_{1j} = 0$) was lower for economic profit regressions than financial profit regressions (Table 3). When stocking rates were compared with 100% of the predicted carrying capacity, the rate of decline of financial and economic profits of C2 cattle ranches was significantly greater (in most cases $P < 0.01$) than that of the three other ranches types. The rate of decline for C4 cattle ranches was also greater (financial profit, $P < 0.01$; economic profit, $P < 0.10$) than that of

Table 3
Differences between slopes of linear regressions in Fig. 2

β_1s compared	$\beta_{1i} - \beta_{1j}$	Probability $\beta_{1i} - \beta_{1j} = 0$	
		Financial	Economic
C2 cattle – C4 cattle	−24.24	$P < 0.000$	$P = 0.019$
C2 cattle – Mixed	−34.46	$P < 0.000$	$P = 0.001$
C2 cattle – Wildlife	−43.28	$P < 0.000$	$P < 0.000$
C4 cattle – Mixed	−10.21	$P = 0.077$	$P = 0.334$
C4 cattle – Wildlife	−19.04	$P = 0.002$	$P = 0.082$
Mixed – Wildlife	−8.83	$P = 0.165$	$P = 0.423$

wildlife ranches, but the slope difference between mixed and wildlife regressions was statistically not significant. When stocking rates were compared with 50% and 122% (upper 95% confidence limit) of the predicted carrying capacity, the rates of decline of profits with increased productivity loss changed relative to those presented in Fig. 2. For the sake of brevity, the associated regressions are not presented graphically, but they are discussed in general terms in order to assess the potential effects of inaccurate carrying capacity estimates on profitability measures incorporating simulated overstocking costs. With 50% of predicted carrying capacity the slopes became more negative (more so for cattle than wildlife ranches), and with 122% of predicted carrying capacity the rates of decline decreased.

As a result of the differences in slopes, both categories of cattle ranches became unprofitable at lower productivity losses than mixed or wildlife ranches (Table 4). This implies that when simulated overstocking costs were subtracted from profit estimates, the probability of ranches remaining financially profitable and economically efficient with increasing rangeland sensitivity to overstocking was greater for wildlife and mixed ranches than cattle ranches. This is because wildlife enterprises appeared to be less dependent on high stocking rates to be viable. However, this conclusion must be treated with caution since the profit bands of each ranch type, resulting from the use of a range of carrying capacity estimates (50%–122% of predicted carrying capacity), widened and progressively overlapped with increasing productivity loss (not shown in Fig. 2).

Table 4
Productivity loss (Z\$ kg^{-1} ha^{-1} overstocked) where financial (F) or economic (E) profits equal zero at predicted carrying capacity (100% CC), 50% of CC, and the upper 95% confidence limit of predicted carrying capacity (122% of CC))

Ranch Type	50% of CC		100% of CC		122% of CC	
	F	E	F	E	F	E
C2 cattle	0.20	0.56	0.30	0.82	0.38	1.03
C4 cattle	0.14	0.50	0.27	0.99	0.44	1.64
Mixed	0.33	1.45	0.82	2.01	1.45	3.45
Wildlife	1.20	5.96	5.96	13.69	45.13	103.67

Although both financial and economic profit estimates were adjusted for simulated overstocking costs in this paper, for reasons previously stated, actual financial profits exclude the costs of production externalities. Comparison of unadjusted actual financial profits (intercepts in Fig. 2a) and economic profits adjusted for overstocking (Fig. 2b) shows that, with increasing productivity loss, there is a decrease in the policy-induced disparities between financial and economic profits, particularly on cattle ranches. This suggests that, with increasing rangeland sensitivity to overstocking, the policy-related production disincentives for cattle ranchers reported by Kreuter (1992) are increasingly counter balanced by overproduction incentives created by externalization of overstocking costs.

4. Discussion

Claims that wildlife can produce greater profits than cattle ranching have been based largely on the high value of big game species, such as elephants and buffalo, but in many semi-arid savannas such megafauna no longer occur. Yet, due to low fertility, erratic rainfall and a lack of supplemental irrigation potential, few alternatives to extensive range-based animal production exist in these areas (Walker, 1988). To ensure sustainable use of such savannas, rangeland resources must be allocated in an economically efficient manner. This implies that all benefits and costs of production are internalized when evaluating the profitability of alternative production systems. But the costs of overstocking effects on future rangeland productivity are frequently deferred, due to response lags to overstocking, or externalized, due to distorted land prices. In Zimbabwe rural land prices fluctuated widely during the survey period due to changes in the government's land acquisition policies during an inflationary period. They therefore did not reflect the costs of decreased productivity due to overstocking.

During the survey period, ranchers had a financial incentive to increase capital investments because, under the prevailing inflation, the speculative returns on holding capital assets, including livestock, were greater than returns from alternative investments. This, together with foot-and-mouth disease marketing constraints, encouraged overstocking in cattle enterprises. Since landowners in Zimbabwe have wildlife user rights, but no title to wildlife occurring on their property, wild animals do not bestow personal wealth. Furthermore, for safari operations, diverse wildlife communities are generally more valuable than large numbers of a few species, and trophy sizes are generally inversely related to population densities. Therefore, wildlife ranchers had less incentive to overstock than cattle producers whose revenues are directly related to stocking rates.

Using traditional accounting methods (which exclude the costs of exploiting biological capital), cattle ranches in areas without wildlife appeared to be the most profitable group, both financially and economically. In areas with abundant wildlife, the financial and economic profits of cattle ranches were similar to those of mixed ranches, but greater than those of wildlife ranches. But when estimated overstocking costs were subtracted from profits, the probability that ranches would remain economically profitable with increasing rangeland sensitivity to overstocking decreased more rapidly for cattle than for either mixed ranches or wildlife ranches.

The effect of internalizing overstocking costs on the allocation of range resources between cattle and wildlife enterprises depends upon the susceptibility of rangeland to overstocking. In the four areas with abundant wildlife, widespread brush encroachment and reduced rangeland productivity were reported by most ranchers to be due to overstocking by cattle. By contrast, in the two areas with sparse wildlife, seasonal waterlogging, due to impervious granitic substrata, appears to have restricted encroachment of woody species into grasslands. The true carrying capacity in the latter areas may therefore be greater than that predicted from mean annual rainfall using Eq. 1, and internalizing overstocking costs might reduce the profitability of cattle ranches in these areas less than our analysis indicated. Nevertheless, internalizing overstocking costs is likely to decrease cattle profitability more than wildlife profitability because of the dependence of cattle enterprises on greater animal densities.

In the long term, partial replacement of cattle by wildlife on Midlands cattle ranches is likely to enhance the sustainability of rangeland use due to reduced stocking pressures required for financial profitability. However, since prices for wild breeding stock exceeded their reproductive value (due to distorted investment incentives created by ranch income tax regulations), this conclusion is likely to be viable only where wildlife populations already exist and are able to expand.

5. Conclusions

Internalizing the costs of overstocking on future rangeland productivity is facilitated by land prices that reflect the productive capacity of land, but land markets frequently fail to achieve this. This paper therefore attempted to develop an indirect method for evaluating the effect of stocking rates on future rangeland productivity. Due to higher stocking rates on cattle than mixed or wildlife ranches, the probability that ranches will remain economically profitable decreased more rapidly for cattle ranches than for wildlife and mixed ranches. But the conclusions of this study must be tempered by uncertainty concerning both the true carrying capacity and the effects of grazing on future rangeland productivity. Past herbivory trials seldom included multiple grazing species, nor have they comprehensively accounted for long-term rainfall variability or attempted to identify thresholds for range degradation in semi-arid savannas. Such information is critical for quantifying the future cost of herbivory and the economic efficiency of alternative production systems, thereby facilitating efficient allocation of semi-arid rangeland resources.

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