Multiple use of public rangeland: Antelope and stocker cattle in Wyoming

CHRIS T. BASTIAN, JAMES J. JACOBS, LARRY J. HELD, AND MICHAEL A. SMITH

Abstract

The government must manage public rangeland in the face of alternative multiple use interests, including wildlife and domestic livestock production. The objectives of this study were to estimate a production possibilities frontier for antelope (*Antilocapra americana* (Ord)) and stocker cattle on the Wyoming Red Desert and then evaluate the most economical combination for the specific production and price assumptions used in the analysis. Nine antelope-steer combinations were derived by using a linear programming model to maximize total number of animals subject to annual forage production on a representative 405-ha range site. The resulting 9 combinations included 72 head of antelope with no steers at one extreme and 35 head of stocker steers with no antelope at the other extreme, with various combinations of each in between. Because of the different forage preferences of antelope (primarily browse) and cattle (primarily grass), the marginal rates of substitution of cattle for antelope ($MRS_{c.a}$) varied widely along the production possibilities frontier. Specifically, the $MRS_{c.a}$ was very low moving from 72 antelope-0 steers, to 69 antelope-29 steers, in terms of sacrificing only a few antelope (3) in exchange for a comparatively large number of steers (29). Conversely, the $MRS_{c.a.}$ moving from 69 antelope-29 steers, to 0 antelope-35 steers was very high in terms of sacrificing a relatively large number of antelope (69) in exchange for only a few additional steers (6). This wide range of substitution rates suggests that economic benefits from antelope and cattle would have to be extremely different before "multiple use" is not preferred in the case study setting.

Key Words: production possibilities frontier, marginal rates of substitution, economic benefits and linear programming

Authors are graduate research assistant and professors, Agricultural Economics Department and associate professor, Range Management Department, respectively, University of Wyoming, Laramie 82071.
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The management and use of public rangeland is becoming a more controversial topic. Conflicts have arisen recently as conservationists and recreational users have become more interested in public lands (Portney 1982). Many of these people hold livestock owners responsible for increased soil erosion along streams, reductions in size of wildlife populations, and the spoiling of their outdoor experience (Haines 1986, Wuerthner 1989). Livestock grazing on public rangeland is important to individual producers as well as the economies of local communities in the western states (USDI 1982, US-GAO 1988). Ranchers often view recreation on these lands negatively (Holechek et al. 1989) because of profit losses stemming from increased incidences of disturbance, vandalism, fires, livestock theft, and animals wounded or killed by traffic or shooting where heavy recreational use occurs. Given these contrasting viewpoints, the public land manager is faced with allocating this resource among alternative uses with an overall goal of maximizing social welfare. Decision makers concerned with this allocation need additional tools or processes to aid them in assessing different allocations.

This study evaluates a hypothetical case of public land managed for grazing by cattle and antelope in the Wyoming Red Desert. Our objectives were to: (1) determine a production possibilities frontier for cattle and antelope (including the 2 extremes of no cattle and no antelope) given a fixed range resource; and (2) determine the most economically efficient combination of grazing cattle and antelope, given the specific assumptions used in the analysis. By placing a value on the activities supported by public land, determining a point of greater, if not maximum, benefits should be possible. The point of greatest benefits received by users will be assumed to represent the greatest social welfare (in terms of the optimum allocation of the range resource), regardless of distribution.

Materials and Methods

Cattle and antelope grazing, marginal rates of substitution, and economic benefits were analyzed using data derived largely from the Red Desert area of southcentral Wyoming. This area is widely used for summer cattle grazing. Antelope are abundant and the most common big game animal in the area. The Red Desert area is largely public land managed by the USDI Bureau of Land Management (BLM), and is typical of many western ranges where analysis of potential competition between uses and values associated with those uses can help resolve multiple use controversies.

Vegetation typical of large parts of the area are described in Severson and May (1967) and Krysl et al. (1984). Yearly and geographic variability are expressed in the above references. The vegetation resource consists largely of shrub-dominated plant communities. Severson and May's (1967) vegetation production and species composition data (Table 1) were used in our analysis.

Dietary composition of antelope in Wyoming and the Red Desert is described by Taylor (1975), Sundstrom et al. (1973), and Severson and May (1967). Cattle dietary composition for some seasons and some factors relating to dietary selection can be found in Krysl et al. (1984), Gomes (1983), Herbel and Nelson (1966), and Holechek (1980). Holman's (1976) seasonal dietary composition data for cattle and antelope grazing the Red Desert were used in our analysis. Antelope diets are characteristically dominated by shrubs while cattle diets are generally dominated by grass species (Table 2). Diet composition data for this area indicates minimal dietary overlap between cattle and antelope.

Table 1. Assumed forage production (kg/ha) on the Wyoming Red Desert study area, (Severson and May 1967).

Species/Group	Average
Shrubs	kg/ha
Big sagebrush (*Artemisia tridentata* Nutt.)	231.6
Douglas rabbitbrush (*Chrysothamnus viscidiflorus* (Hook) Nutt.)	100.0
Winterfat (*Ceratoides lanata* (Pursh) J.T. Howell)	9.4
Grasses	
Western wheatgrass (*Agropyron smithii* Ryd b.)	61.0
Needle and thread grass (*Stipa comata* Trin. & Rupr.)	22.6
Indian ricegrass (*Oryzopis hymenoides* (R. & S.) Ricker ex Piper)	18.9
Bottlebrush squirreltail grass (*Sitanion hystrix* (Nutt.) J.G. Smith)	15.7
Sandberg bluegrass (*Poa sandbergii* Vasey)	6.3
Obtuse sedge (*Carex obtusata* Lilj.)	6.3
Forbs	1.5
Total	473.0

Table 2. Assumed diet composition (%) by season for cattle and antelope grazing in study area (Holman 1976).

Plant class	Winter		Spring		Summer		Fall	
	Antelope	Cattle	Antelope	Cattle	Antelope	Cattle	Antelope	Cattle
	percent[1]							
Grass	13	82	22	91	5	78	5	78
Shrubs	80	14	61	2	64	2	83	16
Forbs	7	4	13	8	30	19	9	5

[1]Percentages do not always ad to exactly 100%, since they are derived as a composite average from several sources.

The simulated site for this analysis is assumed to be 405 ha of uniform vegetation (Table 1) with adequate water supply to accommodate antelope and cattle grazing. Class of cattle is yearling steers. The antelope herd is of mixed age classes typically found in the area. Diet composition is by forage class (Table 2) rather than plant species due to lack of site specific information for both animal species for all seasons. Diets of animals at the various ratios (cattle:antelope) used in the analysis are assumed to not change under the 50% forage utilization constraint of our analysis. Seasonal and geographical variability in vegetative composition, availability, and subsequent animal diets limits the results of this analysis from being directly applicable to any particular situation.

A mixed-integer linear programming model (Table 3) was used to derive a production possibilities frontier for cattle and antelope by estimating 9 feasible combinations with respect to available forage. The objective function was designed to maximize total

Table 3. Linear programming model used to estimate combinations of antelope and cattle which could be produced in the case study area based on defined consumption activities and forage constraints.

	(hd) Antelope	(hd) Steers	(kg) Wtr. Grass	(kg) Spg. Grass	(kg) Sum. Grass	(kg) Fall Grass	(kg) Wtr. Shrub	(kg) Spg. Shrub	(kg) Sum. Shrub	(kg) Fall Shub	RHS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
MAXIMIZE											
1) No. of animals	1	1									
Subject To:											
2) Total grass (kg)			1	1	1	1					$\le$26,775
3) Total shrubs (kg)							1	1	1	1	$\le$14,503
4) Wtr. grass Req. (kg)	13.8		−1								= 0
5) Wtr. shrubs Req. (kg)	56.0						−1				= 0
6) Spg. grass Req. (kg)	24.1	173.5		−1							= 0
7) Spg. shrubs Req. (kg)	42.2	4.1						−1			= 0
8) Sum. grass Req. (kg)	24.5	573.4			−1						= 0
9) Sum. shrubs Req. (kg)	44.5	19.1							−1		= 0
10) Fall grass Req. (kg)	9.6					−1					= 0
11) Fall shrubs Req. (kg)	57.5									−1	= 0
12) Specified no. (hd)	1.0										= K
13) Specified no. (hd)		1.0									= K

production of animals (steers and antelope expressed as integer variables) based on constraints of annual forage production (rows 2–3). Seasonal forage rows (4–11) and columns (3–10) are accounting constraints and activities used to calculate the seasonal consumption of grass and shrubs given a particular combination of antelope and steers. These should not be viewed as constraints on the amount of either grass or shrubs available for a particular season, since the production possibilities are based on annual availability of grass and shrubs without regard to seasonal distribution (rows 2–3). Given the goal of maximizing animal numbers, equal weights (one-to-one values) were placed on antelope and cattle in the objective function.

Because forb production was low in the study area, this category was combined with grasses. Sundstrom et al. (1973) suggest forbs may substitute for grasses in the diets of both animals. If the linear programming model had been optimized with forb production as a specific constraint, it would have been the most limiting of all forage types. Assuming substitutability with grass, this type of constraint could significantly understate the actual production possibilities of the range resource.

The rule of "take half-leave half" for grasses was implemented through the forage production constraints. For example, amount of grass available for consumption was set at one-half (26,775 kg) of assumed production (53,549 kg). Based on actual use estimates of shrubs by Severson et al. (1980), the shrub constraint was adjusted downward to 10.5% of total shrub production due to the large portion of sagebrush in this category. As a result, 14,503 kg was the constraint for the shrub class. The constraint resulted in estimates of antelope density within realistic expectations for this area. Constraints in the linear programming model for total available dry matter from grass and shrubs are in rows 2–3 of Table 3.

A yearling stocker system is considered in this analysis as it tends to be common in the Red Desert. In this scenario steers were grazed 4 months (1 month for spring; 3 months for summer) at an average daily gain of 0.68 kg with beginning and ending weights of 250 and 331 kg, respectively. Seasonal forage consumption was calculated by multiplying percent of diet of each plant class by kg of dry matter (DM) required by the steers (approximately 2.5% of body weight per day) each month (Ensminger and Olentine 1978). The total digestible nutrients (TDN) and crude protein (CP) requirements were met at this level of gain and intake.

Total forage requirements per antelope per season were calculated by multiplying 0.77 kg DM (Severson and May's [1967] estimate of DM consumption per antelope per day) by percent diet for each season and by 90 days per season. This yielded DM consumption for each plant class by season. These estimates were the basis for calculating seasonal forage consumption for selected antelope and steer combinations in the linear programming model.

Given the annual forage constraints, the linear programming model was then used to derive animal combinations. In order to find extreme points (i.e., all of one and none of the other), the constraint for antelope (row 12) or cattle (row 13) was set equal to zero and an optimal solution (given available range forage) was obtained. Maximum number of animals was optimized when both animal constraints (rows 12–13) were relaxed from equalities to inequalities of greater than zero. Other selected combinations were calculated by specifying numbers of animals found between these extremes along the frontier in each of the animal constraints (rows 12–13). For example, the midpoint values between points A and D (Fig. 1) were found by setting the antelope constraint (row 12 in Table 2) equal to integers between the antelope values for those points. An optimal solution was then obtained for each of the new constraint values.

Economic Evaluation

The value of the benefits from cattle grazing was based on kg of

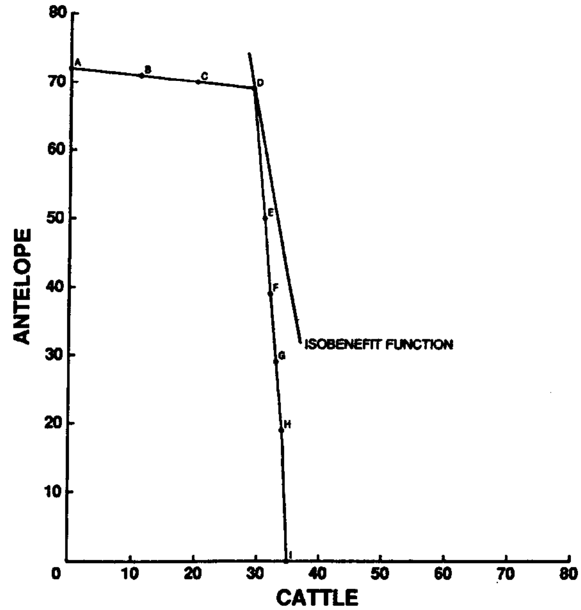

Fig. 1. Estimated production possibilities frontier for cattle and antelope in the Red Desert of Wyoming based on the case study data.

gain for the 4-month period multiplied by the number of animals and average market price for 1977–1986 equal to $1.44/kg (prices from Kearl [1987] expressed in 1983 dollars using the Producer Price Index), minus total costs associated with land use. Included in total cost was an opportunity cost associated with the investment in cattle. The opportunity cost was estimated to be $7.84/head using an average weight of 290.6 kg multiplied by the 1977–1986 average price for that weight class (adjusted to 1983 dollars) times a 6% real interest rate for the 4-month public grazing period. Estimated costs of production associated with federal grazing were reported by Obermiller and Lambert (1985) to be $14.67/AUM. Net benefit per head of cattle ($67.85) equals $1.44/kg times 81.7 kg of gain, minus $7.84/head opportunity cost and production costs of $41.96 (.715 (AUM coefficient) * 4 mo. * $14.67/AUM).[1]

Antelope were assumed to occupy the area yearlong. The value of antelope hunting was based on herd size multiplied by a harvest factor, a hunting value per day, and the number of days per hunt. A value of $19.68/hunting day was estimated in Utah by Sorg and Loomis (1984) using a zonal travel cost method adjusted to reflect travel time, but not substitute sites. Adjusting the $19.68 to 1983 dollars using the GNP price deflator resulted in a value of $20.14/hunter day, used for this analysis. A harvest factor of 0.455 was used to estimate the number of antelope harvested from a sustained herd size which reflects reproductive rates in the Red Desert and desired post-hunting season ratios of 40 bucks per 100 does in that area[2]. For example, in a herd of 1,000 antelope, 455 fawns would survive to yearling age and 455 permits would be issued. The hunting success rate in the Red Desert has typically been close to 100%. The average hunt was assumed to be 1.5 days (Sorg and Loomis 1984). Net benefits per antelope were estimated to be equal to the product of $20.14 value/hunting day times 1.5 days times a 0.455 harvest factor.

Results

Nine steer-antelope combinations were estimated along the pro-

[1]This calculation is based on observing average deflated spring purchase prices for light feeder steers as being approximately equal to average deflated fall sales price for heavier feeder steers over a recent (1977–1986) 10-year period. If spring purchase price for lighter animals proved to be greater than fall sale price of heavier steers, the net benefit of cattle would be less than the $67.85 per head value calculated above.
[2]Based on personal interview with Harry Harjou, Head Biologist, Wyoming Game and Fish Commission, 1988.

Table 4. Nine sustainable combinations of antelope and cattle and the associated estimates of AUMs utilized at each combination (given assumptions about the range site).

Combination	Antelope Head	Antelope AUMs[1]	Cattle Head	Cattle AUMs[1]	Total AUMs[1]
A	72	172.8	0	0	172.8
B	71	170.4	11	31.5	201.9
C	70	168.0	20	57.2	225.2
D	69	165.6	29	82.9	248.5
E	50	120.0	31	88.7	208.7
F	39	93.6	32	91.5	185.1
G	29	69.6	33	94.4	164.0
H	19	45.6	34	97.2	142.8
I	0	0	35	100.1	100.1

[1]AUM is defined as forage required to maintain a 1,000 lb. animal for 1 month. The AUM coefficient used for the steers is .715.

duction possibilities frontier given the constraint of available forage production from the 405-ha area (Table 4). Combination A represents the maximum number of antelope (72) the range can sustain without any cattle grazing. Using an AUM coefficient of 0.20 (USDA 1976), 72 antelope represent 172.8 AUMs. This estimate is slightly greater than Severson's estimated carrying capacity of 67 antelope on 405 ha in the Red Desert, and is near the upper limit of population densities recorded for the Red Desert area. Combination I indicates 35 steers (100.1 AUMs) could be supported by the range if no antelope were allowed to graze during the specified 4 months. Technical guides for the area (USDA 1988) recommend a stocking rate of 100 AUMs for 405 ha in fair condition. The maximum production of animals occurs at combination D where it is estimated the range could support 69 antelope and 29 steers. Total AUMs at this point are 248.5. It should be emphasized that the change that occurs at point D (Fig. 1) is due to the changing of the limiting constraint. Moving from 0 steers to maximum steers, grass availability becomes constraining in the area of point D and shrub availability becomes nonconstraining as you move past point D.

The production possibilities frontier in Figure 1 reflects a competitive relationship and negative marginal rates of substitution between cattle and antelope since fewer antelope are observed with increasing cattle numbers throughout its entire range. In this case the marginal rate of substitution of cattle for antelope ($MRS_{c.a}$) is defined as the change in head of antelope with respect to change in head of cattle ($\Delta A/\Delta C$) or the slope of the production possibilities frontier. Although the $MRS_{c.a}$ is negative (competitive) throughout the entire range of cattle-antelope combinations, it changes abruptly at combination D. Specifically, the average $MRS_{c.a}$ between A (no steers) and D is very low or close to zero [$\Delta A/\Delta C = (72–69)/(0–29) = –0.103$], suggesting only a few antelope (3) have to be sacrificed when adding a comparatively large number of steers (29). However, from D to I (no antelope), the $MRS_{c.a}$ becomes extremely high [$\Delta A/\Delta C$ $(69–0)/(29–35) = –11.5$], suggesting a relatively large number of antelope (69) must be sacrificed given a few additional steers (6). This reflects the dietary habits of antelope and cattle. An important implication behind such a wide range of $MRS_{c.a}$ (–0.103 to –11.5) is that net dollar benefits from cattle versus antelope apparently have to be markedly different from each other, before an "all antelope" or "all cattle" policy supersedes a "combination of antelope and cattle" from an economic standpoint.

Table 5. Estimated value of each simulated combination of antelope and cattle activities.

Combination	Antelope No. Antelope	Antelope No. Hunted	Antelope Dol. Value	Cattle No. Cattle	Cattle Revenue[1]	Cattle (–) Cost[2]	Cattle Dol. Value	Dol. Total
A	72	33	997	0	0	0	0	997
B	71	32	967	11	1,292	548	744	1,711
C	70	32	967	20	2,349	996	1,353	2,320
D	69	31	937	29	3,406	1,444	1,962	2,899
E	50	23	695	31	3,641	1,544	2,097	2,792
F	39	18	544	32	3,758	1,593	2,165	2,709
G	29	13	393	33	3,876	1,644	2,232	2,625
H	19	9	272	34	3,993	1,693	2,300	2,572
I	0	0	0	35	4,111	1,743	2,368	2,368

[1]Rev = no. of hd. (x) kg/animal × \$1.44/kg (10 yr deflated avg for med frame no. 1 700–800 lb. steers).
[2]Costs = no. of AUMs (x) \$14.67/AUMs (estimated cost/AUM associated with federal grazing) plus estimated opportunity cost associated with the cattle (\$7.84/hd.).

An isobenefit function was derived as the ratio of net benefits per head for cattle over net benefits per head of antelope (\$67.85/\$13.75). Given this isobenefit relationship and the nature of the production possibilities frontier, combination D (Fig. 1) represents the optimum number of cattle and antelope, corresponding to the point with the highest total value in Table 5 (\$2,899).

Finally, it should be noted that at combination D (69 antelope and 29 cattle), annual forage harvest is very close to the upper limit of available grass (26,775 kg) and shrubs (14,503 kg) from the 405-ha range site (Table 6). For all simulated combinations including more cattle relative to antelope (E to I), grass harvest remained near the upper limit (26,775 kg), and the harvest of shrubs correspondingly declined, while the opposite occurred for those combinations having fewer cattle relative to antelope (A to C). Also, for all combinations, grass consumption was minimal during the fall and winter seasons. However, with the exception of combination I (no antelope), consumption of shrubs was more evenly distributed over all 4 seasons.

Table 6. Simulated seasonal forage consumption by selected animal combinations.

Comb.	No. Animals Antelope	No. Animals Cattle	Grass Winter	Grass Spring	Grass Summer	Grass Fall	Grass Total	Shrubs Winter	Shrubs Spring	Shrubs Summer	Shrubs Fall	Shrubs Total
	(hd)	(hd)	(kg/405 ha)									
A	72	0	997	1,733	1,762	693	5,185	4,031	3,037	3,203	4,158	14,429
B	71	11	983	3,617	8,045	683	13,328	3,974	3,040	3,369	4,100	14,483
C	70	20	969	5,155	13,181	674	19,979	3,919	3,034	3,496	4,042	14,491
D	69	29	956	6,692	18,317	664	26,629	3,863	3,029	3,623	3,986	14,501
E	50	31	692	6,582	18,999	481	26,754	2,799	2,236	2,816	2,887	10,738
F	39	32	540	6,491	19,303	376	26,710	2,183	1,776	2,346	2,252	8,557
G	29	33	402	6,424	19,632	279	26,737	1,624	1,357	1,920	1,675	6,576
H	19	34	263	6,357	19,961	183	26,764	1,064	940	1,494	1,097	4,595
I	0	35	–	6,073	20,069	–	26,142	–	143	667	–	810

Conclusions

Opposing public views exist concerning use of public rangeland. One view favors cattle grazing on public rangelands, while another does not. Given this specific study area (the Wyoming Red Desert) in conjunction with the particular biological and economic assumptions embedded in the analysis, the estimates of benefits suggest optimal economic use of the range resource should occur when managed for multiple use. Loss of social welfare and underutilization of this renewable resource could occur if the interests of any particular group (e.g., naturalists or livestock producers) were allowed to dictate management of public lands for only single purpose use in this case. In this example, a loss of $1,902 would occur if only antelope were allowed to graze, and a loss of $531 would occur if only cattle were allowed to graze (Table 5).

In many instances the number of big game that are to be maintained in a management area has already been specified. In such cases, this type of modelling approach could be used to determine the number of cattle allowed to graze given the specified number of big game. The model could also be used to evaluate the opportunity costs of this management strategy compared to the optimal strategy suggested by the model.

It should be emphasized that results and conclusions are based on characteristics of this particular study area as well as specific assumptions regarding the estimates of economic benefits, forage requirements, and availability. Consequently, results should be interpreted cautiously for general policy purposes. If, for example, more winterfat had been produced on the site used as the basis of forage production, the cattle diets might have contained a larger percentage of shrubs (Krysl et al. 1984) than specified in this case. Constraining the amount of shrubs and grasses on a seasonal versus an annual basis might also alter the production possibility relationship somewhat. Since data on seasonal forage production were not available, the analysis was conducted using annual forage production. Given the difference in diets, it is not anticipated that using seasonal constraints on forage would alter the production possibility relationship to the extent that the general conclusion would change.

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