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## SESSION 18

AN INCENTIVE-BASED WILD HORSE MANAGEMENT SYSTEM ON PUBLIC RANGELAND  
Ray G. Huffaker\*, James E. Wilen, and B. Delworth Gardner

One of the most controversial environmental issues facing federal rangeland managers is how to alleviate the grazing pressure exerted by domestic livestock and overpopulated wild horses and burros on deteriorating public ranges [8]. Rancher efforts to relieve the competitive grazing pressure for their livestock by rounding up and slaughtering wild horses and burros resulted in the passage of the Wild Free-Roaming Horses and Burros Act of 1971 (WFRHBA). The WFRHBA protects these animals from "...capture, branding, harassment, or death...",<sup>1</sup> and directs public managers to "manage wild free-roaming horses and burros in a manner that is designed to achieve and maintain a thriving natural ecological balance on the public lands".<sup>2</sup> Under legal protection, the wild horse population increased from 17,000 in 1971 to 54,030 in 1978--about 23,000 in excess of the level that the Bureau of Land Management (BLM) determined to constitute an ecological balance [8].

The WFRHBA authorizes the BLM to remove excess animals from rangeland by rounding them up for private adoption, or for destruction if no adoption demand exists or they are old, sick, or lame.<sup>3</sup> However, about 7,000 excess horses are backed up on rangeland for two major reasons [8]. First, roundups have been impeded by judicial actions brought by animal rights activists [1],[2],[8]. Second, the BLM has not found an easy or inexpensive way to dispose of unclaimed captured horses. The BLM has refused to destroy them because of potentially large public opposition. Moreover, reduction by adoption has been slowed by animal rights activists' recent success in convincing a federal district court to order the Secretary of the Interior

(Secretary) to withhold title from adopters who intend to exploit them for slaughter or as bucking stock in rodeos [8]. Finally, Congress has refused to authorize the Secretary to sell horses outright after roundup. Hence, unclaimed captured horses (currently numbering about 8,670 [8]) must be held in federal pens at great public expense.<sup>4</sup>

After taking the teeth out of the roundup/adoption policy, federal courts have directed the BLM to investigate policy alternatives for relieving the competitive grazing pressure on public rangeland in Environmental Impact Statements [2]. Any such policy must satisfy three major statutory mandates.

First, the Federal Land Policy and Management Act of 1976 (FLPMA) requires the BLM to allocate public rangeland vegetation to multiple uses at high-level sustained yields.<sup>5</sup> The multiple-use requirement has been interpreted by federal courts to imply that a wild-horse policy can give neither livestock nor wild horses an exalted status over the other [1]. Hence, the two grazers must be made to coexist unless grazing permittees elect voluntarily for nonuse of their allotments. Moreover, the multiple-use mandate requires that a wild-horse policy allocate vegetation to nongrazing multiple uses competing for forage such as the protection of ecosystems (plant, fish, and wildlife) and environmental quality [9].

Second, the Public Rangeland Improvement Act of 1978 (PRIA) directs the BLM to implement the Experimental Stewardship Program<sup>6</sup> (ESP). The intent of the ESP is to discover whether allowing qualified federal grazing permittees to actively direct decisionmaking (i.e., to determine livestock numbers and seasons of use) can improve public rangeland conditions [7].

Third, public grazing statutes require policy "...to prevent economic disruption and harm to the western livestock industry...."<sup>7</sup>

In many ways, these statutory restrictions on grazing policy are similar to the political constraints imposed in designing pollution reduction policies. In the pollution reduction arena, issues have traditionally revolved around realigning traditional use patterns to effect environmental quality improvement without unduly and adversely affecting original users, often those with historical rights. Recently, emphasis has also been placed on incentive-based mechanisms, such as charges- and rights- based systems, rather than systems which allocate by fiat (e.g., standards) [4]. A natural concern is thus whether an incentive-based system is a feasible means of handling the conflicts between wild horse advocates and traditional livestock operators on public lands. This paper explores such a system with particular attention to the constraints imposed by federal grazing statutes.

An incentive-based wild-horse policy satisfies the above FLPMA and PRIA requirements by persuading permittee-stewards to voluntarily decrease livestock when increased forage is needed for the sustenance of wild horses and nongrazing competing uses. The mechanism proposed in this paper is a counterbalancing incentive system which relies on increased grazing fees per animal to discourage stocking when necessary. Compensatory transfer payments are included to satisfy the statutory mandate of preventing economic disruption to the western livestock industry. Ranchers who acquire grazing permits at a value that have capitalized the net benefits from past low grazing fees stand to suffer large financial losses if grazing fees are significantly increased [3],[5]. Hence, the system fixes compensatory payments at levels



counterbalancing permittee financial losses from increased grazing fees (when needed to induce multiple-use compliance).

The paper is organized as follows. The first section develops the analytical grazing model underpinning the wild-horse counterbalancing incentive system. The second section derives the system. The last section discusses how the system may be useful in practical application.

#### THE GRAZING MODEL

Suppose that the permittee is assessed a public grazing fee each time period  $t$  for each animal stocked,  $g_f$  (\$/hd/t). Suppose also that the permittee receives compensations each period for every pound of forage consumed by wild horses,  $p_h$  (\$/lb dm), and every pound of forage left ungrazed on the allotment,  $p_f$  (\$/lb dm); and that the wild horse population grazing the permittee's allotment each period,  $H_t$ , is an exogenous policy variable controlled by the BLM consistently with the WFRHBA. Suppose finally that the permittee's assumed objective is to select the cattle stocking strategy which results in a present-value maximizing allocation of range vegetation among livestock grazing, wild-horse grazing, and nongrazing multiple uses over the term of an  $n$ -year permit, subject to biological constraints on plant and animal productivity.

The analytical formulation of this problem is

$$(1) \max_{S_t} \int_0^n e^{-rt} \{ [p_w W_t(F) - (g_f + c)] S_t + p_h C_{h,t}(F_t) H_t + p_f F_t \} dt ,$$

subject to  $S_t, F_t, H_t, p_w, c \geq 0$ , and

$$(2) F_{t=0} = F_0, F_{t=n} = F_n,$$

$$(3) \quad S^L = 0 \leq S \leq S^U,$$

$$(4) \quad W_t(F_t) = m \text{ Cn}_{s,t}(F_t)$$

$$(5) \quad \dot{F}_t = G_t(F_t) - \text{Cn}_{s,t}(F_t)S_t - \text{Cn}_{h,t}(F_t)H_t,$$

where,  $F_t$  is the perennial vegetation density in  $t$  (state variable, lbs. d.m./acre),  $S_t$  is the cattle stocking rate in  $t$  (control variable, head/acre),  $r$  is an exogenous market-determined periodic real interest rate,  $p_w$  is the beef price (\$/lb),  $W_t$  is animal productivity in  $t$  (lbs./head/t),  $c$  is the sum of incidental and opportunity costs of holding livestock on range (\$/head/t),  $\text{Cn}_{h,t}$  is the wild horse forage consumption rate (lb dm/head/t),  $S^L$  ( $S^U$ ) is the minimum (maximum) stocking rate in  $t$  (head/acre),  $\text{Cn}_{s,t}(F_t)$  is the livestock forage consumption rate (lb dm/head/t),  $\dot{F}$  is the rate of net change in the forage stock in  $t$  (eq. of motion, lbs dm/acre/t), and  $G_t$  is the vegetation growth rate (lb dm/head/t). Time subscripts are dropped below where no ambiguity exists.

The first term in the integrand of equation 1,  $[p_w W_t(F_t) - (g_f + c)] S_t$ , measures periodic weight-gain profits from grazing livestock. The second term,  $p_h \text{Cn}_{h,t}(F_t) H_t$ , measures the periodic compensation the permittee receives for the forage consumed by wild horses. Finally, the third term,  $p_f F_t$ , measures the periodic compensation the permittee receives for ungrazed vegetation left to supply nongrazing uses.

Equations 4 and 5 comprise the ecological component of the grazing model and rely on assumptions prevalent in the grazing ecology literature [10],[11]. Equation 4 assumes that livestock productivity per head is monotonically and linearly related to the rate of forage

consumption per head. Equation 5 assumes that the net change in the forage stock in a period is forage growth less total consumption by livestock and wild horses during the period. Forage dynamics are assumed to remain stationary through time.

### The Solution

Equations 1-5 pose a most rapid approach problem (MRAP) which utilizes a bang-bang livestock control sequence from equation 6 below to drive forage to the optimal (singular) solution  $F^*$  as rapidly as possible [12]

$$(6) \quad S = \begin{cases} S^U & \text{if } \sigma > 0 \quad (F > F^*) \\ S^* & \text{if } \sigma = 0 \quad (F = F^*) \\ S^L & \text{if } \sigma < 0 \quad (F < F^*), \end{cases}$$

where  $S^*$  is the (constant) livestock control which keeps  $F = F^*$  so long as  $0 < S^* < S^U$ . Since forage dynamics are assumed to be stationary and parameters are assumed to be constant through time, the singular solution holds for each grazing season in the n-year horizon of the problem.

The Pontryagin necessary conditions stipulate that the steady state stocking and forage levels ( $S^*, F^*$ ) satisfy

$$(7) \quad S \Big|_{F=0} = [G(F) - Cn_h(F)H] / Cn_s(F)$$

$$(8) \quad F^2 + \frac{[(a-r-qH)P + bK(g_f+c) + c^x(p_f+p_hqH)]}{2bP} F + \frac{rK(g_f+c)}{2bP} = 0$$

where  $P = p_w mc^x - (g_f+c)$ ; forage growth,  $G(F)$ , follows a pure



compensation logistic model,  $G(F) = aF - bF^2$ ; forage consumption per head by livestock,  $Cn_s(F)$ , follows a "type 2" saturation functional response [6],  $Cn_s(F) = c^x F / (F+K)$ ; and forage consumption per head by wild horses follows a "type 1" linear functional response [6],  $Cn_h(F) = qF$ .<sup>8</sup>

Equation 7 is the forage isocline derived by setting the equation of motion (equation 5) equal to zero. It requires that the singular forage solution be drawn from stocks equilibrating the ecological component of the grazing model. The positive root associated with the quadratic equation in 8 gives the singular forage solution as a function of the fixed parameters of the grazing model

$$(9) \quad F^* = F^* \{p_w, c, r, a, b, c^x, K, m, q, p_f, g_f, p_h, H\}.$$

$F^*$  is the standing stock remaining each period after the associated sustained yield,  $G(F^*)$ , is grazed by a present-value maximizing level of livestock and an exogenously determined wild horse population. Hence, it is the magnitude available to supply nongrazing uses when the grazing system is in bioeconomic equilibrium.  $F^*$  embeds two necessary conditions for maximizing the discounted net returns from grazing: (1) the opportunity cost of stocking the marginal animal equals the present value of the marginal gain; and (2) the marginal present value of the forage stock depreciates at the sum of the rates at which the forage stock contributes to immediate discounted revenues through livestock grazing, wild horse grazing, nongrazing uses, and the value of forage stock accumulation.

#### THE COUNTERBALANCING INCENTIVE SYSTEM

The counterbalancing incentive system generates prices designed to

induce the permittee-steward to select a cattle stocking strategy accomplishing two purposes. First, the strategy sustains a standing vegetation level satisfying nongrazing uses. Second, the sustained yield generated by the sustained vegetation level satisfies the periodic grazing needs of a present-value maximizing level of livestock and an exogenously determined wild horse population. The incentives are formulated so that the permittee realizes a steady-state wealth position consistent with some specified prior level, for example, that under current grazing fees and no compensation for wild horses or sustained forage.

The offsetting mechanism requires the construction of "iso-supply" and "iso-PV" (present value) functions. The iso-supply function gives the combinations of  $p_f$ - $g_f$  which induce the permittee to sustain the vegetation level satisfying government-determined multiple-use levels,  $F^{\text{mu}}$  and  $H$ . It is derived by fixing the particular forage solution  $F^{\text{mu}}$  in equation 9 and solving for  $p_f$  as a function of variable  $g_f$

$$(10) \quad p_f(g_f | F^* = F^{\text{mu}}) = a_1 + b_1 g_f$$

where  $a_1 = -p_w m(a - 2bF^{\text{mu}} - r) + (c/c^x)[(a - 2bF^{\text{mu}} - r) - (k/F^{\text{mu}})(r + bF^{\text{mu}})] + (q/c^x)[p_w m c^x - c - c^x p_h]$ ;

$$b_1 = 1/c^x[(a - 2bF^{\text{mu}} - r) - (k/F^{\text{mu}})(r + bF^{\text{mu}}) - qH]; \text{ and}$$

the wild horse compensation rate,  $p_h$ , is arbitrarily set by the government. The iso-supply function can be shown to be inversely related to the grazing fee  $g_f$  for all positive levels of forage and wild horses. Increasing the wild horse population on the permittee's grazing allotment can be shown to: (1) shift the intercept of the iso-supply

curve upward (downward) when the net return for diverting a pound of forage to livestock production,  $(p_w mc^x - c)/c^x$ , is greater (less) than the compensation for diverting the pound to wild horse grazing,  $p_h$ ; and (2) give the iso-supply curve a steeper negative slope (see Figure 1).

The iso-PV function is composed of the  $p_f$ - $g_f$  combinations which hold the present value of livestock profits constant at a given level, e.g., at the steady-state level consistent with stewardship under a fixed status quo grazing fee,  $g_f = g_f^{sq}$ ; no compensation for forage supporting nongrazing uses; and a wild horse population of zero, i.e.,

$$(11) DF_t \{ S^{\mu} [p_w W(F^{\mu}) - (g_f + c)] + p_f F^{\mu} + p_h q F^{\mu} H \} = DF_t \{ [p_w W(F^*) - (g_f^{sq} + c)] S^* \}$$

where  $DF_t$  is the relevant discount factor. The iso-PV (present value) curve is derived by solving equation 11 for  $p_f$  in terms of variable  $g_f$ :

$$(22) p_f(g_f | dPV=0) = a_2 + b_2 g_f$$

where  $a_2 = [p_w W(F^*) - (g_f^{sq} + c)] [S^* / F^{\mu}] - [p_w W(F^{\mu}) - c] [S^{\mu} / F^{\mu}] - p_h q H$

$$b_2 = S^{\mu} / F^{\mu}.$$

The tradeoff between  $p_f$  and  $g_f$  in the iso-PV function is positive since  $p_f'(g_f) = S^{\mu} / F^{\mu} > 0$ . Increasing the wild horse population on the permittee's grazing allotment shifts the intercept of the iso-PV curve down while leaving the slope unchanged (See Figure 2).

The offsetting price incentives are given by the combination of  $p_f$ - $g_f$  at the intersection of the iso-supply and iso-PV functions. Figure 3 shows the counterbalancing combinations associated with two wild horse populations,  $H^1$  and  $H^2$ , and an arbitrarily set wild horse compensation,  $p_h$ . As the population increases from  $H^1$  to  $H^2$ , the



counterbalancing grazing fee,  $g_f^{cc}$ , increases while the forage compensation,  $p_f^{cc}$ , may increase or decrease depending on the slope of the iso-supply curve associated with  $H^2$ .

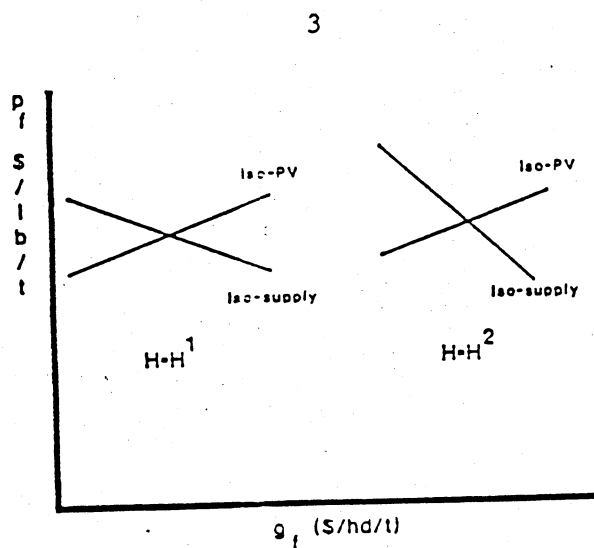
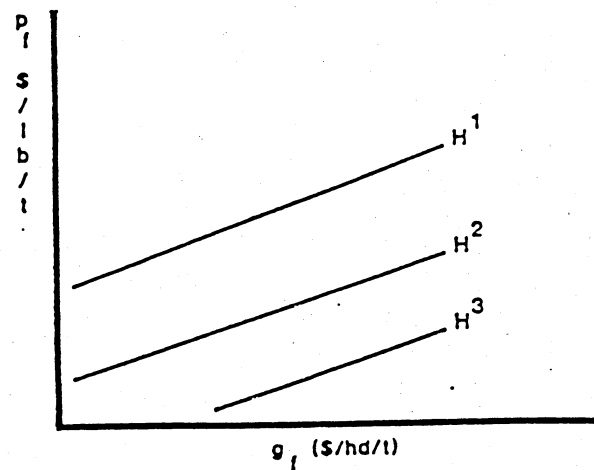
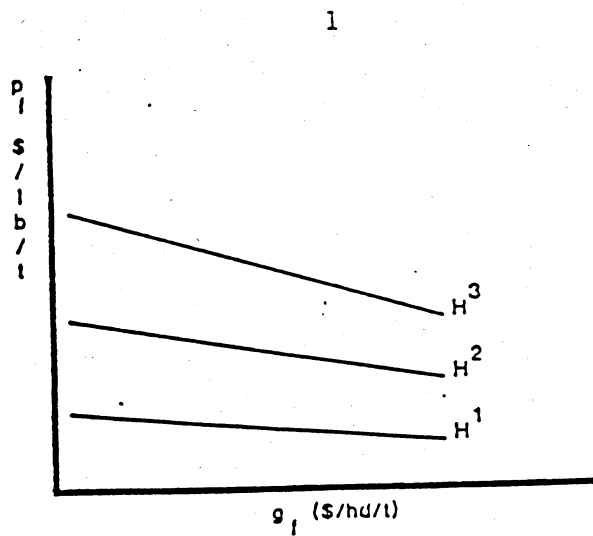
#### SUMMARY AND DISCUSSION

To summarize, the public rangeland manager determines the wild horse population grazing the permittee's allotment and the sustained vegetation level satisfying nongrazing uses. The manager then calculates a counterbalancing combination of grazing fee and compensatory forage payment associated with an arbitrarily set compensatory wild horse payment. The counterbalancing incentives: (1) induce the permittee-steward to voluntarily select a sustained cattle stocking rate accommodating wild horse grazing and nongrazing uses; and (2) keep the permittee's discounted livestock profits intact at a predetermined level. When underlying circumstances change (e.g., underlying biological or economic parameters change), the open-loop structure of the underlying grazing model requires the range manager to recalculate the grazing fee and compensation.

The sizable amount of allotment-specific information required by the counterbalancing incentives system thwarts its practical application. However, limited application may be practical if the government uses the theoretical economic and ecological relationships set out in the analytical model as a basis for iterating toward a combination of grazing fee and compensation that induces the desired cattle stocking response. In this way, the permittee (who has more of the required information than the government) reveals his valuation of the opportunity costs of converting forage to various levels of nonlivestock use.

Limited application of the system requires that the compensatory payments be financed. One possibility is for the government to redirect grazing fee revenues back to permittees or to use general tax revenues. Another possibility is to assess a fee for nonlivestock services to specific beneficiary groups whenever they can be identified. Some beneficiary groups are readily identified by their rent seeking activities (i.e., lobbying and judicial activities) to promote their interests.

The major argument against assessing beneficiary groups a nonlivestock use fee is that it is opposed to the interpretation that nonlivestock users give the public trust doctrine; namely that they are entitled to enjoy nongrazing uses of public rangeland without cost. The major argument for assessing a nonlivestock fee is that beneficiary groups are forced to face a portion of the social costs generated by the uses they promote (e.g., the huge opportunity and incidental costs of capturing and holding excess wild horses). Hence, they are induced to be more economical in their requests. Moreover, donating members of these groups may also benefit as donations finance conservation directly through nonlivestock fees, instead of indirectly through expensive lobbying and judicial activities. Finally, assessing nonlivestock fees to these groups seems symmetrically equitable in light of the grazing fees assessed specifically to ranchers.



$$H^1 < H^2 < H^3$$

Figure 1: Iso-supply curves associated with increasing wild horse populations

Figure 2: Iso-PV curves associated with increasing wild horse populations

Figure 3: Counterbalancing incentives associated with increasing wild horse populations



## FOOTNOTES

1. 16 U.S.C.A. sec. 1331 (1971).
2. 16 U.S.C.A. sec. 1333(a) (1971).
3. 16 U.S.C.A. sec. 1333(b)(2)(B) (1971).
4. Each horse costs taxpayers approximately \$165 to capture and \$2.25/day to sustain in captivity. The program has cost \$92 million since 1980 [13].
5. 43 U.S.C. sec. 1732(a) (1982).
6. 43 U.S.C. sec. 1908(a) (1982).
7. 43 U.S.C. sec. 1901(a)(5) (1982).
8. Given the above functional responses for  $G(F)$  and  $C_n(F)$ , a linear vegetation consumption response for horses is necessary for the optimization problem to generate a unique steady state forage solution for a given combination of  $g_f$ ,  $p_f$ , and  $p_h$ . The inaccuracy of approximating a saturation functional response with a linear response can be mitigated by choosing a value for the linear grazing efficiency coefficient  $q$  such that the two responses are approximately equal in the neighborhood of the target steady state solution.

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## Grazing Impacts to Forage Production and the Rangeland Stocking Rate Decision

L. Allen Torell, William W. Riggs, E. Bruce Godfrey and Kenneth S. Lyon

The stocking rate decision has been described as the most important grazing management decision from the standpoint of vegetation, livestock, wildlife and economic returns (Holechek et al., p. 173). It is widely known, if stocking rates are heavy enough, livestock grazing can be detrimental to long-term range condition and forage production, and can alter the botanical composition of rangeland plant communities to include less desirable woody brush species. In practice, stocking rate recommendations and allowances are based on the perceived ability of forage plants to sustain grazing pressure (Holechek et al., Stoddart et al.). Economics has been of only minor importance in the stocking rate decision, although the profit motive of ranchers has been widely blamed for deterioration of some western rangelands.

Past economic stocking rate studies (Hildreth and Riewe, Hart et al. 1988a,b, Workman) have taken a myopic view and have excluded dynamic forage production impacts of grazing. This exclusion has not occurred because of failure to recognize its importance. Rather, lack of long-term data defining the magnitude of these impacts has generally precluded their inclusion.

In this paper we develop a dynamic economic model of stocking rates on rangeland. We first describe a traditional single-period economic model of optimal input use as applied to the economics of grazing. It is included so the conditions for traditionally defined economically-efficient stocking rates can be contrasted with the results of a more complex dynamic stocking rate model. It will also serve as an introduction to the dynamic model, and provide a review of procedures that have been used in previous economic stocking rate studies. The economic principles developed have general application to all types of rangeland and pastures, and although yearling steers and season-long grazing are considered here, the same principles are applicable to other livestock types, grazing systems and rangeland uses.

To demonstrate the economic principles involved, an example adapted from a long-term grazing study in eastern Colorado is used (Sims et al.). This example was chosen because it is one of the few grazing studies with adequate design and length to determine long-term impacts of grazing on livestock and forage production, and to evaluate the dynamics of the economic stocking rate decision.

### A MYOPIC MODEL OF ECONOMICALLY OPTIMAL STOCKING RATES

The standard production economic model of efficient input use has been applied to the problem of stocking rates on rangeland by numerous authors including Hart et al. (1988a,b), Hildreth and Riewe, Riewe, Torell and Hart, and Workman. Although definition of the variable input differs, these economic evaluations start with definition of input/output relationships, the production function. Most recently, stocking rate studies have standardized the grazing input in the production process to grazing pressure (GP), which is defined to be the number of stockers grazing per unit of herbage (H) production per ha (Hart et al. 1988a, Scarnecchia).

$$GP = SD/H = v \cdot SR/H, \quad (1)$$

where SR = Stocking Rate, the number of stockers grazing per ha;  $v$  = length of the grazing period; and SD = Stocker Days, the number of stocker days of grazing per ha.

In this single-period model, herbage production and the length of the grazing period are exogenously determined and defined (or estimated) when the stocking rate decision is made. Thus, the choice variable is SR. The relationship between gain per animal per day (Average Daily Gain, ADG) and SR is defined to be a quasi-concave function given by

$$ADG = f(GP(SR)), \quad (2)$$

with  $df/dSR < 0$  and  $d^2f/dSR^2 \leq 0$  over the economically relevant range of production.