

On the Choice Between the Stocking Rate and Time in Range Management¹

by

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Abstract

A long standing question in range management concerns the relative importance of the *stocking rate* versus the length of *time* during which animals graze a particular rangeland. We address this question by analyzing the problem faced by a private rancher who wishes to minimize the long run expected net cost (*LRENC*) from range operations by choosing either the stocking rate or the length of time during which his animals graze his rangeland. We construct a renewal-theoretic model and show that, in general, this rancher's *LRENC* with an optimally chosen stocking rate is *lower* than his *LRENC* with an optimally chosen grazing cycle length.

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1. Introduction

1.1. Preliminaries

All parts of the world that are not bare deserts, that are not cultivated, and that are not covered by bare soil, ice, or rock can be thought of as *rangelands*. This means that rangelands include most deserts, forests, and all natural grasslands. The key feature of a rangeland is that it consists of uncultivated land that can and typically does provide habitat for browsing and grazing animals. *Browsing* refers to the consumption of leaves and twigs from woody plants such as shrubs and trees by animals. In contrast, *grazing* refers to the consumption of standing forage such as grasses by animals.

Range management is “the manipulation of rangeland components to obtain the optimum combination of goods and services for society on a sustained basis” (Holechek *et al.*, 1998, p. 5). As noted by Stoddart *et al.* (1975, pp. 2-3) and by Holechek *et al.* (1998, p. 5), in contemporary times, the task of range management is based on five basic precepts. First, a rangeland is a renewable resource. Second, solar energy captured by the green plants of a rangeland can only be harvested by browsing and grazing animals. Third, the productivity of a rangeland is determined by climatic, soil, topographic, and use factors. Fourth, in comparison with cultivated lands, rangelands provide humans with food and fiber at very low energy costs. Finally, a variety of goods and services such as food, minerals, timber, and recreation are obtained from rangelands.

A range manager can manipulate the components of a rangeland in several ways. Put differently,

this manager can accomplish his managerial objectives⁵ with a variety of choice variables. In this paper, we are interested in shedding light on a particular controversy in the range management literature. This controversy concerns two choice variables, namely, the stocking rate and the length of a grazing cycle. The *stocking rate* concept is used in more than one way by range managers. Consequently, it is important to be clear about the precise meaning of this concept. The meaning that we shall use in this paper tells us that the “stocking rate is typically expressed as animal units per section of land” (Holechek *et al.*, 1998, p. 190). The *length of a grazing cycle* is more straightforward and it is defined to be the length of time in a calendar year during which animals graze a given rangeland.⁶

With these two definitions in place, we are now in a position to state the above mentioned controversy in the form of a simple question: Is the stocking rate more important or is time more important in range management?⁷ The objective of this paper is to answer this question. We now discuss this range management controversy in greater detail and then we comment on the way in which we plan to address the underlying issues.

1.2. The controversy

Although there are many aspects to the task of range management, today, range scientists agree that one important aspect concerns the determination of the appropriate stocking rate. Consider the position

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Examples include the maximization of (i) range livestock productivity and (ii) the economic returns from the rangeland.

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In the rest of this paper, we shall use the terms “length of grazing cycle” and “time” interchangeably. The reader should note that both these terms refer to the length of time during which animals graze a given rangeland.

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Readers may be wondering whether there exist choice variables, intermediate between the stocking rate and time, that dominate these two control variables. This and related issues are discussed in section 5.

of two standard range management texts on the subject of the stocking rate. Stoddart *et al.* (1975, p. 262) tell us that correct livestock “numbers are important for the perpetuation of the range, the well-being of the livestock, and the economic stability of the operator.” Holechek *et al.* (1998, p. 221) go even further and state that proper “stocking is the most important part of successful range management.”

However, not everyone agrees that the stocking rate is the most salient part of successful range management. In particular, Allan Savory (1983, 1988) and his adherents—see Goodloe (1969), Savory and Parsons (1980), and Savory and Butterfield (1998)—have forcefully argued that the stocking rate is *less* important than is commonly believed. Savory and Butterfield (1998, p. 41, emphasis in original) have pointed out that until “very recently no one truly explored the question of *when* animals are there as opposed to how many there are.” The central point of Allan Savory and other like minded scholars is this: Overgrazing bears “little relationship to the number of animals but rather to the *time* plants [are] exposed to the animals” (Savory and Butterfield, 1998, p. 46, emphasis in original).⁸

This polarized state of affairs raises an important question. Is the stocking rate more important or is time, i.e., the length of the grazing cycle, more important in range management? We shall answer this question by analyzing the decision problem faced by a private rancher who wishes to minimize the long run expected net cost (hereafter *LRENC*) from range operations by choosing either the stocking rate or the length of time during which his animals graze his rangeland.⁹ Note that this long run focus means that our

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Allan Savory’s views on grazing have been variously described as time-controlled grazing, as short-duration grazing, and as the Savory grazing method. For more on this and related issues, see Holechek *et al.* (1998, pp. 229-256).

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Note that minimizing long run expected net cost is equivalent to maximizing long run expected profit. We have decided to focus on net cost and not on profit because this focus makes some of the subsequent algebra a little cleaner.

rancher cares about the expected net cost from his range operations and about the well being of his rangeland. Our analysis shows that, in general, this rancher's *LRENC* with an optimally chosen stocking rate is *lower* than his *LRENC* with an optimally chosen grazing cycle length.

Given the obvious importance of this stocking rate versus time question for practical range management, one would expect this question to have been studied thoroughly. Although there are many studies that have evaluated the impact of alternate stocking rates on animal performance and on forage production,¹⁰ and some empirical studies of Allan Savory's time-controlled grazing,¹¹ these studies have not resolved this stocking rate versus time controversy. Moreover, on the theoretical side, the matter is even less settled. To the best of our knowledge, there are *no* previous theoretical studies of this question. This state of affairs has led Holechek *et al.* (1998, p. 254) to conclude that the long "term impacts of [time-controlled] grazing...[have yet] to be determined." As such, we now proceed to our analysis of the long run effects of the stocking rate versus time in range management.

The theoretical framework of this paper is adapted from Batabyal (1999) and the rest of this paper is organized as follows. Section 2 presents and analyzes a renewal-theoretic¹² model of the decision problem faced by a private rancher who wishes to minimize his *LRENC* from range operations by choosing the stocking rate optimally. Section 3 analyzes a similar model; however, in this section, the rancher minimizes his *LRENC* from range operations by choosing the length of the grazing cycle optimally. Section

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See Holechek *et al.* (1998, pp. 248-256) and Holecheck *et al.* (1999).

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See Graham *et al.* (1992), Hart *et al.* (1993), and Holechek *et al.* (1998, pp. 248-256).

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For more on renewal theory, see Ross (1996, pp. 98-161; 1997, pp. 351-410) and Taylor and Karlin (1998, pp. 419-472).

4 first compares the optimized value of the rancher's *LRENC* from sections 2 and 3 and thereby determines which choice variable—stocking rate or time—results in lower *LRENC*. Next, this section discusses the relationship between the analysis of this paper and other related natural resource management problems. Section 5 concludes and offers suggestions for future research.

2. Range Management with an Optimally Chosen Stocking Rate

Consider a private rancher who owns livestock animals (cows) and a fenced plot of rangeland. In the model of this and the next section, our private rancher conducts his range operations with reference to a particular grazing period in a calendar year. For instance, this grazing period might be from May 2 to July 15, which would correspond to the grazing period for intensive-early stocking, or it might run from May 2 to October 3, which would correspond to the grazing period for normal season-long grazing (Holechek *et al.*, 1998, pp. 231-236). At the beginning of a grazing period, our rancher lets his animals into his fenced rangeland in accordance with a Poisson process¹³ with rate λ . This rancher believes that the appropriate stocking rate for his rangeland corresponds to A animals. As such, once A animals have been allowed into the rangeland to graze, entry of additional animals is prohibited for the grazing period under consideration. Put differently, once A animals have been allowed in, this rancher's rangeland is closed to grazing in the current calendar year grazing period.

As a result of his range operations, our rancher incurs costs and obtains benefits from two sources. The first, or direct, source of net cost (total cost less total benefit) stems from things like the deleterious effects of grazing on the plant species of the rangeland (a cost) and from the weight gain accruing to animals

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For more on the Poisson process, see Ross (1996, pp. 59-97; 1997, pp. 249-301) and Taylor and Karlin (1998, pp. 267-332).

as a result of forage intake (a benefit). We capture this direct source of net cost by supposing that our rancher incurs net costs at the rate of $\$ac$ per unit time, where a refers to the number of animals grazing at that time and c can be thought of as the instantaneous net cost per animal. The second, or indirect, source of net costs arises from things like the need to feed animals that have not been allowed in to the rangeland (a cost) and from stocking the rangeland at the correct rate (a benefit). This benefit arises because correct stocking means that the rangeland's grazing capacity will not be exceeded. In turn, this means that this rangeland will be able to provide the rancher's animals with a flow of forage in the long run. In every calendar year grazing period, we suppose that our rancher incurs a net cost of $\$C$, when he closes his rangeland to additional animals.

Now, if we say that a grazing cycle for the calendar year is completed whenever the rancher closes the rangeland to additional animals, then the description of events in the previous two paragraphs constitutes a renewal-reward process.¹⁴ Consequently, we can use the renewal-reward theorem to compute our rancher's *LRENC* from his range operations. The renewal-reward theorem tells us that the rancher's *LRENC* equals the expected net cost in a grazing cycle divided by the expected length of this grazing cycle. Formally, we have

$$LRENC = \frac{E[\text{net cost per grazing cycle}]}{E[\text{length of grazing cycle}]}, \quad (1)$$

where $E[\@]$ is the expectation operator.

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For more on renewal-reward processes and the renewal-reward theorem, see the references cited in footnote 12.

Let us now compute the two expectations on the right hand side (hereafter RHS) of equation (1). In any given grazing cycle, let X_a denote the time between the arrival of the a th animal and the $(a+1)$ th animal into the rancher's rangeland. Then the numerator on the RHS of equation (1) is given by

$$E[\text{net cost per grazing cycle}] = C E[cX_1 + 2cX_2 + 3cX_3 + \dots + (A+1)cX_{A+1}]. \quad (2)$$

Because the rancher's cows are brought into the rangeland in accordance with a Poisson process with rate λ , the mean interarrival time is $1/\lambda$. Mathematically, this means that $E[X_i] = 1/\lambda$, $i = 1, \dots, (A+1)$. Using this result, the RHS of equation (2) can be simplified to

$$E[\text{net cost per grazing cycle}] = C \frac{cA(A+1)}{2\lambda}. \quad (3)$$

In order to compute the denominator on the RHS of equation (1), it suffices to note that the expected length of a grazing cycle is simply the expected time it takes for the A animals to begin grazing on the rancher's rangeland. Because the mean interarrival time for the cows is $1/\lambda$, we get

$$E[\text{length of grazing cycle}] = \frac{A}{\lambda}. \quad (4)$$

Now combining the results from equations (3) and (4), we get an expression for the rancher's *LRENC*. That expression is

$$LRENC = \frac{\lambda C}{A} \frac{cA(A+1)}{2}. \quad (5)$$

Having computed the expression for our rancher's *LRENC*, we are now in a position to state this rancher's *LRENC* minimization problem. Specifically, this rancher chooses the stocking rate A to minimize the *LRENC* from his range operations. Formally, our rancher solves

$$\min_{\{A\}} \left[\frac{\acute{a}C}{A} + \frac{c(A+1)}{2} \right]. \quad (6)$$

Treating A as a continuous choice variable and using the calculus, we see that the stocking rate that minimizes the rancher's *LRENC* is given by¹⁵

$$A^* = \sqrt{\frac{2\acute{a}C}{c}}. \quad (7)$$

In words, the optimal stocking rate equals the square root of the ratio of the product of twice the rate of the Poisson arrival process (\acute{a}) and the indirect net cost from closing the rangeland to additional animals (C) to the instantaneous net cost per animal (c). Inspecting equation (7) it is easy to verify two properties of the optimal stocking rate. First, as the indirect net cost per grazing cycle (C) goes up, the rancher finds it desirable to *raise* the optimal stocking rate. Second, if the instantaneous net cost per animal (c) increases, then it is in the interest of the rancher to *lower* the optimal stocking rate.

Let us now substitute the expression for the optimal stocking rate from equation (7) into the minimand in equation (6). This gives us an expression for the minimal *LRENC* that our rancher will incur

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The second order condition is satisfied.

by choosing the stocking rate optimally. Denote this minimal *LRENC* by $(LRENC)_{SR}^{\zeta}$. Some algebra tells us that

$$(LRENC)_{SR}^{\zeta} = \sqrt{2\acute{a}cC} + \frac{c}{2}. \quad (8)$$

Inspecting equation (8), we see that the minimal *LRENC* that our rancher will incur by choosing the stocking rate optimally equals the square root of the product of twice the rate of the Poisson arrival process (\acute{a}), the instantaneous net cost per animal (c), and the indirect net cost per grazing cycle (C), less one-half the instantaneous net cost per animal.

We now study the case in which the focus of our private rancher is not on the stocking rate *per se*, but on the *length* of the grazing cycle on his rangeland. After computing the optimal length of the grazing cycle, we shall compare equation (8) with the corresponding equation for this latter case in which the rancher's focus is on time.

3. Range Management with an Optimally Chosen Grazing Cycle Length

Instead of choosing the stocking rate optimally, our rancher now follows a different strategy. In particular, this rancher now chooses the length of the grazing cycle (T) to minimize the *LRENC* from his range operations. In the context of the discussion in the first paragraph of section 2 (see p. 7), this means that if the grazing period in a calendar year happens to be 75 days long (May 2 to July 15), then our rancher chooses T with this 75 day grazing period in mind. So, in this example, the optimal T would be some real number between 0 and 75. If the optimal $T = 0$, then this means that the rancher rests his rangeland for the entire grazing period in that calendar year. At the other end, if optimal $T = 75$, then this

means that the rancher's grazing cycle and the grazing period for that calendar year coincide.

In this setting, our rancher chooses the length of the grazing cycle (time) to minimize the *LRENC* from his range operations. Consequently, let us now compute the *LRENC* that is incurred by the rancher when this rancher's focus is on time rather than on the stocking rate. As in the previous section, at the beginning of the grazing period, our rancher lets his animals into his rangeland in accordance with a Poisson process with rate λ . We suppose that this rancher lets his animals graze the rangeland for T units of time. In other words, when T units of time have elapsed, the rangeland is closed to grazing. This means that a grazing cycle is completed when T units of time have elapsed. As explained in the previous paragraph, the length of this grazing cycle will either be less than or equal to the length of the grazing period in a calendar year.

We shall use the renewal-reward theorem (equation (1)) to compute our rancher's *LRENC*. The computation of $E[\text{net cost per grazing cycle}]$ will be facilitated by conditioning on $N(T)$, the total number of animals that are grazing the rancher's rangeland by time T . This yields

$$E[\text{net cost per grazing cycle}/N(T)] = C\% \frac{cTN(T)}{2}. \quad (9)$$

Using the properties of the expectation operator and equation (9), we get

$$E[\text{net cost per grazing cycle}] = C\% \frac{\lambda c T^2}{2}. \quad (10)$$

Now note that $E[\text{length of grazing cycle}] = T$. This result and equation (10) together tell us that our

rancher's *LRENC* is given by

$$LRENC = \frac{C}{T} + \frac{\acute{a}cT}{2}. \quad (11)$$

Having computed the expression for our rancher's *LRENC*, we are now in a position to state this rancher's *LRENC* minimization problem. This rancher chooses the length of the grazing cycle (T) to minimize the *LRENC* from his range operations. Formally, our rancher solves¹⁶

$$\min_{\{T\}} \left[\frac{C}{T} + \frac{\acute{a}cT}{2} \right]. \quad (12)$$

Using the calculus, we see that the grazing cycle length that minimizes the rancher's *LRENC* is given by¹⁷

$$T^* = \sqrt{\frac{2C}{\acute{a}c}}. \quad (13)$$

In words, the optimal length of the grazing cycle equals the square root of the ratio of the product of twice the indirect net cost from closing the rangeland (C) to the product of the rate of the Poisson arrival process (\acute{a})

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To keep this minimization problem simple, we have not imposed a constraint requiring T to be bounded below by zero and above by the length of the grazing period in a calendar year. If the optimal T turns out to be larger than the length of the grazing period, then we simply set the optimal T equal to the length of the grazing period. For example, as discussed in the first paragraph of this section, if the length of the grazing period happens to be 75 days and the optimal T turns out to be 78 days, then we simply set this optimal T equal to 75 days.

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The second order condition is satisfied.

and the instantaneous net cost per animal (c). Inspecting equation (13) it is easy to verify two properties of the optimal length of the grazing cycle. First, as the indirect net cost per grazing cycle (C) goes up, the rancher finds it optimal to *lengthen* the grazing cycle. Second, if the instantaneous net cost per animal (c) increases, then it is optimal for the rancher to *shorten* the grazing cycle.

Let us now substitute the expression for the optimal length of the grazing cycle from equation (13) into the minimand in equation (12). This gives us an expression for the minimal $LRENC$ that our rancher will incur by choosing the grazing cycle length optimally. Denote this minimal $LRENC$ by $(LRENC)_T^{\zeta}$. After some algebra, we get

$$(LRENC)_T^{\zeta} = \sqrt{2\acute{a}cC}. \quad (14)$$

Inspecting equation (14), we see that the minimal $LRENC$ that our rancher will incur by choosing the grazing cycle length optimally equals the square root of the product of twice the rate of the Poisson arrival process (\acute{a}), the instantaneous net cost per animal (c), and the indirect net cost per grazing cycle (C).

Recall that the objective of this paper is to answer the following question: Is the stocking rate more important or is time, i.e., the length of the grazing cycle, more important in range management? We now provide an answer to this question.

4. Stocking Rate versus Time in Range Management

Equation (8) gives us an expression for the $LRENC$ incurred by our rancher when he chooses the stocking rate optimally. Similarly, equation (14) gives us an expression for this rancher's $LRENC$ when he chooses the length of the grazing cycle (time) optimally. Comparing these two expressions, we see that

$$(LRENC)_{SR}^{(c)} = \sqrt{2acC} + \frac{c}{2} < \sqrt{2acC} = (LRENC)_T^{(c)} \quad (15)$$

Equation (15) clearly tells us that the rancher's *LRENC* with an optimally chosen stocking rate is *lower* than his *LRENC* with an optimally chosen grazing cycle length. It is in this sense that the stocking rate is *more important* than time in range management. Put differently, if a rational rancher had to choose a single control variable from a control set consisting of the stocking rate and time, then this rancher would choose the stocking rate over time. We now discuss the relationship between the analysis of this paper and other related natural resource management problems.

4.1. Our analysis and other resource management problems

In addition to rangelands, a number of other natural resources are also managed with temporal and non-temporal choice variables. For instance, commercial and recreational hunters for most game are subject to seasonal (time) restrictions. Moreover, such hunters are generally required to hunt during daylight hours. Similarly, Batabyal and Beladi (1999) have pointed out that most commercial fisheries are subject to season length (time) restrictions. Given this state of affairs, it would certainly be useful to know whether society is better off with such temporal restrictions or whether non-temporal choice variables—such as the number of animals hunted and the number of fishing boats used—result in higher welfare to society.

The theoretical framework of this paper can be used to answer these sorts of questions. Recall that an important result of this paper is that there are circumstances in which the use of a non-temporal choice variable leads to higher welfare for the decision maker. As such, the conduct of analyses along the lines undertaken in this paper will enable us to determine whether one can make a general theoretical argument against the use of temporal choice variables in natural resource management.

5. Conclusions

In this paper, we used a renewal-theoretic approach to analyze the decision problem faced by a private rancher who is interested in minimizing the *LRENC* from his range operations. On the basis of our analysis of two optimization problems for this rancher, we concluded that the stocking rate is more important than time in range management. To the best of our knowledge, this is the *first* theoretical answer to this stocking rate versus time question in range management.

The analysis of this paper can be extended in a number of directions. In what follows, we suggest two possible extensions. First, recall that in footnote 7, we mentioned that given this paper's focus on the stocking rate versus time, some readers may be wondering whether there exist choice variables, intermediate between the stocking rate and time, that dominate these two control variables. To answer this question, consider the seminal work of Roberts and Spence (1976). Environmental economists now know that it is possible to construct an "intermediate" control instrument that is part-price (fee or tax) and part-quantity (emissions permit scheme). Roberts and Spence (1976) showed that this intermediate control instrument can always be converted into a pure price or pure quantity control instrument. Consequently, in comparison with either a pure price or pure quantity control instrument, a regulator will do at least as well—and often much better—with this intermediate control instrument. A useful extension of this paper would be to determine whether this logic carries over to the subject of range management. In other words, the open question is to check whether it is possible to construct, in a dynamic and stochastic setting, a control instrument that is intermediate in the sense that it is part stocking rate and part time. If it is possible to do so, then it should be fairly straightforward to demonstrate that this intermediate control instrument dominates a pure stocking rate and a pure time control instrument.

Second, in section 2, we studied the decision problem faced by a private rancher who owns a single species of livestock animals (cows). As such, it would be useful to ascertain whether the results of this paper hold when this rancher's decision problem with the stocking rate as a choice variable is modified to account for situations in which the rancher owns more than one animal species. Studies of range management that incorporate these aspects of the problem into the analysis will provide additional insight into the roles that the stocking rate and time play in successful range management.

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