DISSERTATION

USING THE PRODUCTION POSSIBILITIES FRONTIER TO DEMONSTRATE ALTERNATIVE ALLOCATIONS OF RECREATION AND WILDLIFE

Submitted by

Nicole L. Haynes

Department of Forest Sciences

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I HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUT SUPERVISION BY NICOLE L. HAYNES ENTITLED USING THE PRODUCTION POSSIBILITIES FRONTIER TO DEMONSTRATE ALTERNATIVE ALLOCATIONS OF RECREATION AND WILDLIFE BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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Adviser

Department head/Director

ABSTRACT OF DISSERTATION

Using the Production Possibilities Frontier to Demonstrate Alternative Allocations of Recreation and Wildlife

The level of use and geographic extent of recreational activities is increasing (Holecek 1993). The popularity of outdoor activities is affecting wildlife and wildlife habitat (Boyle and Samson 1985). In this context, outdoor recreation research has not produced a decision tool that facilitates effective resource planning (Workman et al. 1990). If the relationship between recreation and wildlife is poorly understood, this may result in undesirable natural resource decision-making.

The conflicts between wildlife and recreation are caused by limited resources for the provision of both. As such, an economic model, the production possibilities frontier (PPF) may be an appropriate tool to address this issue. This paper investigates the potential of the PPF for allocating wildlife habitat and recreation, demonstrates the use of cumulative effects modeling in the development of a PPF, and discusses the managerial implications of using the PPF model.

In a two-output production decision, input employment is determined by the marginal rate of transformation between the two outputs, their relative prices, and social preferences. The PPF establishes the first of these pieces. In most allocative decisions, the PPF is assumed to be concave (Nicholson 1995), this however, is not necessarily the case in the allocation of recreation and wildlife.

Non-concavities that arise could be attributed to the production function of wildlife, which includes a joint variable for recreation. This variable affects the marginal rate of productivity for the other inputs in the function. Therefore, while the PPF assumes all inputs are fixed, this will not be the case if one of the outputs is an input into the production of the other output.

The PPF's application for recreation and wildlife production was evaluated using cumulative effects modeling for bald eagles and grizzly bears. Habitat availability was used to represent the potential for stability of the wildlife populations. Results show a concave PPF for grizzly bear habitat and a concave/convex PPF for bald eagle habitat availability. Sensitivity analysis was used to address uncertainty by creating a confidence band around the PPF frontier. The model also allows for divergent data to be mapped onto a PPF and differing frontiers can be compared.

Nicole L. Haynes
Department of Forest Sciences
Colorado State University
Fort Collins, CO 80523
Fall 1999

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Finally, I thank Sean McCoy for believing in my ability to successfully finish, and my parents, Steve and Georgia Haynes for nearly three decades of love and support and for instilling in me the confidence that I could accomplish anything. Well, I did.

Nicole L. Haynes

To my father.

TABLE OF CONTENTS

Introduction

The level of use and geographic extent of recreational opportunities is increasing (Holecek 1993). Concurrently, the popularity of outdoor activities is stimulating an escalating demand for access to public lands (O'Brien 1999). These activities are increasing impacts on wildlife and wildlife habitat (Boyle and Samson 1985). Natural resource managers are faced with a dilemma: to find a managerial balance between providing for the health and fecundity of wildlife species and for the outdoor-oriented recreational demands of the public.

In this context, outdoor recreation research has not produced a decision tool that facilitates effective resource planning (Workman et al. 1990). If the relationship between recreation and wildlife is not understood, then this incomplete knowledge can result in poor natural resource decision-making. Resource managers need a model that integrates social recreational demands with biological requirements of wildlife in a manner that reflects the relationship of the two and identifies the tradeoffs between them. The conflicts between wildlife and recreation are caused by limited resources for the provision of both. The discipline of economics is based on allocating scarce resources among competing end uses (Nicholson 1994). As such, an economic model may be an appropriate tool to address this issue. Currently, most research completed by both recreation management theorists and economists has focused on demand issues without enough attention paid to resource characteristics and to the inputs over which the management agencies control (Workman et al.1990). Efficient input employment is critical in natural resource management, as is recognition of the potential for jointness between the production of recreation and wildlife.

Numerous studies have documented varying effects of human disturbance on many wildlife species (Colorado State Parks 1998) and most of these view the dilemma in terms of conflict. A scarcity of resources, namely land for recreation which also serves as habitat for wildlife, is the source of this perception. However, if recreation and wildlife are viewed as two potential outputs in a production setting, then the problem is defined as one of competing production. This paper theorizes that joint production and the production possibilities frontier, PPF, can be used to represent the tradeoffs between production of recreation and wildlife. If the PPF is an appropriate tool, it would advance managerial decision-making by allowing resource managers to: (1) graphically view the rate of product transformation between two outputs, thus enabling marginal analysis of an addition or subtraction of either wildlife or recreation, (2) provide a sensitivity analysis to account for uncertainty and (3) efficiently employ resource inputs to optimize allocation of recreation opportunities and wildlife.

This paper addresses the impacts increased recreation may have on wildlife species, discusses the history and extent of the conflict, examines the current state of the research on controlling disturbance, and advances the theory of the PPF to an applied managerial tool.

This dissertation will

- investigate the potential of the PPF as a tool for allocating wildlife and recreation
- demonstrate the use of cumulative effects modeling in the development of a PPF
- discuss the managerial implications of using the PPF model
- address future directions for using the PPF model in wildlife/recreation decision-making

Background

Human disturbance has long been known to be disruptive to wildlife species. Until recent decades, most of the concern centered around what has been defined as consumptive recreation such as hunting and motorized off-road vehicle use. However, as the popularity of outdoor recreation increases, so do the impacts of what once was thought of as non-consumptive recreation. In 1976, R. Weeden published a paper entitled *Non-consumptive users: A Myth,* discussing that there may be no such thing as non-consumptive recreation, that all recreation in one way or another consumes natural resources. Currently it is believed that most impacts are in fact caused by recreationists who innocently create stressful situations for wildlife (Hammitt and Cole 1995).

Even low impact recreational activities are known to result in the loss of vegetative cover, plant species, and cause erosion and soil compaction (Cole 1985, 1993). They are also known to disrupt many wildlife species, having significant impacts on more sensitive species including mountain goats (Lyons and Price 1987), bighorn sheep (Hicks and Elder 1979, MacArthur et al. 1982, King and Workman 1986), raptors (Anderson et. al

1990, Knight and Skagen 1988, Stalmaster and Associates 1998), trumpeter swans (Henson and Grant 1991), and black bears and grizzly bears (Amstrup and Beecham 1976, McClellan and Shakelton 1989). Human disturbances can result in changes in wildlife physiology, behavior, reproduction, species composition, and diversity (Hammitt and Cole 1995).

Technological advances in recreational equipment providing greater accessibility to the outdoors and a more active populace (Chavez 1992) are resulting in not only more recreation pressure, but a greater variety of recreation activities. Rock climbing and mountain biking, two of the fastest growing outdoor sports which also have the potential for significant impacts on natural resources, were nearly unheard of two decades ago. Advances such fat tires for better traction, shocks, and light-weight materials are encouraging more people to try these sports. Lagging behind the increased demand is research into their impacts. The first mountain bike impact studies were published in the early 1990's, a decade later there are still few studies addressing their impacts.

Wildlife exhibit a range of reactions to human disturbance, from aberrant behavior to direct mortality (Knight and Cole 1995). Wildlife responses to disturbance vary between and within species, and frequently depend on age and geographic location. Certain species are known to adapt to human disturbance (Kuss et al. 1990), but the extent of this habituation is also a factor of species, age and geography (Knight and Cole 1995). Goodson (1978) documented that bighorn sheep in Rocky Mountain National Park were more tolerant of humans in areas where people were frequent and expected. Sheep in back country areas were far more wary of human presence. King and Workman (1986) found that desert bighorn who were historically exposed to higher levels of human disturbance were more sensitive to human encounters than those living in relatively undisturbed areas. Cassirer (1992) determined that elk in Yellowstone National Park were very disturbed by cross-country skiers, requiring at least a 650 meter buffer to minimize disturbance. Fergusen and Langvatn (1985) found that while elk and moose tended to move away from heavily used trails during ski season, the distribution of elk across the landscape was unaffected while the distribution of moose was affected. Stalmaster (1998) and Newman (1978) observed that human disturbances resulted in adult bald eagles flushing at greater distances than younger eagles. Furthermore, flight distances among bald eagles have been found to differ within and between sites as well as seasonally (Fraser et al. 1985).

Not all species are negatively affected by human disturbance. Miller et al. (1998) observed that generalist birds were more abundant near trails than are specialist species. Specialist species may be more sensitive to perturbations in the environment because all of their adaptations are concentrated on a specialized way of life, whereas generalist species generally have a broader niche and may be more adaptable to change (Odum 1989). Blair (1996) determined that exotic species were more prevalent in a business district while native species were found in relatively undisturbed areas. Furthermore, a habitat gain has been shown for mallards and wood ducks when they are able to use open-water lakes and reservoirs developed for recreation as nesting sites (Hammitt and Cole 1995). Generally, species that benefit from human disturbance may be of less concern to wildlife managers than more sensitive wildlife. Nevertheless, the complementary nature of this relationship can also be described with a PPF.

While there have been few studies that investigate the impact of varying numbers of recreationists on wildlife, it is known that the number of recreationists must be considered with activity type along with species' requirements, habits, and habitat attributes (Hammitt and Cole 1995). Attempts at modeling a direct biological response to recreation management are few and almost no consideration has been given to indirect effects (Johnson and Johnson 1990).

To date, most research into disturbance has led to recommendations for minimizing the impact of human activities (Knight and Cole 1995, Cole 1985, T&W 1998, Stalmaster 1998).

However, impact minimization implies a constraint with respect to wildlife species and often that constraint is vague, such as maintaining a population, or worse, undetermined. If the goal is to minimize impacts, but disturbance activities are increasing, then inevitably so does the minimal impact. Additionally, minimization in and of itself does not imply an efficient allocation of resources. Minimization can optimize according to given constraints, but those constraints may be inefficiently determined. Finally, minimization has no reference to address cumulative impacts of disturbance and may not provide an acceptable big picture analysis. If an eagle flushes from a boater or an elk runs from snowmobile noise, what does that mean in terms of population stability? What effect does one more recreationist or a more intensive form of recreation have on a population? If a population is habituated, does that mean additional recreation can be allowed? These questions can be addressed with the use of the production possibilities frontier.

Production Possibilities Frontier: Theory

In economics, the goal of the firm is to maximize profits and the goal of society is to maximize utility. The production possibilities frontier represents alternative outputs of two (or more) goods that can be produced with a fixed amount of inputs if those inputs are employed efficiently (Nicholson 1995). This locus provides the foundation for maximizing both the profits of the firm and social utility.

Production

Production is characterized by the conversion of inputs into outputs (Nicholson 1995). In production, the relationship between inputs and outputs can be formalized by a production function of the form

$$q = f(K, L, M, \ldots) \tag{1}$$

where q is the quantity of the good produced and K, L, and M are the factors capital, labor and other inputs used in the production of q. These inputs, applied efficiently, can generate an optimal level of q. Because firms are profit maximizers, the optimal level of q produced will likely be the one at which profit is maximized.

Equation 1 provides, for any conceivable set of inputs, possible combinations of inputs to create output. To determine the effect on q of an individual input, we can measure marginal productivity. The marginal product, MP, of an input is the additional output that can be produced by employing one more unit of that input. Mathematically,

$$MP_K = \delta q / \delta K \qquad (2)$$

$$MP_L = \delta q / \delta L \qquad (3)$$

$$MP_M = \delta q / \delta M \qquad (4)$$

Marginal productivity of an input depends on how much of that input is employed in producing the output. Diminishing marginal productivity is expected to occur in most production situations where those inputs that create the greatest output are used first and less-productive inputs are added later.

$$\delta MP_K / \delta K < 0 \qquad (5)$$

$$\delta MP_L / \delta L < 0 \qquad (6)$$

$$\delta MP_M / \delta M < 0 \qquad (7)$$

However, in most situations, cross-productivity effects will be positive. That is, as one input is increased (decreased), the productivity of other inputs will increase (decrease).

$$\delta MP_K / \delta L > 0 \tag{8}$$

$$\delta MP_L / \delta K > 0 \tag{9}$$

$$\delta MP_{L,K} / \delta M > 0 \tag{10}$$

Profit Maximization

Profit maximization, while commonly thought of in terms of financial gain, is a way to demonstrate economic efficiency. Profits are determined by the cost of producing an output versus the revenue gained from its production. A profit- maximizing firm will produce where marginal revenue equals marginal cost:

$$\pi\text{max:} \ \frac{\delta \text{TR}}{\delta q} * \frac{\delta q}{\delta input_i} = \frac{\delta TC}{\delta q} * \frac{\delta q}{\delta input_i} \tag{11}$$

if

$$MR = dTR/dq$$

$$MC = dTC/dq$$

then

$$\pi\text{max:} \ MR = MC$$

A firm's economic profits can also be expressed as a function of the inputs it employs:

$$\pi(K, L, M) = Pq - TC(q) = Pf(K, L, M) - (\mathrm{r}K + \mathrm{w}L + \mathrm{v}M) \qquad (12)$$

where P is the price of good q, r is the rent on capital w is the cost of labor, and v is the cost of other inputs. Hence, total cost increases as the cost of the individual inputs increases:

$$\delta TC / \delta r > 0 \qquad (13)$$

$$\delta TC / \delta w > 0 \qquad (14)$$

$$\delta TC / \delta v > 0 \qquad (15)$$

The marginal cost of the inputs is a function of their individual marginal costs,

$$MC_K = r / MP_K \qquad (16)$$

$$MC_L = w / MP_L \qquad (17)$$

$$MC_M = v / MP_M \qquad (18)$$

If more than one output is produced by a firm, because of the scarcity of resources, the inputs will be divided between the two outputs.

Frequently in natural resources, the production of two or more goods creates a situation of joint production. Joint production can occur for a number of reasons, one primary cause being that the two outputs share an allocatable fixed input, land (Shumway et al.

1984), as is the case with multiple use in natural resources. In this case, the cost of production of one output is affected by the production of the other output. This necessitates a method for establishing the tradeoffs between the two output in a manner that accounts for both the input requirements of the two goods but also the interaction that may occur between them.

Therefore, say that input *M* is the presence of y output and that the joint affect is negative. The marginal productivity of *M* in the production of *q* will be negative and the cross productivity effects will also be negative,

$$MP_M = \delta q \, / \, \delta M < 0 \tag{19}$$

$$\delta MP_{L,K} \, / \, \delta M < 0 \tag{20}$$

Not only does good *M* reduce the amount of other inputs available for the production of *q*, but the presence of good *M* also reduces the marginal productivity of the other inputs. More capital and labor must be employed in order to produce the same amount of *q* as was produced without any *M*. Holding all other inputs constant, an additional unit of *M* will decrease the amount of *q* produced. The marginal cost of labor and capital increases, hence, profit decreases.

Production Possibilities

Given the production function for each good, how inputs are employed in production will be determined by the marginal rate of transformation between the two outputs, the relative prices of the outputs, and social preferences. The production possibilities frontier is a general equilibrium model that establishes the first of these pieces.

In economics, alternatives in production are addressed by the production possibilities frontier. The slope of the PPF shows how one output can be substituted for another. Generally, the PPF is concave, all points along the frontier are potential loci of production. This concavity represents an increasing rate of product transformation for clockwise movements around the curve. Figure 2 shows that for output levels very near 100 units of Y, very little Y must be sacrificed for an additional unit of X. As more and more X is produced, an increasing amount of Y must be sacrificed.

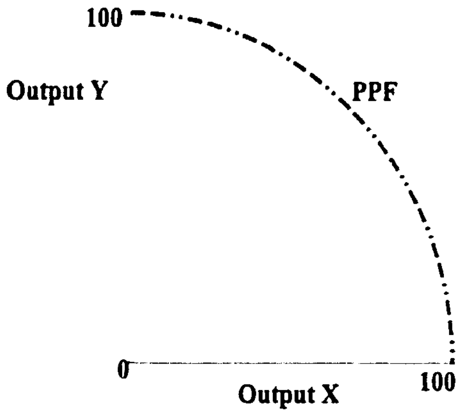

Figure 1.

Assumptions of Concavity

The most common rationale for the concave shape is the assumption that both goods are produced under conditions of diminishing returns. Increasing the output of X will raise its marginal cost while decreasing the output of Y will decrease its marginal cost. Another assumption for concavity is specialized inputs. This explanation is somewhat intuitive, as it is assumed that the inputs best suited for an output's production are employed first to produce that output. As more and more of that output is produced, inputs less suited for its production are employed. As a result, the marginal cost of production for that output is increasing. Since the rate of product transformation is equal to the ratio of the marginal cost of X to the marginal cost of Y, this will create a concave PPF. The last explanation for concavity is differing factor intensities. If production of each output requires labor and capital in different proportions, then the PPF will be concave (Nicholson 1995).

PREFERENCES AND THE PRICE LINE

As discussed previously, the goal of both profit and utility maximization can occur only with the tangency of three pieces of information: (1) the PPF, (2) social utility function, and (3) relative prices. Although this paper does not specifically address (2) and (3), discussion and interpretation of the PPF requires some background on social preferences and the price line.

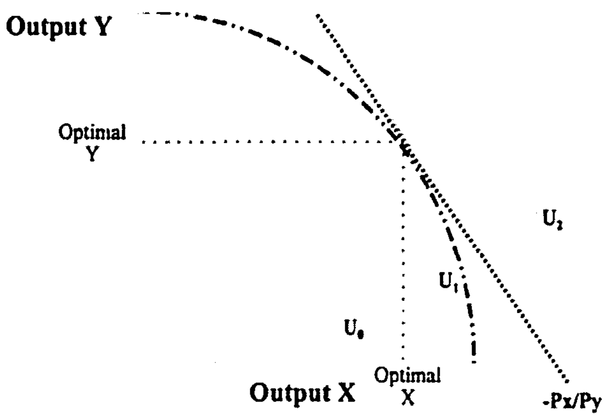

Figure 2.

Figure 2 illustrates how all three pieces come together to produce an optimal amount of the two outputs. While the entire area under the PPF is feasible for production, only production along the frontier is considered efficient. This occurs because, at any point interior to the frontier, more of one good or the other could be produced using the same amount of inputs.

Both an individual's and society's preferences can be represented by a utility function. The utility function relates to overall satisfaction and is affected by a number of factors, including consumption of commodities, personal experience, psychological attitudes, and culture (Nicholson 1995). In a two-good scenario, the general utility function is

$$utility = U(X, Y) \tag{21}$$

where X and Y are quantities of the two goods in question and other factors are held constant . The utility function describes those combinations of X and Y from which an individual derives the same utility, the curve representing these functions is called the indifference curve. The slope of this curve, *-dY/dX*, represents the rate at which an individual is willing to trade more of one good for another. Because of a diminishing rate of marginal substitution, as more of one good is substituted for the other, the opportunity cost of giving up that good increases. This results in a convex indifference curve.

One of the assumptions in economic theory is that everything else being equal, individuals prefer more of a good to less. An indifference curve corresponds to one level of utility. Higher levels of utility can be gained by increasing the potential combinations of X and Y. Each additional level of utility is represented by another indifference curve that is further from the origin than the one preceding it. Therefore, for an individual (or society) to maximize their welfare, they will want to be on the highest indifference curve possible. This curve will be the one that is just tangent to the PPF, the limit of the producer's capability. In figure 3, three indifference curves are shown, but for the output bundles produced by the PPF, line U_2 achieves the highest level of utility.

The third piece of information, the price line, is determined by market mechanisms. Both the demand of consumers for a goods at varying prices, and the amount producers are willing to supply at these prices result in an equilibrium price. The price line is frequently referred to as society's budget constraint and is commonly written as

$$Budget = P_x X + P_y Y \tag{22}$$

The slope of the price line is determined by the relative values of the two outputs, and is shown by the line $-P_x/P_y$. If output X is more valued than output Y, the slope of the price line will steepen, causing more of X to be produced.

Tangency of the PPF, the preference curve, and the price line occurs at where the slopes of the functions are equal:

$$\frac{MC_x}{MC_y} = \frac{-dy}{dx} = \frac{-P_x}{P_y} \tag{23}$$

Production Possibilities Frontier: Application to Natural Resources

Natural resource management involves planning for multiple uses. These uses can be defined as outputs in a production process. Resource managers must decide what combinations of outputs to produce, the cost-effectiveness of these combinations, and on what specific areas to produce them (Loomis 1993). Efficient use of inputs is necessary for optimal management planning. With the many demands placed on natural resource managers, a less than optimal employment of resources results in an unnecessary loss of habitat or recreation experience. Efficiency has become so important that one requirement of the regulations guiding forest planning is that the most economically efficient set of management activities should be chosen to achieve the goals of the forest plan (Schweitzer et al. 1990). Clawson (1978) discusses three types of information required for optimum multiple use management: (1) an inventory of resources, (2) a production-interaction or tradeoff function between resources, and (3) preference ratings or valuation functions. The inventory of available and potential resources establishes the production function for each good, the tradeoff function can be represented by the PPF, and preference ratings determine the location along the PPF that production should occur.

Joint production theory and the PPF have been used in a natural resource setting to theorize efficient allocation of AUMs between livestock and elk (Workman 1986). The PPF has also been used represent alternatives in production between wildlife habitat and mineral extraction (Loomis 1993), and timber versus commercial salmon and steelhead production (Loomis 1988).

Workman (1986) hypothesized a complementary-competitive relationship (figure 3) between production of livestock and elk forage. It was thought that careful cattle grazing on grasses in early spring allows forbs to better compete for later use by elk. However, under a heavier livestock grazing regime, elk forage is actually reduced.

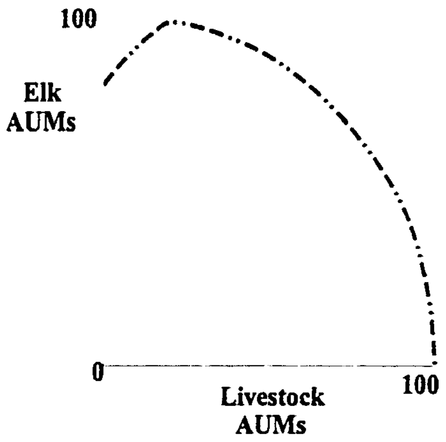

Figure 3.

Loomis (1988, 1993) used a habitat model that related watershed characteristics to carrying capacity (Heller et al. 1983) and then translated the change in carrying capacity to the effect on fish numbers to establish a PPF for alternative production of timber mbf or salmon and steelhead. This relationship is illustrated in figure 4.

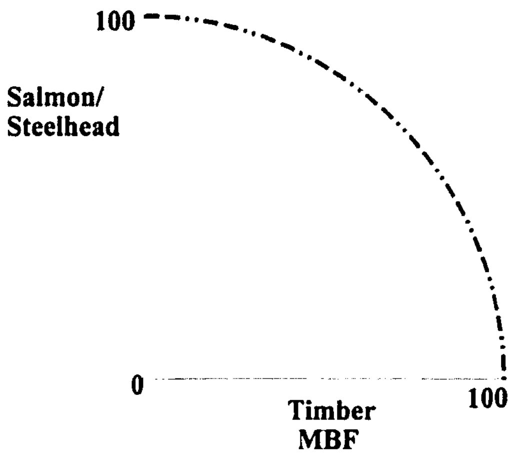

Figure 4.

For the AUM example, establishing a PPF is fairly straightforward. If land area is fixed, forage quality and quantity can be quantified, as can the potential for improvements. The allocation of AUMs to either elk or livestock production can be completed according to the number of AUMs desired for each species.

The timber-fish example is a more complicated. There is more uncertainty regarding the effects of timber harvesting on fish populations. However, after construction and application of the two biological models, a physical link between harvesting practices and fish survival was established.

Production Possibilities Frontier: Wildlife and Recreation

If recreation and wildlife are viewed as two outputs in production, then it is reasonable to assume that the PPF model can be used to represent alternative combinations of these two outputs. However, applying the PPF to recreation and wildlife is difficult due to the ambiguity of the relationship these two outputs have with one another. While recreation can cause erosion, soil compaction, and loss of vegetation, the effect it has on wildlife is believed to be more behavioral and physiological (MacArthur et al. 1982) than physical. Human presence can cause wildlife to avoid or abandon sections of habitat, affecting both fecundity and survival (Knight and Miller 1996). Because recreation may not reduce much actual habitat, a behavioral model that explains a reduction in effective habitat is needed.

Defining the Inputs

As with all production decisions, the inputs available in the production of wildlife and recreation include land, labor, and capital. Labor is the staffing available for trail design and maintenance, habitat improvements, environmental interpretation and instruction, etc. Land and capital are usually grouped together under the name *capital*, and throughout this paper references will be made to labor and capital, assuming land is included. For explanatory purposes here, I will define all three. Capital is that equipment and facilities used to make improvements, provide recreationists with rest areas, or to make improvements. While all inputs must be employed efficiently in order to maximize the production opportunities, land may be the most significant input in the production of these two outputs because outputs are land-intensive. Land is required for habitat of wildlife species, and by recreationists for hiking, biking, climbing, rafting, etc. To use the PPF, all inputs must be fixed in the short run. For the production of recreation and wildlife, it is reasonable to define the short term as a season. Staffing resources, area size, and budgets for capital improvements are likely to be fixed during a season. Additionally, habitat quality, wildlife requirements, and recreational distribution and activity types can vary considerably between seasons and analysis is further simplified by fixing the shortened time period.

Defining the Outputs: Wildlife

Most research into the effects of human disturbance on wildlife species measures flight distances, alert behaviors, and interruption of feeding (Stalmaster 1998, Knight and Miller 1996). A few studies have attempted to measure the cost of these disturbances in terms of energetics (Cassirer 1992). Other research has focused on denning success, nest abandonments, and fledgling survival (White and Thurow 1985). However, little research has been completed extrapolating these results and the cumulative impacts of recreation into the long term survival of a species.

While measuring recreation impact on actual population numbers would be ideal, because of concern over the impact of harassment experiments on sensitive species and the political unpopularity of experiments which harass less-sensitive wildlife and measure mortality, it is usually infeasible to use actual wildlife numbers.

While the physical impact recreation has on a landscape may be restricted to a relatively narrow width of trail or constrained to a campground or parking area, human disturbance creates a zone of influence around the activity that exceeds the physical delineation of the recreation area. Knight and Miller (1996) describe varying sizes of a zone of influence for hikers with and without dogs, on and off-trail. The zone of influence is also determined by the sensitivity of the wildlife species of concern. For the mule deer, the zone of influence of a hiker on a trail is limited to the trail itself. If that hiker were with a dog, the zone of influence is approximately 60 meters in diameter. For a hiker off-trail, the zone of influence is approximately 40 meters in diameter, if that hiker had a dog, the zone of influence increases to over 120 meters in diameter. For other wildlife species, the concept of zone of influence can be extrapolated to distance to flight as with eagles and elk (Stalmaster 1998, Cassirer 1992), a species' avoidance of a particular area as with bears (Kasworm and Manley 199X), or nest abandonment (White and Thurow 1985).

A zone of influence effectively eliminates a portion of habitat from use by a wildlife species for a certain period of time. The amount of this reduction and the size of the zone of influence is determined by the recreation activity (type of use, duration, frequency), the geography of the area (habitat type, size, diversity) and the wildlife species in question. For the production of wildlife and recreation, it is the zone of influence that will likely be the factor that contributes to the jointness between the two outputs.

Because it is known that the success of a wild population is a function of its habitat (USFWS 1980), production of habitat is a reasonable proxy for the production of wildlife. While behavioral and physiologic responses are difficult to extrapolate to a population's success or failure, habitat may be easier. Habitat is the place occupied by a specific population and can often be characterized by a dominant vegetation or physical characteristic (USFWS 1980). Habitat-animal relationships have been extensively studied for many species (USFWS 1980), and although population dynamics cannot always be predicted by habitat quality and or quantity, it is a good measure to assess a population's potential.

Therefore, for a species and area of concern, how much habitat is affected by recreational pressure will be determined by the type and intensity of recreational use. One output then becomes the percentage of habitat (effectively) available.

It is important to note that the output is species and area specific due to the variability in reactions to human disturbance both between and within species. This, however, is not as constraining to a manager as it might seem. If there is a threatened or endangered or especially sensitive species in the resource area, then the impacts of recreation on these species will likely be a critical concern. Or, if a manager feels that the presence of a certain wildlife species is a good indicator of overall ecosystem health, managing habitat for that species may serve as a proxy for the habitat of several species.

Defining the Outputs: Recreation

The recreation output is most easily defined by user days. As visitor days increase, so does the impact on wildlife habitat. The impact recreation has on a wildlife species is determined by a number of variables, including the activity type, intensity, predictability, timing, and location (Knight and Cole 1995). Measuring visitor days requires incorporation of these variables; while ten hikers per day and ten motor bikes per day result in the same number of visitor days, they are not likely to have the same impact on wildlife habitat.

Production Relationships

Inputs in the production of recreation include the land or water area on which the activity would occur, facilities including trails, campgrounds, and rest areas which accommodate the experience and the labor and capital required to provide and maintain the experience.

When recreation and wildlife share an input, such as land area, the potential for joint production exists. Therefore, the production function for wildlife should include a variable accounting for the amount of recreation present. The reverse, however, is not the case for this paper. While it is has been established that a recreation may have a negative impact on wildlife, the effect wildlife has on recreation may be either complementary or competing, depending on the situation and wildlife species in question. So while the production of the *recreation experience* would include a variable for wildlife, for simplicity this paper assumes the goal is to produce only visitor days, and will assume the production function is not affected by wildlife. However, this model does not neglect the complementary relationship that may exist between the recreational experience and wildlife, as this can be expressed by the demand function that will be translated into the shape and direction of the indifference curves established by the utility function.

THEORETICAL DEVELOPMENT: EXPECTED RESULTS

Concavity

Much literature suggests that there is a curvilinear relationship between use intensity and wildlife populations (Kuss et al. 1990). It is expected that if inputs are employed efficiently in the production of both recreation and wildlife, the PPF will assume the traditional concave shape shown in figure 5. If the production of both goods falls under at least one of the requirements for concavity, diminishing returns, specialized inputs, or differing factor intensities, then the PPF should retain a concave shape.

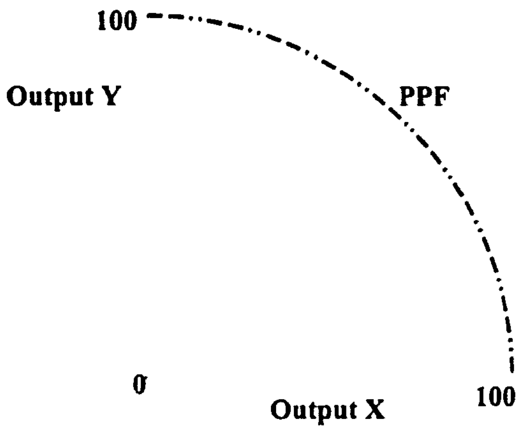

Figure 5.

Of the three requirements, differing factor intensities will most often be the cause of concavity. While both recreation and wildlife are land intensive, it is reasonable to assume that wildlife are relatively more land intensive than is recreation.

Example

Consider, for example, 8,000 acres of habitat are required to maintain a healthy population of a particular wildlife species. There are 10,000 acres available, through which run a number of trails totaling 10 miles. It has been determined that the zone of influence around the trail is 200 meters, therefore the total acres occupied by recreation is 800. For the season of concern, there are 1,000 hours of man-hours available for trail and facility maintenance as well as for habitat improvements. The manager of the area knows that trail maintenance on these 800 acres is expected to occupy 500 labor hours.

$$\textit{Total K available} = \textit{10,000 acres} \quad (24)$$

$$\textit{Total L available} = \textit{1,000 hours} \quad (25)$$

$$L_{rec} = 500\ hours \tag{26}$$
$$K_{rec} = 800\ acres \tag{27}$$

Under these conditions, then there would be 9,200 acres and 500 labor hours allocated to wildlife habitat. Therefore, the capital to labor ratio would be

$$Recreation\text{: } 800K/500L = 1.6 \tag{28}$$
$$Wildlife\ Habitat\text{: } 9200K/500L = 18.4 \tag{29}$$

The example shows that even though both recreation and wildlife are capital intensive, wildlife are relatively more capital intensive than recreation. Now say that since the wildlife species needs only 8,000 of the 10,000 acres, suppose a resource manager decided to construct additional trails so the total number of acres used by recreationists occupied 2,000 acres. If 500 labor hours were required for 800 acres of recreation, then, assuming an average of .63 hours per acre of recreation, then 2,000 acres of recreation would require 1,250 hours of labor. Since this is not possible, assume an increasing marginal rate of productivity for labor so that the number of hours required for the new recreation is somewhat less than 1,000. For recreation to become more capital intensive than wildlife, the number of labor hours devoted to trail maintenance and facility repair would have to be less than 200. Even with the increasing productivity of labor, with more than 20 miles of trail to maintain, this is unlikely to occur.

Non-Concavities

If none of the three requirements for concavity are met by the production of both goods, or if differing factor intensities exist but either recreation and/or wildlife exhibit increasing returns to scale in production, non-concavity of the PPF can occur. Because a PPF represents alternative output combinations if inputs are employed efficiently, a non-concave PPF may result. This PPF would not represent the potential of a true PPF because inputs are not being employed efficiently[1]. Increasing returns to scale indicate that the rate of product transformation from recreation to wildlife habitat decreases with a clockwise movement along the curve. The rate of product transformation decreases in this manner because the marginal cost of producing one good falls as more of that good is produced.

$$RPT_{w,r} = MC_w/MC_r \tag{30}$$

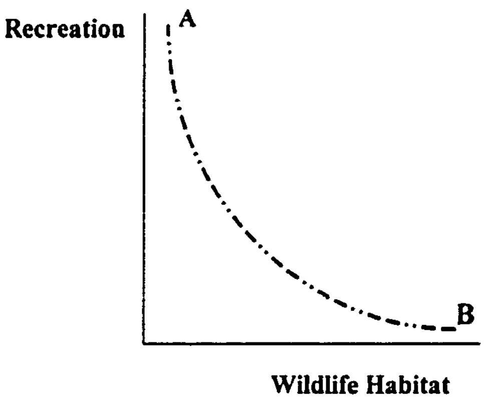

Figure 6.

1

All points along a PPF represent tangencies of production isoquants for the two outputs (Nicholson 1995). A non-concave PPF may indicate that production is occurring at a point of non-tangency, hence, using the same inputs, more of one good could be produced without reducing the production of the other output.

Intuitively, a convex PPF like the one shown in figure 6 for the allocation of wildlife or recreation is not unreasonable. If the habitat area for a particular wildlife species is too small or of too poor quality to maintain a healthy population, a wildlife species may be very sensitive to even a small amount of introduced human disturbance. The inputs may be better used to improve wildlife habitat than to provide an additional unit of recreation. Alternatively, if this area is already experiencing a high degree of recreational intensity, allocating small amounts of land to species conservation will have little beneficial effect.

Example

Suppose a manager has been charged with restoring the habitat of a 1,000 acre natural area for the use of the Wyoming Pocket Gopher, endemic to Sweetwater and Carbon counties, Wyoming. At present, the area is used extensively by off-road vehicles, and although the area could be ideal habitat for pocket gophers, there are currently no gopher residents.The manager has consulted with biologists who have determined that a pocket gopher colony needs at least 50 habitat units/acre in order to survive. The manager has evaluated the natural area, and with proper care, the area could yield a maximum of 100 habitat units per acre. A graph of the problem is shown in figure 7.

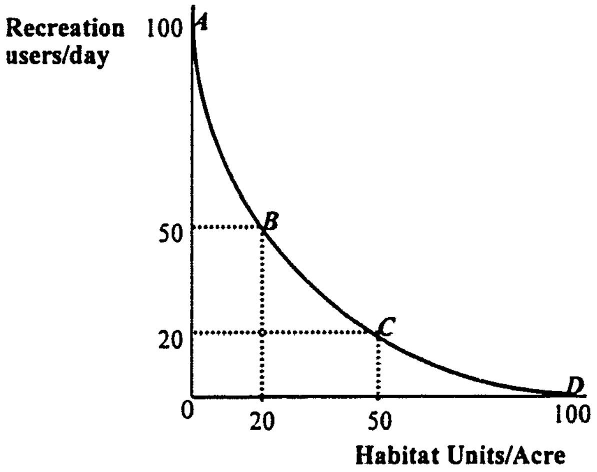

Figure 7.

At present, the natural area is at point A, 100 recreationists/day. The manager immediately allocates fifty percent of the area, 500 acres, to gopher habitat, reduces recreation to 50 recreationists/day but finds he gains only 20 habitat units/acre for the gopher, point *B*. This occurs because at such high levels of recreation, the marginal cost of an additional habitat unit is extremely high. The manager finds that in order to maintain 50 habitat units/acre, point *C*, there can only be 20 recreationists/day. Between *B* and *C*, the marginal cost of allocating acres to gopher habitat units or recreation is about equal. Between *C* and *D*, however, the marginal cost of an additional unit of gopher habitat is very small--very little recreation must be given up in order to provide a great deal more habitat.

Efficiency

Even though the manager in the above example may desire only 50 habitat units/acre, this is an inefficient point in terms of input employment. With a concave PPF, all points along the frontier are potential loci of production. However, this is not the case with a convex PPF. In economics, a convex PPF forces a corner solution (which corner is determined the slope of the price line, discussed later in this paper) in the production of the two goods.

A convex PPF has significant implications for managers. For particularly sensitive species, a corner solution indicates that the inputs, land, labor, and capital, are best employed at either maintaining all of the area for wildlife (and no recreation) or at providing as much recreation as possible without concern for the impacts to wildlife species (commonly referred to as *sacrifice areas*).

Concave/Convex PPFs

It is possible that a PPF representing recreation and wildlife production could be concave in one part of its range and convex in another, depending on what level of each output is being produced. This relationship can be characterized by heavy impact at low use levels and little additional impact as use continues to increase or by relatively little impact for low use levels and high impact at mid-levels.

The PPF shown in figure 8 may occur if a wildlife population is particularly sensitive to the first units of recreation introduced, but, after some time, habituation occurs amongst a portion of the species and they are able to tolerate additional units of recreation. In terms of efficiency, any point between *A* and *B* is a potential locus of production, but between *B* and *C*, only *B* or *C* are potential points of production.

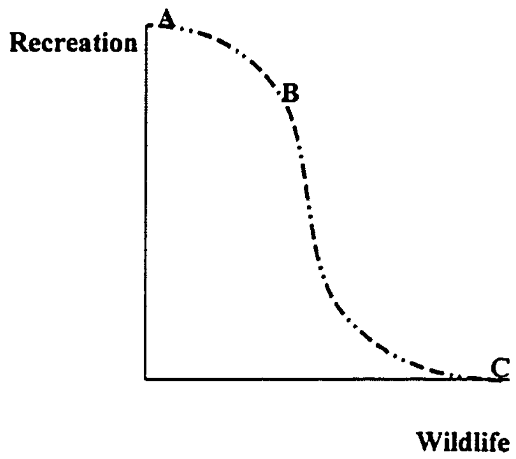

Figure 8.

Additionally, a PPF may be concave with initial introduction of recreation, show in figure 9 and later reach a threshold at which even small additions of recreation begin having a large negative effect on the species. At some point, the population may become so reduced that those species remaining (if any) may be tolerant of even the most intense recreational use. In terms of efficiency, any point including and between *B* and *C* is a potential loci of production, however, to the left of *B*, only *A* is efficient. This sigmoidal shape has been found with bald eagle flushing distance and avoidance of habitat (Stalmaster 1998, Monopoli and Anderson 1991).

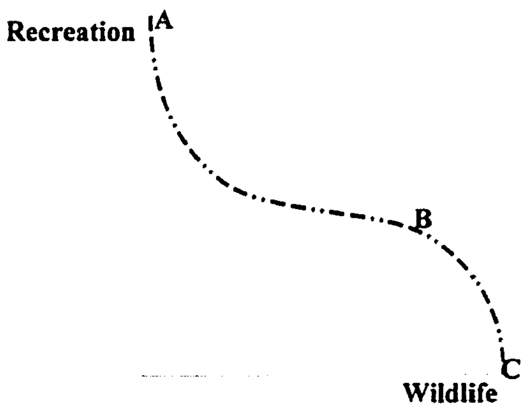

Figure 9.

Linear PPF

A linear PPF indicates that the first unit of recreation introduced has the same impact on wildlife habitat as the *nth* unit of recreation. In this case, the rate of product

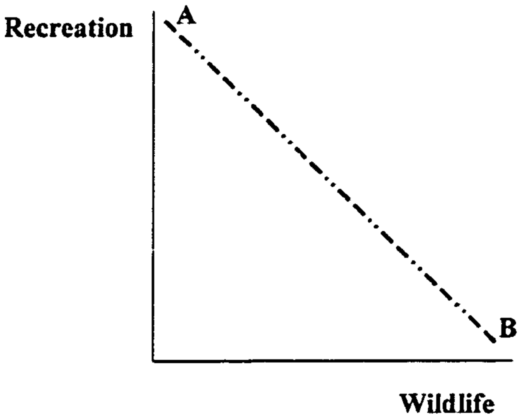

Figure 10.

transformation is constant throughout the length of the PPF.

A linear PPF could occur if the production relationship exhibits constant returns to scale and labor and capital are used in the same proportions. Any point along a linear PPF could be considered efficient, however, for any point between A and B to be a loci of production, the price line would be coincident to the PPF. This would imply that both outputs are equally valued by the consumer. If the price line held any other slope, the resulting tangency of the price line and the PPF would be a corner solution. A linear PPF is very sensitive to relative prices and values, as a slight change in the slope of the price line can result in a complete re-allocation of inputs from the production of one output to the other.

Non-Concavities and Inputs

A PPF that is non-concave through any amount of its reach indicates that the effect recreation is having on wildlife is larger than it could be. Sensitivity of a wildlife species to the first incremental amount of recreation may indicate that the recreation is being produced in an inefficient manner. A non-concavity indicates to a manager that the marginal productivity of the natural resource area's inputs is lower than it could be. A sigmoidal curve may imply that the combination of inputs that are efficient at one level of production are not efficient at all levels of production. This could be caused by the jointness variable in the production of wildlife and increases in efficiency may be achieved by re-allocating existing inputs.

Joint Production and Non-Concavities

The PPF represents alternative outputs of two goods when all inputs are fixed. However, with joint production, if one output is an input to another output, then this will not be the case.

$$\text{Joint Production Function: } Output_1 \; f(K, L, Output_2) \qquad (31)$$

Equation 31 shows that the production of output 1 is a function of inputs which include output 2, recreation. As the level of production of output 2 changes, its affect on the production of output 1 will vary. Hence, all inputs in the production of output 1 are not fixed.

With all other inputs fixed, non-concavities in the shape of the PPF could be attributed to effects from the unfixed variable in the production of one of the outputs. In the production of wildlife, that variable is recreation.

$$Wildlife \; f(K, L, Recreation) \qquad (32)$$

The marginal productivity of capital and labor for the production of wildlife may be affected by the presence of recreation[2]. Non-concavities in the PPF indicate a change in the marginal productivities of the inputs that is greater than expected.

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2 When these affects occur outside of a market, they are commonly referred to as externalities.

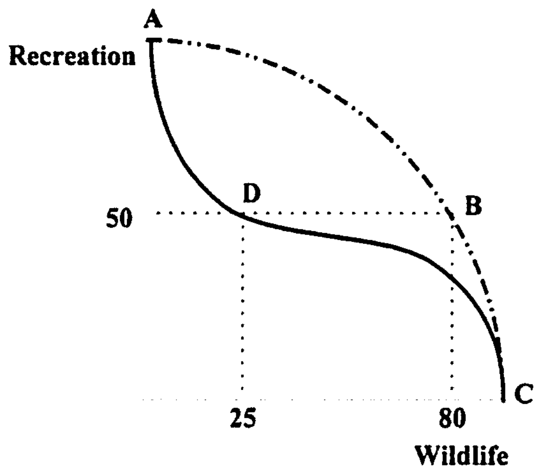

Figure 11.

Combinations of output occurring in convex sections of the PPF indicate that capital and labor are not being employed to their maximum efficiency. Figure 11 shows how non-concavities of the PPF affect the potential allocation of the two outputs. With a concave PPF, all inputs can be employed to produce 50 units of recreation and 80 units of wildlife. However, with a convex PPF, if 50 units of recreation are produced, only 25 units of wildlife can be generated with the remaining inputs.

At very high levels of recreation, a concave PPF would suggest that a small amount of recreation could be given up for a large amount of wildlife habitat gain. This shows that at high levels of recreation, the marginal productivity of the inputs is higher for wildlife than for recreation. A curve that is convex where the proportion of outputs allocated to recreation is relatively high indicates that the effect of the joint variable on wildlife is also high, thus lowering the marginal productivity of inputs for the production of wildlife. This is consistent with the notion that as recreation increases, so does the impact of the jointness. A curve that is convex where the proportion of outputs allocated to wildlife is relatively high indicates that the marginal productivity of inputs employed towards additional wildlife is increasing. This could occur because where recreation is low, so is the impact of the jointness.

Convexities can show up at any point along the PPF. Where they occur and to what extent will likely be determined by the species affected, as the production function for wildlife and the strength of a joint variable will be species specific.

Production possibility frontiers that display convexities may be demonstrating a *threshold effect,* where at some point in the allocation of recreation and wildlife, the effect of the joint variable, recreation, begins to have dramatic effects on the marginal productivity on the production of wildlife. This may occur with the first addition of recreation and lessen with subsequent additions, or may occur at a mid-level of recreation and increase with additional units of recreation.

Changes and Shifts

Since the PPF is the locus of production alternatives of two goods under a fixed set of inputs, improvements or disimprovements in their effectiveness can result in shifts or changes in the shape of the PPF. The PPF can shift outward with technological advances, creating more potential output for the same amount of inputs, or it can shift inward with technological impediments, resulting in less potential output for the same amount of inputs. Also, if a technological change affects only one of the outputs, the curve can stretch upwards or downwards without changing its intersection with the unaffected axis.

In the production of recreation and wildlife, if the PPF is concave throughout, advances in the use of inputs could shift or alter the shape of the PPF. If, however, the PPF is convex or concave/convex, improvements in input employment will change the shape of

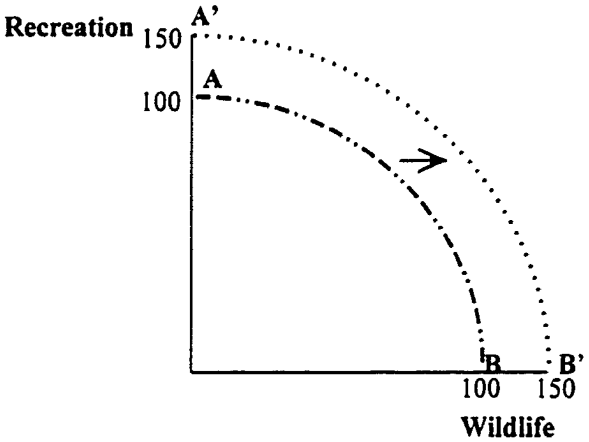

Figure 12.

the PPF while advances in technologies will shift the PPF. In the production of wildlife, a technological advance might be a habitat improvement project providing more cover or additional forage.

For the production of recreation, a technological advance may be lower-impact treads on hiking boots. Another advance may be environmental education that encourages visitors to remain on the trail. Better use of capital in trail placement can also buffer wildlife from recreationists, reducing the affected zone of influence or reducing the effect on the zone of influence. A trail through a riparian area may have a greater impact on wildlife than a trail along a hillside (Colorado State Parks 1998). This also may allow a greater number of recreationists with a lessened impact on wildlife (as shown in figure 13).

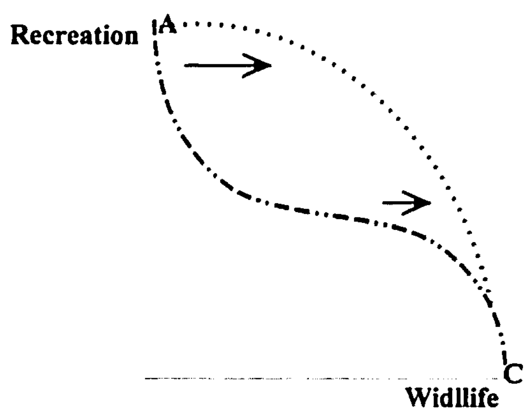

Figure 13.

A species' habituation to human disturbance can also cause the PPF to become more concave. Elk in Rocky Mountain National Park maintain very healthy herds amidst a high degree of human presence (Schultz and Bailey 1978).

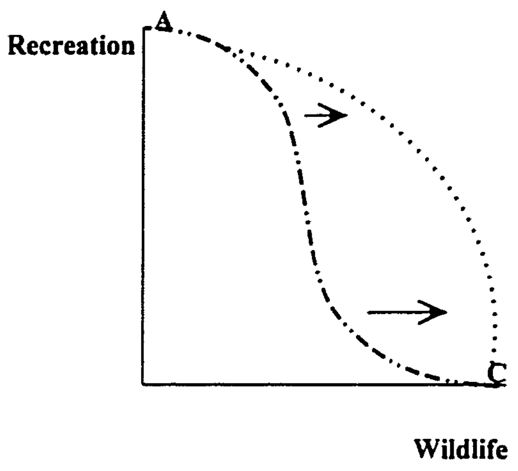

Figure 14.

EMPIRICAL EVALUATION: THE PPF FOR RECREATION AND WILDLIFE

To be useful, the PPF should be applicable to real world managerial situations. The PPF proposed for recreation and wildlife, although interesting in its theoretical implications, is designed to be a useful managerial tool. There are substantial data addressing human impacts on wildlife and the goal is to find existing data that could be applied to the model. This would demonstrate the model's use as decision-making tool that could be supported by existing science. To test the model, I chose two dissimilar species, the grizzly bear, *Ursus arctos horribilis*, and the bald eagle, *Haliaeetus leucocephalus*.

These two species were chosen for a number of reasons. First, their behavior and physiology have been studied extensively. Their responses to human disturbance have been relatively well documented, even though the data from most of these studies was not appropriate for this model. Additionally, they are both considered to be sensitive to human disturbance and their populations are endangered (although the eagle is scheduled to be de-listed this year). Lastly, they were chosen because the cumulative impacts of human disturbance has been addressed with each species.

Cumulative Effects Analysis

Cumulative effects are perturbations in a system that occur closely enough in both space and time that their ramifications may become either additive or synergistic (Weaver et al. 1985). Decreases in water quality as a result of accumulated pollution, changes in wildlife populations due to certain harvesting practices, and habitat fragmentation resulting from multiple developments, are all examples of cumulative effects (Orians et al. 1986).

Cumulative effects modeling quantifies how human activities affect the environment in both space and time and how these changes may influence wildlife (Christensen 1985). Wildlife are known to be susceptible to a number cumulative effects resulting from human disturbance, including timber harvesting, road-building, and recreation. One significant aspect of cumulative effects is the potential for non-linearity. Ecological sciences often refer to a *threshold*, the point where a maximum/minimum value is reached, and if exceeded, causes the impact to take on new importance (Geppert et al. 1985). The effect of human disturbance on wildlife is seldom a linear function;

cumulative impacts from one or a number of sources can lead to a population collapse (Orians et al. 1986). The PPF model allows managers to employ cumulative effects modeling to address the additive and synergistic effects of disturbances (Weaver et al. 198x) and identify thresholds that may occur with the addition of recreation.

Cumulative Effects and the PPF

Cumulative effects analysis can be useful in addressing joint production because the model allows assessment of levels of perturbation to determine the effect they have on the species of concern. Cumulative effects modeling first determines the habitat components that are relative to a wildlife species. The process then tracks activities that potentially affect habitat by reducing available space and foods or by influencing the time and manner in which other related activities can be accomplished (Christensen 1985). Although each activity taken independently may be relatively innocuous, the synergistic effects may be significant.

Therefore, not only do the recreation activities themselves require labor and capital (such as the actual width and length of a trail), but they effect the productivity of labor and capital that are employed for production of wildlife habitat. A general production function for wildlife habitat then, may have the form,

$$Habitat\ f(food,\ cover,\ diversity, \ldots, recreation\ impact) \qquad (33)$$

The impact recreation has on the production function variables, L and K is a function of displacement, *Recreation impact f(L, K, displacement factors)* (34)

And displacement is a function of a number of disturbance factors,

Displacement f(disturbance type, nature, intensity, duration,...) (35)

Cumulative effects models evaluate potential displacement by quantifying the effects of each of the variables which are described in the function. How each of these are quantified depends on the wildlife species of concern and the geography of the area. Because this effect can be quantified, so can the reduction in habitat resulting from the presence of displacement and the resulting decreases in the marginal productivities of capital and labor can be estimated.

A cumulative effects analysis can be designed so that the disturbance of least impact is introduced first and that additional disturbances are added according to their strength. This structure allows for that activity with the lowest marginal cost and highest marginal benefit to be added first. With a concave PPF, the first unit of recreation added will cost very little in terms of wildlife. Subsequent additions of recreation will have a larger and larger impact on wildlife species as the marginal rate of transformation increases.

Cumulative effects that result in a non-concavity show that the addition of one unit of an output can cause a significant decrease in the production potential of the alternative output. This can be described as an inefficient employment of resources, as the marginal value product of the inputs is reduced in transferring their employment to the production of that output.

Grizzly Bear

Cumulative effects models (CEM) of human disturbance on grizzly bears were extensively developed in the 1980's (Weaver et al. 1985). Since then, CEM has been refined and introduced into a GIS-based system. The CEM model for grizzly bears includes three submodels: habitat, displacement, and mortality. The habitat and displacement submodels interact to quantify a measure of habitat effectiveness, which will become the x-axis on the PPF. The mortality submodel is not used in this analysis as it does not relate to habitat effectiveness.

The habitat submodel uses three variables, (1) food and cover, (2) habitat diversity, and (3) seasonal equity to calculate a habitat value for a bear management sub-unit. A subunit is the size of a yearly home range of a female bear (Barber 1999), usually 10,000 to 90,000 acres (Barber 1999, Weaver et al. 1985). The first two variables are quantified according to their potential use by grizzly bear during a particular season. The values of the variables are determined using information from *Forest Habitat Types of Eastern Idaho-Western Wyoming* (Steel et al. 1983). The quantified habitat values are categorized into six levels of value to the grizzly, very low, low, low moderate, high moderate, high, and very high. The number of habitat units available are calculated by multiplying the habitat value by the number of acres in the subunit.

The displacement model incorporates four variables, (1) location relative to hiding cover, (2) nature of activity, (3) type of activity, and (4) disturbance intensity. These variables are used to calculate a disturbance coefficient, a number between 0 and 1. A coefficient close to zero indicates a high amount of disturbance, while coefficients close to one indicate a low amount of disturbance. Further explanations of the variables described can be found in the appendices.

The disturbance coefficient generated from the displacement model is multiplied by the habitat value to obtain a measure of habitat effectiveness. Figure 15 shows the construction of each model and how the individual resulting values are used to calculate habitat effectiveness.

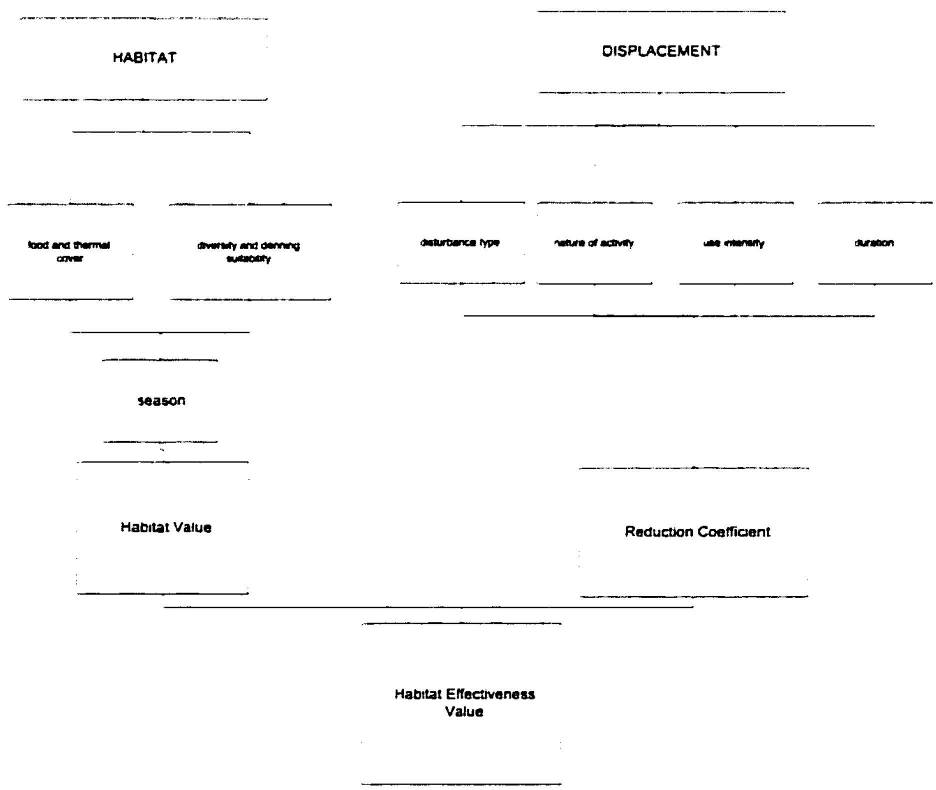

Figure 15.

Cumulative Effects Modeling: Grizzly Bear

The habitat effectiveness value is multiplied by the number of acres in the zone of influence and the habitat value is multiplied by the remaining undisturbed acres. These values are added together and the result can then be compared to the habitat units available without any disturbance.

$$\textit{Habitat Value } f(\textit{cover, food, diversity, season}) \tag{36}$$

$$HV * Acres = \textit{Total Habitat Units} \tag{37}$$

$$\textit{Reduction Coefficient } f(\textit{disturbance type, nature, intensity, duration}) \tag{38}$$

$$HV * RC = HE \ (\textit{habitat effectiveness}) \tag{39}$$

$$HE * \textit{Acres Affected} = \textit{Reduced Habitat Units} \tag{40}$$

$$HV * \textit{Remaining Acres} = \textit{Remaining Habitat Units} \tag{41}$$

$$\textit{Reduced HU} + \textit{Remaining HU} = \textit{Habitat Units after disturbance} \tag{42}$$

The Shoshone National Forest in Cody, Wyoming has been refining a GIS-based CEM for use in southern Montana and northern Wyoming. Kim Barber, head of the CEM group, provided an abbreviated set of data that was applied to the CEM and the results were used to create a PPF. Data for the CEM on the Shoshone were gathered from several sources. The coefficient derivations for habitat value and disturbance are from Mattson (1998). Disturbance coefficients were calculated from previous research obtained from the Yellowstone area (Barber 1999) and the calculations of the disturbance coefficients can be found in Mattson (1998).

Table 1.

Acres for Allocation: 10,000		
Habitat Submodel		
Variable	**Data Provided**	**Variable Values**
food and cover	high cover	Habitat Value = 42
habitat diversity	marginal diversity	
seasonal equity	May 15- July 15 (estrus)	Days in season = 61

Table 1 illustrates the data provided for the habitat submodel which includes a subunit of an assumed 10,000 acres with a grouse whortleberry habitat description (subunits usually include more than one habitat descriptor, but only one was used for simplification). It has not been burned or harvested in the past 20-30 years and is not winter range for elk or bison. The season is estrus, May 15-July 15, and the categorical value for this period of time is low–the bears are not deriving many calories from this habitat during estrus (Barber 1999).

Table 3 shows the disturbance activities that occur on this 10,000 acres, disturbance types are defined in table 2. For simplification, it was assumed that these activities do not overlap.

Table 2.

KEY	
Disturbance Type	**Definition**
DNML/DNMH	dispersed non-motorized low/high use (high use: >20 each-way parties per week low use: <3-19 each-way parties per week) example: off-trail recreation such as hunting or berry picking.
DML/DMH	dispersed motorized low/high use. example: off-road vehicles
LNML/LNMH	linear non-motorized high/low use. example: hiking on-trail, mountain biking on-trail
LML/LMH/LMI	linear motorized high/low/incidental use (incidental use: < 3 each-way parties per week) example: vehicle traffic
PNMD/PNM24	point non-motorized diurnal/24-hour use example: campgrounds, summer homes, trail heads, picnic areas
PMD/PM24	point motorized diurnal/24-hour use example: drilling operations, timber harvesting, generator sites

Table 3.

Displacement Submodel

Disturbance Type	Zone of Influence (acres)	Average Groups/Day	Days Disturbed
DNML	13.00	1.43	23.00
DNMH	13.00	4.29	30.00
DNMH	11.10	4.29	45.00
DNML	497.00	1.43	30.00
DNMH	497.00	4.29	15.00
LML	71.56	1.43	15.00
LNML	71.56	1.43	61.00
LMH	119.27	4.29	30.00
LML	47.71	1.43	61.00
PNMD	194.00	4.29	45.00
LNML	143.10	1.43	61.00
PNMD	194.00	4.29	61.00
LNMH	167.00	4.29	45.00
LNMH	167.00	4.29	61.00
LNML	668.00	1.43	30.00
LML	1,860.60	1.43	36.00
LMH	3,578.00	4.29	61.00

Formulating the PPF

The CEM was run holding all variables in the habitat submodel constant. With no disturbance on the 10,000 acres, the number of habitat units available were 420,000.

$$HU = Acres * HV \tag{43}$$
$$HU = 10{,}000 * 42 = 420{,}000 \tag{44}$$

Each disturbance type that occurs on this 10,000 acres was ranked according to how much it reduced the total habitat units.

After ranking the disturbance types, each activity was iteratively added to the landscape and its impact on habitat units was recorded. Results were tabulated and then graphically displayed. To facilitate ease of understanding, a percentage was used to represent the reduction habitat available with the addition of human disturbance.

Results

The results of the iteratively run CEM are shown in table 4 and are demonstrated graphically in figure 16.

Table 4.

Disturbance Type	HUs	Sum Reduced HUs	Percent of Total
NO DIST	420,000.00	0.00	100.00
DNML	419,997.94	2.06	100.00
DNMH	419,992.57	7.43	100.00
DNMH	419,985.69	14.31	100.00
DNML	419,883.03	116.97	99.97
DNMH	419,780.37	219.63	99.95
LML	419,196.52	803.48	99.81
LNML	418,053.78	1,946.22	99.54
LMH	416,698.79	3,301.21	99.21
LML	415,115.78	4,884.22	98.84
PNMD	413,132.21	6,867.79	98.36
LNML	410,848.33	9,151.67	97.82
PNMD	408,159.49	11,840.51	97.18
LNMH	404,640.99	15,359.01	96.34
LNMH	399,871.47	20,128.53	95.21
LNML	394,628.22	25,371.78	93.96
LML	358,194.62	61,805.38	85.28
LMH	275,542.82	144,457.18	65.61

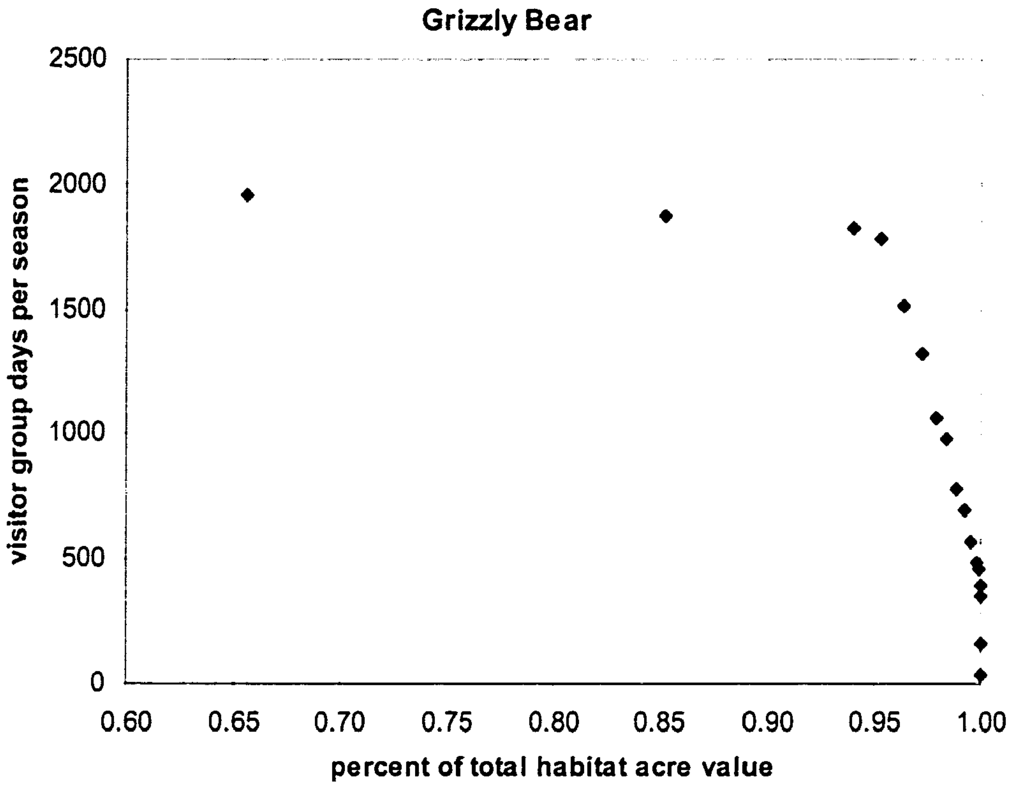

Figure 16.

Interpretation

Results shown in figure 16 indicate that production of alternative outputs of grizzly habitat and recreation group days follow the expected shape of the PPF. Overall, the recreation activities occurring on the landscape result in a 35 percent reduction in habitat units. Very low levels of recreation, dispersed non-motorized activities occurring on a very small number of acres have virtually no impact on the number of habitat units available to grizzlies. The addition of low levels of linear recreation (motorized and non-motorized) occurring on less than 3 percent of the landscape resulted in a reduction in habitat units of less than 2 percent. The most significant impacts occur from linear motorized recreation that occur on about 50 percent of the area. The last addition, linear motorized high use occurring on 3,578 acres for every day of the season results in nearly a 20 percent reduction in habitat units in and of itself.

Weaver et al. (1985) suggested that for grizzly recovery efforts, the minimum acceptable levels of habitat effectiveness is 80 percent From a managerial standpoint, then, all activities except the last two additions would be acceptable.

These results are consistent with grizzly bears in high cover during the middle of summer. Grizzly bears are known to respond more strongly to ground-based human activities when in the open than when in cover (McClellan and Shakelton 1989). Furthermore, grizzly bears are believed to be more active during spring and fall and therefore a behavioral response to disturbance is expected to be less in the summer (Mattson et al. 1988).

The initial steepness of the PPF as the first units of recreation are substituted for grizzly habitat indicate that the rate of product transformation is very high, large increments of recreation can be added with very little loss in wildlife habitat. This remains the case for the addition of several more disturbance activities; this rate decreases slowly. The rate of product transformation decreases dramatically, however, when the last two disturbances are added, showing that the addition of linear motorized recreation in both low and high levels on large tracts of land is very costly in terms of wildlife habitat.

This concave PPF appears to yield the result that occurs with an efficient allocation of inputs in producing both outputs. Activities occur during times and in places that are least likely to be disruptive to the bears. Linear recreation, while occupying a large percentage of the landscape, is predictable, and dispersed recreation occupies a very small portion of the landscape. Because the existing activities reduce habitat units by only 40 percent, it would be interesting to see if the curve maintains its concave shape as habitat is reduced to zero or if somewhere lower than 60 percent the curve becomes convex. A change in the concavity of the curve would indicate that the additions of recreation that reduce habitat units from 90 percent to 60 percent may not be efficient allocations of inputs.

Additionally, some grizzly bear research suggests that the bears are very sensitive to low levels of disturbance (McClellan and Shakelton 1989) and that the zone of influence around a trail is considerably wider than the largest zone of influence, 500 meters, offered by the CEM. McClellan and Shakelton (1989) observed that grizzly bears flee greater than 1 kilometer from hikers in both open and forested habitat. Therefore, it is recommended that the PPF be run with a different set of data and the result analyzed.

Bald Eagle

The effects of human disturbance on bald eagles have been studied extensively since the 1960's when the dramatic decline of the bald eagle population became a major natural resource concern. Bald eagles are known to be particularly sensitive to disruption as their most critical habitat is located along river corridors and riparian areas (Stalmaster et al.

1978) where there tends to be a concentration of boaters and fishermen. In 1986, the Greater Yellowstone Bald Eagle Working Team asked George Montopoli and Donald Anderson (1991) to construct a cumulative effects model that would quantitatively evaluate the impacts of human disturbance on bald eagles. They used conjoint[3] analysis to model expert's judgements on the effects of different combinations of human disturbances. Five human disturbance categories were used: number of rafts, number of bank users, number of undeveloped boat pull-outs, number of developed pull-outs, and number of concentrated use areas. Montopoli and Anderson then designed a logistic model to assess the impacts of the combinations of the five disturbances:

$$\ln\left(\frac{p}{p(1-p)}\right) = \beta_0 + \sum_{i=1}^{5}(\beta_i x_i + \beta_{ii} x_i x_i) + \sum_{i=1}^{4}\sum_{j=i+1}^{5}\beta_{ij} x_i x_j \qquad (45)$$

As this CEM modeled only the judgments of experts in the field, it was important that it be validated with real data. The authors used a 27 mile section of the Snake River extending from Pacific Creek to Moose on which habitat quality was known and data were available on raft and bank users from 1985 through 1988. Validation yielded an adjusted R^2 of 88.9%, indicating a reasonably good fit.

Montopoli created a CEM computer program that could compute the regression parameters under differing variable intensities. I used Montopoli's computer program to

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Conjoint analysis: The application of experimental design to obtain knowledge about preferences.

generate the data that could be used to construct a PPF. The program allows a user to test human disturbances under five different scenarios, (1) one mile specific scenario, (2) variable segment specific scenario, (3) what-if evaluation, (4) time analysis. Only the *what-if* scenario allows the user to input the five disturbance categories in different intensities. The CEM assumes all inputs are fixed, that the land and labor available for habitat and habitat improvements is constant. The results given are a percentage reduction in habitat from a *no disturbance* scenario.

Formulating the PPF

For this PPF, the y-axis was boats and bank users per mile of river and the x-axis is percent habitat available for perching or foraging. The first units added for either output should have the lowest marginal cost. Recreationists were added one at a time and the resulting impacts to wildlife habitat were graphed onto a PPF.

Using the CEM program under the *what-if* scenario, I first held bank users at zero and added boats until percentage habitat available reached zero. Second, I held boats at zero and added bank users until the percentage habitat available was zero. Next, I ran 70 varying combinations of boats and bank users, from 100 percent habitat available to zero percent habitat available. Finally, I held bank users constant at varying levels (0,1,3,5 per mile) and varied the number of boats per mile until the percentage of habitat available reached zero. I repeated the process holding boats constant at three different levels and varied the number of bank users. For all the iterations, the three other disturbance factors, number of developed and undeveloped boat pull-outs and concentrated use areas were held at zero. All scenarios were run for both perching and foraging habitat. Those results not discussed in the body of the text can be found in the appendix.

Results

All results obtained this logistic regression are sigmoidal, with an inflection point at 50 percent (x-axis). Each of these curves shows a first decreasing then increasing rate of product transformation for movement along the curve from right to left. When the first recreationist is added as a production alternative, the cost in terms of input usage is low. For example, if we were to re-allocate one unit of land to recreation, the marginal cost of this first increment of recreation would be relatively lower than for the last unit dedicated to habitat. As more recreationists are added, the cost of each additional recreationist increases. However, after the inflection point, the cost of additional recreationists begins to decrease, requiring fewer and fewer inputs until all inputs are employed in the production of recreation.

If there are no bank users on the river, the tenth boat reduced percent habitat available for foraging to two percent (figure 17). The inflection point occurs at 4.5 boats per mile. Eagles are known to be more sensitive to bank users than boats (Stalmaster 1998); it is not surprising that eagle foraging habitat reaches zero at 9 bank users per mile (figure

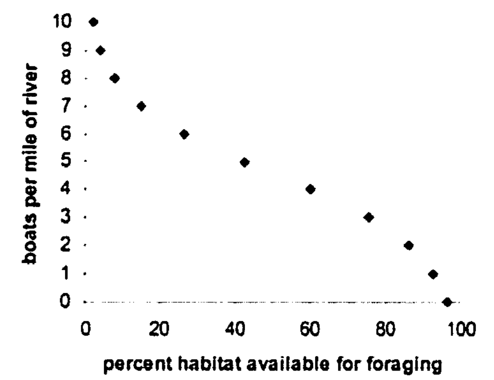

Figure 17.

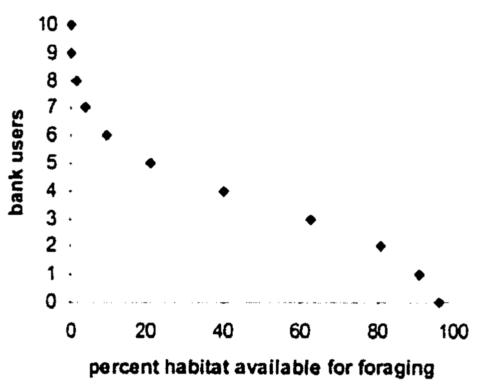

Figure 18.

18). For bank users, the inflection point occurs at 3.5 bank users per mile.

Perching eagles are less affected by human disturbance than are foraging eagles. Boats have less initial impact on perching habitat (figure 20), with a steeper PPF as the first

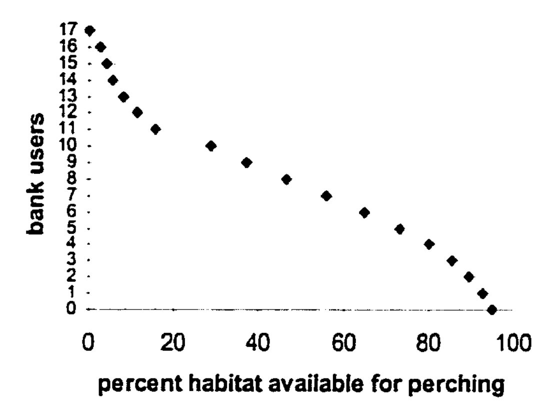

Figure 19.

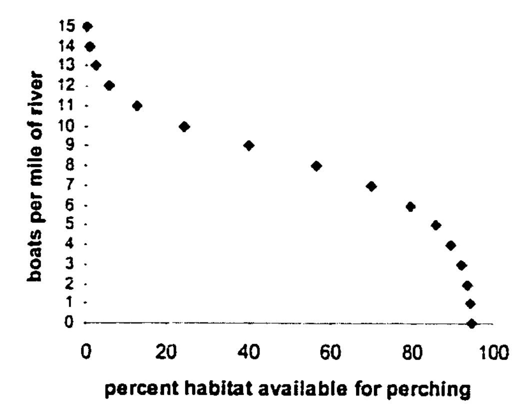

Figure 20.

habitat units are traded for boats per mile of river. The addition of boats 7 through 10 has the largest impact. As can be seen graphically, the first addition of bank users has a larger impact that the first additions of boats (figure 19). The rate of product transformation of the PPF from zero boats to one boat is 2.5, from zero bank users to one bank user, however, this rate falls to .43. However, additions of subsequent bank users have less impact than do boats, by the time the sixth boat or bank user is added, the rates are nearly equal, at .10 and .11 respectively. Percent perching habitat doesn't reach zero until 17 bank users per mile whereas percent perching habitat reached zero at 15 boats per mile of river. The initial rapid change in slope for boat users indicates that the rate of product transformation is decreases less quickly than it does for bank users. Therefore, even though both boats and bank users form a concave frontier, more boats can initially be added than can bank users for the same reduction in wildlife habitat. Boats and bank users usually both occur at the same time on a river system. Figure 21 illustrates results of the 70 combinations of boats and bank users. For foraging habitat, initially the frontier is formed by sole use of boaters. However, at four recreationists per mile for foraging habitat and, the frontier becomes a combination of boats and bank users. This indicates that, at some point, concentrated use by boat users has a greater impact on eagle habitat than a mixture of boats and bank users.

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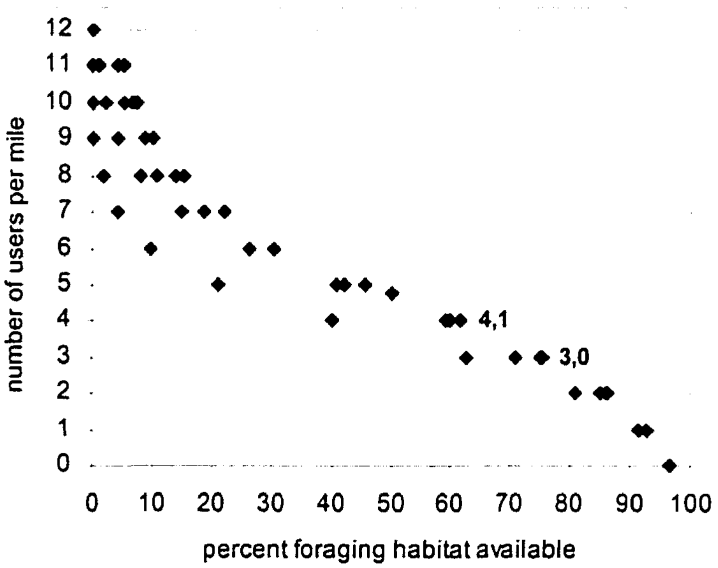

Figure 21.

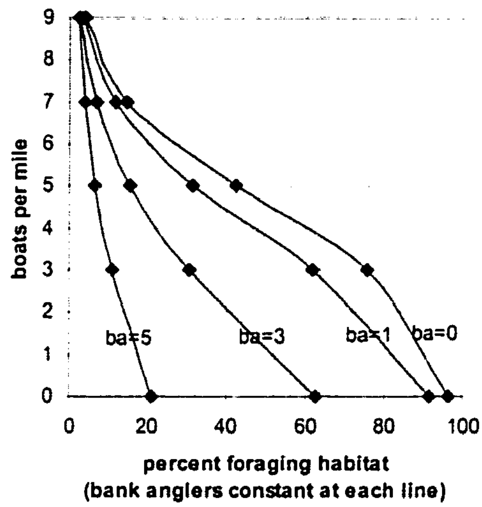

Figure 22.

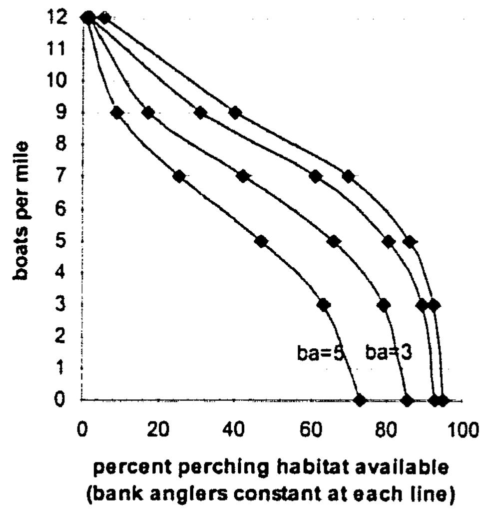

Figure 23.

The graphs shown in figures 22 and 23 were made by holding the number of bank users per mile constant at four different levels, 0, 1, 3, 5, and varying the number of boats per mile. The results indicate that as the number of bank user increases, the incremental impact of additional boats becomes larger and larger. For foraging habitat, the PPF becomes concave throughout at three bank users per mile. Interestingly, for zero levels of bank users, perching habitat is nearly concave throughout. Overall these graphs show how perching habitat is much less sensitive to higher levels of boats per mile than is foraging habitat.

Overall, foraging habitat is more sensitive to disturbance than is perching habitat. This is not surprising, considering foraging occurs on the river and eagles are more vulnerable during feeding (Stalmaster 1998). The sigmoidal shape of the PPF indicates that eagles are relatively tolerant of the first units of recreational users, but at some point a threshold is met and they become very sensitive to increased use. Once their available habitat declines to fifty percent, additional increments of recreation have less and less impact on the remaining eagles.

Interpretation

Although not specified in the model, experts who were queried in its creation believed that at least 30 percent of available habitat was needed in order for eagles to survive (Montopoli 1999). The model does state that elimination of foraging on the river occurs with 4.5 boats or 4.5 bank users per mile and elimination of perching occurs with 9 boats or 9 bank users per mile (Montopoli and Anderson 1991). This should be questioned, as it conflicts with results that show with only boats on the river, five boats per mile allow for 45 percent foraging habitat, for perching habitat, 9 boats per mile result in nearly 50 percent habitat remaining.

The sigmoidal shape of the PPF curves and the potentiality for tangency of the price line demonstrate that economic efficiency will occur somewhere greater than 50 percent or at zero percent. In a mixed-use setting for foraging habitat, this point is at 75.5 percent, for perching habitat, 65.3 percent. What this means for managers is that for optimal use of their inputs, recreationists should be limited to eight users per mile (four boats and bank users each) for perching habitat or three recreationists per mile (three boats, no bank users) for foraging habitat or provide no perching or foraging habitat at all, allowing greater than 12 recreationists per mile.

If the 30 percent mark was actually a zero value, as maintained by some experts, then the intersection of the y-axis would occur at the 30 percent mark. The PPF would be concave throughout most (or all) of its reach and nearly all points along the frontier would be efficient in terms of production.

The Montopoli and Anderson model did not address either time of day or duration of activity as potentially relevant variables. Research has indicated that eagles are particularly sensitive to recreationists during feeding times, and to boats and bank users who either stop to observe the birds or try to approach them (Stalmaster 1998). It is possible that limitations such as constraining recreationists to certain times on the river could cause the PPF to adopt a more concave shape, thus achieving more efficient use of the inputs. If the PPF were concave throughout (as in the 30 percent case) an improvement in the employment of inputs could stretch the PPF upwards.

Additionally, the Montopoli and Anderson model will always result in a sigmoidal PPF, as this shape is inherent in the functional form of the regression equation. Data that may indicate eagles do not respond in this manner would not be incorporated into a PPF using this logistic equation. The open framework of the PPF allows for many functional forms to be used in assessing the tradeoffs between recreation and wildlife.

Discussion: The PPF for Recreation and Wildlife

A joint production model and the production possibilities frontier can be used to represent alternative outputs of recreation and wildlife. The output, wildlife, is most difficult to define and measure, however using wildlife habitat as a proxy for wildlife appears to work quite well. Recreation can be defined as visitor days, group days, or visitors per unit of measure, depending on the goals of the manager. With minimal interpretation, the graphical nature of the PPF model is easy to understand and interpret. This makes the PPF particularly useful in management planning at both the community and policy-making level.

Uncertainty

Because of the uncertainty existing in wildlife management and opposing research surrounding the impacts of human disturbance on wildlife, one set of data to create a PPF may not provide sufficient rationale for decision-making. One way to address uncertainty is to use sensitivity analysis. Two (or more) PPFs can be mapped on to one another, providing a manager with the opportunity to view and analyze alternative frontiers and their implications. This technique could be particularly useful in situations where

wildlife may or may not habituate to specific human disturbances. The interior frontier would dictate wildlife that would not habituate, an outer frontier would show the same wildlife species after habituation. If there is concern over that species ability to habituate without threatening the health of the population, the manager may want to make

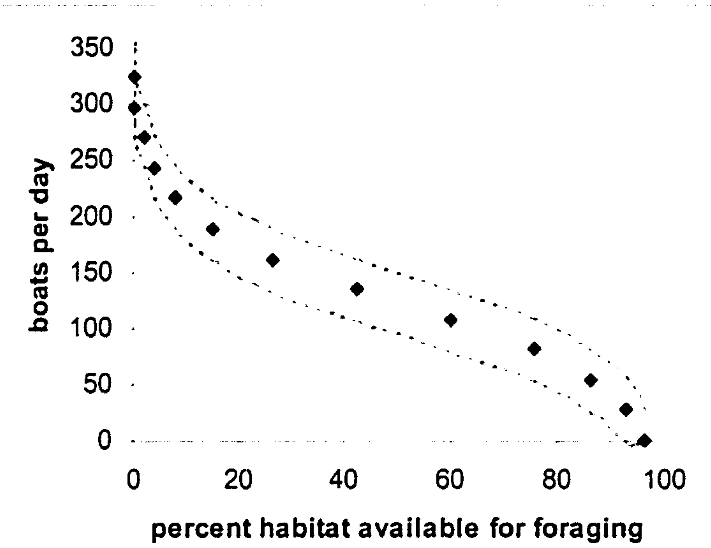

Figure 24.

decisions according to the interior frontier. This could be especially useful for a manager who is concerned with a particular wildlife species that is known to habituate in some situations and not in others. If data are unavailable at the location of concern, data from two separate places where the species behaves differently could each be mapped onto a PPF and then compared.

Another way of addressing uncertainty through sensitivity analysis is to use the standard deviation on the function which generated to PPF to create what is effectively an error band. Figure 24 shows an error band of two standard deviations. This technique provides managers who are fairly certain that a wildlife species' behavior mimics the general shape of the PPF, but who believe there may be variability in their responses to disturbance, a belt, rather than a frontier, in which to operate.

Non-concavities are likely to be common in the recreation–wildlife PPF. This occurs because a wildlife species is particularly sensitive to the kind of human disturbance introduced. What non-concavities imply are inefficiencies in input employment. Human disturbance can affect habitat selection, causing heavy use of marginal habitat (Morgantini and Hudson 1980). Identifying a non-concavity can provide managers with incentives to better use available resources.

Non-concavities also indicate that the middle ground managers so often search for may not be desirable. Until better input efficiency can bring about a more concave shape, the best use of the inputs would be to focus production towards either all (or nearly all, depending on the non-concavity) recreation or all wildlife.

Constraints can be added quite easily into to PPF model. Consider, for example the eagle data just discussed. After running the PPF, a resource manager in Grand Teton has the option of producing more than 75 percent eagle habitat and very few recreation user days or zero eagle habitat and many recreation user days. See figure 25. Since eagles are a protected species, the manager must maintain at least two nesting pairs on a 5 mile stretch of river. This requires at least 50 percent habitat per mile. The manager no longer

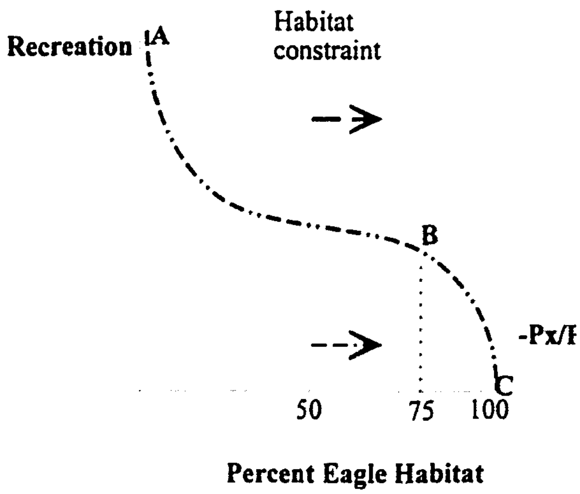

Figure 25.

has the option of producing all recreation and no habitat. Furthermore, rather than producing the required 50 percent habitat, the manager would be making better use of the resources to produce 75 percent eagle habitat.

Additionally, recreation constraints can be added. If crowding literature suggests that a recreation experience of more than three boats per mile of river is undesirable, a horizontal constraint could be added to the PPF and more wildlife habitat would be produced as a result.

Unresolved Issues

The issue of joint production in the production of wildlife and recreation needs to be further investigated. Although this model could determine that joint effects were likely occurring, it does not explain the extent to which they occur or why they occur, nor does it provide a mathematical model of the interaction.

Additionally, the assumption that production of visitor days does not include a variable for wildlife should be explored; it would be interesting to see a production function in which that variable could have either a positive or negative effect on the marginal productivities of capital and labor.

One of the main problems with using the model is the availability of applicable data. As stated earlier, there is a great deal of information available regarding the effects of human disturbance on wildlife but little is available that addresses the cumulative nature of these effects and their ultimate impacts on populations.

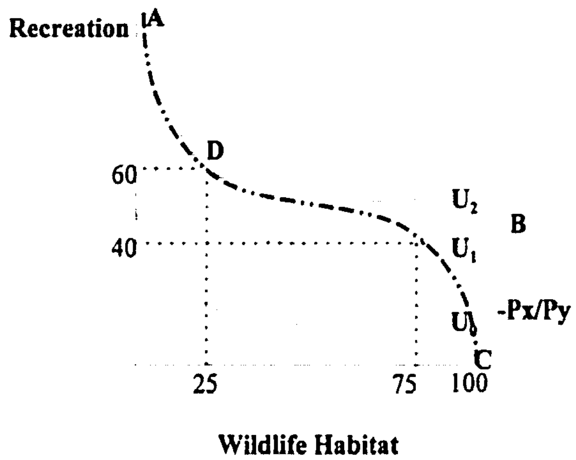

Figure 26.

A final issue is the tangency of the utility function with the PPF. If the PPF is convex through all or part of its reach, there is the potential that a tangency of an indifference curve may occur at a low point in this convexity (Baumol and Oates 1995). For user preferences, then, a corner solution or any other solution further out on the frontier would yield a lower level of utility. Figure 25 shows that U_1 would cross the PPF at *B*, the point of tangency of the price line with the PPF. However, a higher level of utility, U_2, is tangent to the PPF at *D*. This creates a managerial dilemma: the requirements of input efficiency would dictate production at a different location than the tangency of the PPF and the indifference curve. Therefore, should managers provide for the demands of the consumers or should they employ the available resources to their maximum efficiency? This predicament would provide further incentive to better employ inputs to create a concavity from the convexity, thus producing the outputs at an even higher level of utility than previously and at a point that maximizes efficiency.

FUTURE RESEARCH

Data for the PPF

Although there is a large amount of data available on human disturbance and wildlife, very little was applicable to a PPF format. Data that are usable in a PPF must correlate varying levels of human disturbance into a resulting change in a species population or habitat availability.

It would be interesting to see results from a study in which human disturbance was introduced into a relatively undisturbed area. Over the course of a season (or more) increasing numbers of recreation would be introduced in a manner which is known to have the lowest impacts on wildlife, i.e. trails out of riparian areas and sensitive habitat, recreationists stay on-trail, no dogs, etc. In a similar undisturbed site, recreationists would be introduced in a high-impact manner. Study participants would walk along riparian areas, frequently drift off trail, stop often to view wildlife, walk through sensitive areas, and the like. For each site, the species' avoidance or abandonment of the area over the course of several seasons could be measured and compared to the undisturbed data.

A long-term study that could test the idea of changing the shape of a convex PPF would be to convert a resource area from a high impact site to a lower-impact site. Trails would be re-routed, vegetation restored, campgrounds delineated, etc. to encourage wildlife to return to the area. Before and after numbers of wildlife or habitat potential could be measured and graphed to show any changes in the PPF.

The Next Step

Once the first piece of the puzzle is established, it is still necessary to determine the slope of the price line and the utility of consumers in order to achieve an optimal solution. While the PPF is biologically determined, the slope of the price line and consumer preferences are socially ascertained. The first objective is to establish consumer's preferences for different combinations of wildlife and recreation. One way to establish the shape and direction of indifference curves is through a survey method in which recreationists at different locations are asked to rank their preferences. These answers would yield both the relative values different consumer groups place on recreation and wildlife and any inferiority or superiority of the goods.

The second objective is to establish the slope of the price line under which various resource management agencies should be managing. It is important to note that even though it is called the price line, this line is not necessarily determined by dollars. The price line is simply a measure of relative values. The slope of the price line will determine the desired managerial emphasis that will optimize input employment for individual resource areas. The price line will most likely be both value and policy determined.

Given that there are numerous variables affecting natural resource policy, it can be difficult to determine the desired relative managerial emphasis on wildlife or recreation. A reasonable way to address this issue is to view managerial emphasis along a continuum, with wildlife at one end and recreation at the other. The political and community issues involved in establishing policy are the variables which, working in concert, place an agency towards one end or the other of this continuum.

A regression equation might be used to calculate the relative emphasis a natural resource area places on wildlife or recreation, as determined by a number of variables. Sensitivity analysis would provide the basis for a range of variability in management strategies.

Using the general form of the PPF, it is possible to overlay the policy considerations of a resource area to demonstrate the region of the PPF in which a park ought to lie figure 26. This variability can be translated into a range of slopes for the price line under which it is acceptable for a particular agency to manage. Based upon the slope of the PPF for the wildlife species of concern and the park's designation, a manager will be able to determine what level of recreational activities are optimal.

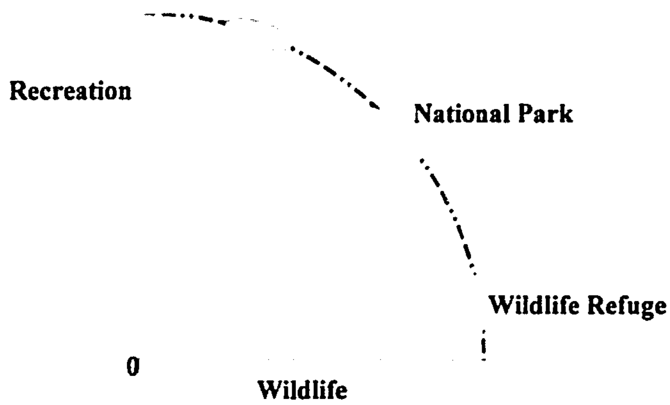

Figure 27.

Once all three pieces are established, putting them together will give a resource area an idea of how best to employ its inputs in order to satisfy consumer demand, biological requisites, and policy requirements. Accomplishing this goal would require an integration of the variables for one resource area and one wildlife species.

Conclusions

An economic model, the production possibilities frontier, may be an effective tool in allocating wildlife and recreation output decisions. The PPF framework combined with cumulative effects modeling works well in identifying the effects of joint production and allows for identification of improperly allocated inputs. The graphical nature of the PPF is a useful visual tool that can be easily understood by resource managers, policy-makers, and others involved in a decision-making process. The PPF provides a framework for the integration of biological principles and social demands, changing a situation of perceived conflict into one of competing production. For scientists, it is particularly useful in that it provides a means for research, disparate results, and sensitivity analysis to be incorporated into the decision-making process.

Because of the uncertainty inherent in many natural resource decisions, the PPF also allows for uncertainty to be built into the model through the use of confidence bands. These allow a resource manager to address the ramifications of best and worst-case scenarios before they actually occur.

The PPF, although species-specific, can be applied to any species with adequate data availability. For some wildlife, it may demonstrate a purely competitive relationship, as was demonstrated with bald eagles and grizzly bears, or it may show a complementary-competitive relationship for some edge species.

When combined with the price line and preference information of consumers, the PPF framework allows a resource area to assess (1) where it currently is on the continuum, (2) where it ought to be on the frontier, and (3) how it can efficiently accommodate recreational demands without compromising policy objectives.

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APPENDICES

Appendix A

LOGISTIC MODEL: EAGLE HABITAT

An expert system model was used because direct experimentation was prohibited because the bald eagle was an endangered species during this period of time.

Model Process:

1.Sixty-three scenarios were designed that spanned the range of all possible combinations of five disturbance factors.

2. A panel of experts in bald eagle behavior evaluated each scenario for the proportion of habitat available for foraging and perching. (*no scenario eliminated all habitat)

3. Coefficients were estimated in a logistic regression model according to the panel's prediction of habitat available for foraging and perching given any disturbance scenario.

4. The expert system model was validated with real data.

Model:

$$\ln\left(\frac{p}{p(1-p)}\right) = \beta_0 + \sum_{i=1}^{5} (\beta_i x_i + \beta_{ii} x_i x_i) + \sum_{i=1}^{4} \sum_{j=i+1}^{5} \beta_{ij} x_i x_j$$

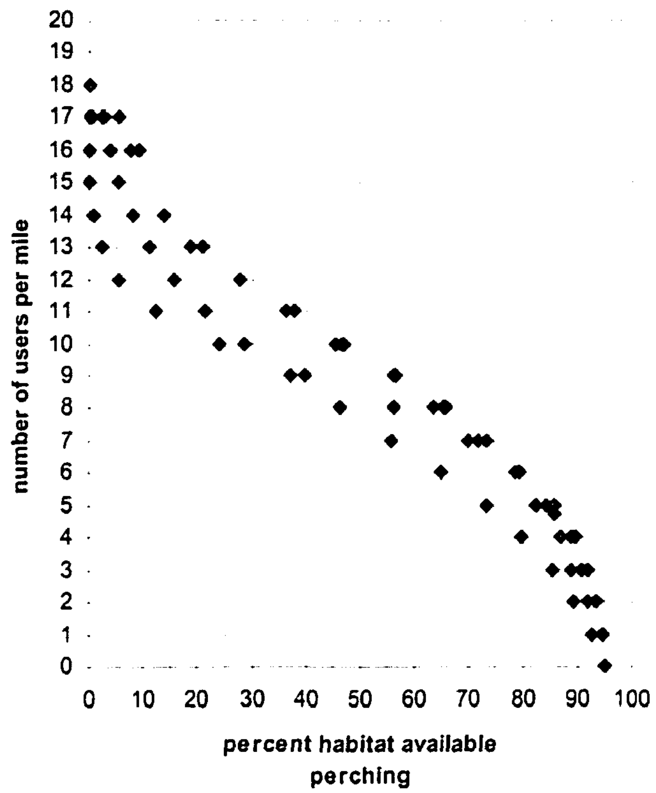
where p is the proportion of available habitat

and x_{ij} are the disturbance scenarios

standard deviation for boats: actual-estimated = 14 per day

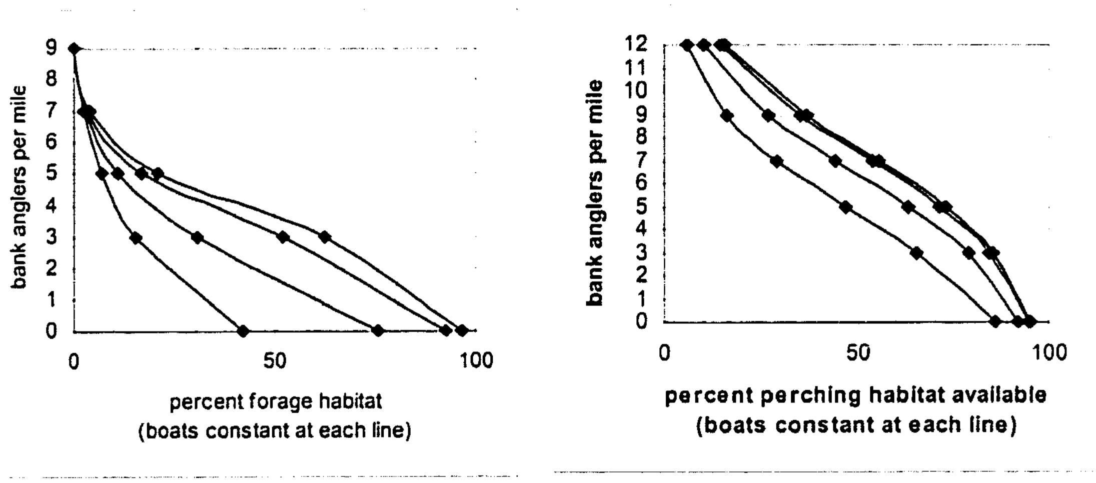
standard deviation for bank users: assuming a Poisson distribution (variance = mean) = the square root of bank users for a given day

Boats and Bank Users: Perching Habitat



Perching habitat is initially less sensitive to incremental additions of both boats and bank users. The rate of product transformation decreases less quickly for perching habitat.

**Percent foraging and perching habitat per mile:
bank users**

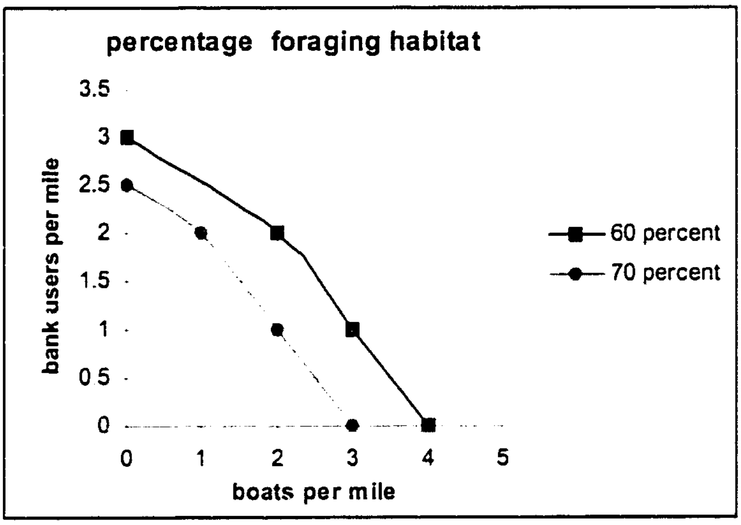


As with the graphs in the body of the text where bank anglers were held constant at each line, perching habitat is less sensitive to the first increments of bank anglers introduced than is foraging habitat. The impact of additional bank anglers have greater for both foraging and perching when boat users are already present.

Production Possibilities Frontier
Decision-Making Options

boats	bank users	60% forage
4	0	60.0
3	1	61.7
2	2	59.0
0	3	62.6

boats	bank users	70% forage
0	2.5	72.6
1	2	71.1
2	1	75.1
3	0	75.5



Once the PPF is established for recreation and wildlife, a manager can decide how much habitat is optimal for the production capabilities of the area and the demands of the recreationists. The PPF can be run again holding the desired percentage of wildlife habitat constant and the tradeoffs between boats and bank users can be established.

Results From Eagle CEM

boats	bank anglers	total recreationists	% forage habitat	% perching habitat
0	0	0	96.4	94.9
1	0	1	92.8	94.5
0	1	1	91.4	92.6
2	0	2	86.3	93.6
1	1	2	85.0	92.1
0	2	2	80.8	89.5
3	0	3	75.5	92.1
2	1	3	75.1	90.9
1	2	3	71.1	88.8
0	3	3	62.6	85.4
4	0	4	60.0	89.7
2	2	4	59.0	87.2
3	1	4	61.7	88.9
3.25	1.5	4.75	50.2	86.0
0	4	4	40.0	79.9
5	0	5	42.2	85.7
3	2	5	45.7	84.5
2	3	5	40.8	82.3
0	5	5	21.0	73.1
6	0	6	26.3	79.4
0	6	6	9.6	64.9
3	3	6	30.6	78.8
7	0	7	14.9	69.7
0	7	7	4.0	55.8
3	4	7	18.7	71.7
4	3	7	22.0	73.4
5	3	8	15.3	65.5
8	0	8	7.8	56.0
0	8	8	1.6	46.2
4	4	8	13.9	65.3
3	5	8	10.8	63.3
9	0	9	4.0	39.7
0	9	9	0.0	36.9
4	5	9	8.5	56.1
5	4	9	10.2	56.5
9	0	9	4.0	39.7
5	5	10	6.7	46.9
6	4	10	7.4	45.4
4	6	10	5.1	46.6
10	0	10	2.0	23.9
0	10	10	0.0	28.5
6	5	11	5.2	36.2
5	6	11	4.3	37.6
11	0	11	1.0	12.3
0	11	11	0.0	21.4
6	6	12	0.0	27.9
0	12	12	0.0	15.6
12	0	12	0.0	5.5
6	7	13	0.0	20.9
7	6	13	0.0	18.7
0	13	13	0.0	11.2
13	0	13	0.0	2.2
7	7	14	0.0	13.6
0	14	14	0.0	7.9
14	0	14	0.0	0.8
0	15	15	0.0	5.5
15	0	15	0.0	0.0
16	0	16	0.0	9.0
6	10	16	0.0	7.7
0	16	16	0.0	3.9
8	8	16	0.0	0.0
3	14	17	0.0	5.2
14	3	17	0.0	0.3
0	17	17	0.0	2.7
10	7	17	0.0	2.1
17	0	17	0.0	0.0
9	9	18	0.0	0.0
8	10	18	0.0	0.0
0	18	18	0.0	0.0

Data: Boats/Bank Anglers Constant

boats	bank anglers	percent forage	percent perch		bank anglers	boats	percent forage	percent perch
0	0	96.4	94.9		0	0	96.4	94.9
3	0	75.5	92.1		3	0	62.6	85.4
5	0	42.2	85.7		5	0	21	73.1
7	0	14.8	69.7		7	0	4	55.8
9	0	4	39.9		9	0	0	36.9
12	0	0	5.5		12	0	0	15.6
0	1	91.4	92.6		0	1	92.8	94.5
3	1	61.7	88.9		3	1	51.8	84.4
5	1	31.5	80.4		5	1	17	71.5
7	1	11.6	61.1		7	1	3.7	53.8
9	1	3.6	30.9		9	1	0	35.1
12	1	0	1.8		12	1	0	14.6
0	3	62.6	85.4		0	3	75.5	92.1
3	3	30.6	78.8		3	3	30.6	78.8
5	3	15.3	65.5		5	3	10.8	63.3
7	3	6.9	42.1		7	3	3.2	44.5
9	3	3	17.2		9	3	0	27.1
12	3	0	1.8		12	3	0	10.5
0	5	21	73.1		0	5	42.2	85.7
3	5	10.8	63.3		3	5	15.3	65.5
5	5	6.7	46.9		5	5	6.7	46.9
7	5	4.1	25.3		7	5	2.7	29.1
9	5	2.4	8.8		9	5	0	16
12	5	0	0.8		12	5	0	5.7

Appendix B

Variable Definitions: Grizzly CEM

Habitat Submodel:

$$UHV'_{jk} = \left((\sum_{j=1} UFV_{ik} * X_{ijk} * APF_{ijk})(DI_{jk} * F_k) \right) / UHV_{jk}\ \mathrm{max}$$

UHV: unit habitat value

UFV: value of diet item

APF: preference for feed site density

X: proportionate representation of feeding activity types

D: diversity of recorded feeding activity

F: seasonally disparate numbers of utilized habitat components

HV: individual component value

HV=UHV adjusted for cover based on distance to edge and protein-rich areas

Displacement Submodel:

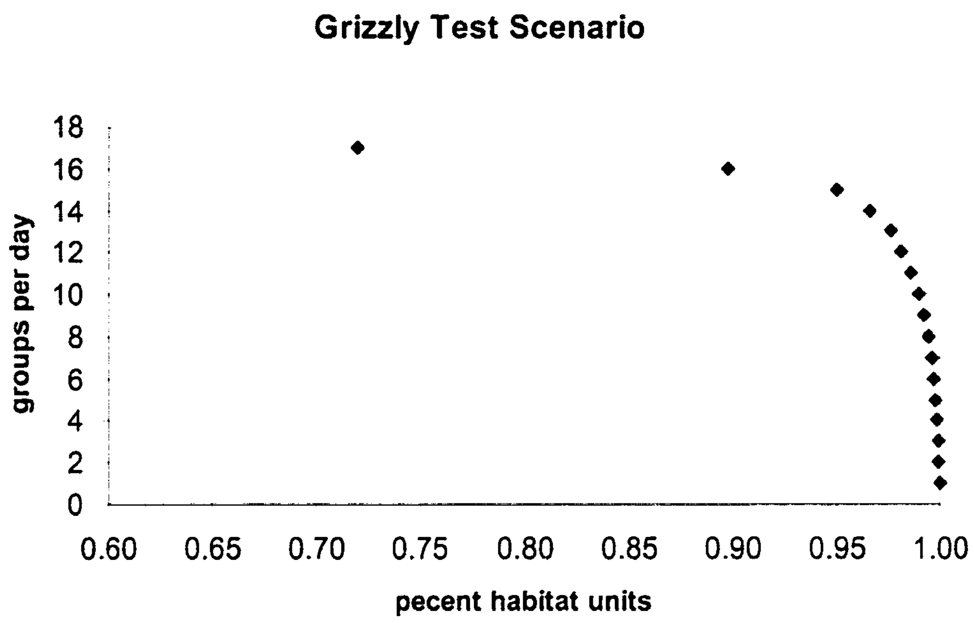
Zone of Influence: the distance in which grizzlies would be affected by an activity.

Disturbance Coefficient: the degree of disturbance (between 0 and 1). Disturbance can influence bear use of habitat in two ways: actual displacement and a change in use patterns that reduce the time available for a bear to use an area. A disturbance coefficient of .5 would indicate that (1) either half the bears are displaced or (2) that all the bears can use the area only 50 percent of the time.

Cover: vegetation capable of hiding 90 percent of a standing adult bear from view of a human at a distance equal or less than 60 meters.

Timing and Duration: proportion of an activity's duration during the assessment period.

Assessment period: usually monthly, aggregated to season



The grizzly CEM was computed under a test scenario which included all potential disturbances on a 100,000 acre subunit. All disturbances were introduced only once, were introduced for one day in a one day season and were assumed not to overlap. The above graph shows the PPF constructed from the CEM data.With all other variables held constant, the graph shows the effects of the individual disturbances.

Acres	100,000
Habitat Type	grouse whortleberry
HV	42
Estrus	May 15- July 15
Season length	1 day during estrus
Days disturbed	1 day

Displacement			Remov	ed L	ow Co	ver	Low/H	igh	High/	Low	High	Covr		
Type Code	ZOI	ZOI	ZOI	Src	Edge	Src	Edge	Src	Egde	Src	Edge	Src	Edge	Description
	meters	circle area	acres											
AIRCRAFT	1610	8,143,341	2012	0.42	0.42	0.42	0.42	0.61	0.61	0.61	0.61	0.79	0.79	"Aircraft"
DEVELOPED	5000	78,540,000	19407	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	"Major Development"
D_M_H	0	0	0	0.13	0.13	0.13	0.13	0.31	0.31	0.31	0.31	0.48	0.48	"Dispersed Motorized High Use"
D_M_L	0	0	0	0.66	0.66	0.66	0.66	0.75	0.75	0.75	0.75	0.84	0.84	"Dispersed Motorized Low Use"
D_NM_H	0	0	0	0.92	0.92	0.92	0.92	0.95	0.95	0.95	0.95	0.98	0.98	"Dispersed Non-motorized High Use"
D_NM_L	0	0	0	0.97	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.99	0.99	"Dispersed Non-motorized Low Use"
EXPLOSIVES	1610	8,143,341	2012	0.15	0.15	0.15	0.15	0.33	0.33	0.33	0.33	0.5	0.5	"Explosives"
L_M_H	500	785,400	194	0.21	0.21	0.21	0.21	0.33	0.33	0.33	0.33	0.45	0.45	"Linear Motorized High Use"
L_M_I	300	282,744	70	0.27	0.27	0.27	0.27	0.4	0.4	0.4	0.4	0.53	0.53	"Linear Motorized Incidental Use"
L_M_L	300	282,744	70	0.19	0.19	0.19	0.19	0.2	0.2	0.2	0.2	0.21	0.21	"Linear Motorized Low Use"
L_NM_H	300	282,744	70	0.18	0.18	0.18	0.18	0.25	0.25	0.25	0.25	0.32	0.32	"Linear Non-motorized High Use"
L_NM_L	300	282,744	70	0.25	0.25	0.25	0.25	0.39	0.39	0.39	0.39	0.62	0.62	"Linear Non-motorized Low Use"
P_M_24	1000	3,141,600	776	0.18	0.18	0.18	0.18	0.28	0.28	0.28	0.28	0.38	0.38	"Point Motorized 24 Use"
P_M_H	1000	3,141,600	776	0.18	0.18	0.18	0.18	0.28	0.28	0.28	0.28	0.38	0.38	"Point Motorized High Diurnal Use"
P_M_L	1000	3,141,600	776	0.47	0.47	0.47	0.47	0.57	0.57	0.57	0.57	0.67	0.67	"Point Motorized Low Diurnal Use"
P_NM_24	500	785,400	194	0.18	0.18	0.18	0.18	0.28	0.28	0.28	0.28	0.38	0.38	"Point Non-motorized 24 Use"
P_NM_D	500	785,400	194	0.47	0.47	0.47	0.47	0.57	0.57	0.57	0.57	0.67	0.67	"Point Non-motorized Diurnal Use"

Results of Grizzly CEM:
Actual Scenario

displacement	Total Acres	ZOI acres	groups /day	days disturbed	total visitor days	%days d	%days n/d	HV	RC	remaining AC	HU	remaining HU	days no dis HU	days dis reduced HU	new total HU	% total	reduced HU
DNML	10,000	13	10	23	230	0.38	0.62	42	0.99	9,987.00	420,000	419454	204	340	419998	1.00	2
DNMH	10,000	13	30	30	900	0.49	0.51	42	0.98	9,987.00	420,000	419454	263	277	419995	1.00	5
DNMH	10,000	11.1	30	45	1350	0.74	0.26	42	0.98	9,988.90	420,000	419534	337	122	419993	1.00	7
DNML	10,000	497	10	30	300	0.49	0.51	42	0.99	9,503.00	420,000	399126	10163	10608	419897	1.00	103
DNMH	10,000	497	30	15	450	0.25	0.75	42	0.98	9,503.00	420,000	399126	5030	15741	419897	1.00	103
LML	10,000	71.56	10	15	150	0.25	0.75	42	0.21	9,928.44	420,000	416994	155	2266	419416	1.00	584
LNML	10,000	71.6	10	61	610	1.00	0.00	42	0.62	9,928.40	420,000	416993	1864	0	418857	1.00	1,143
LMH	10,000	119.3	30	30	900	0.49	0.51	42	0.45	9,880.73	420,000	414991	1109	2546	418645	1.00	1,355
LML	10,000	47.71	10	61	610	1.00	0.00	42	0.21	9,952.29	420,000	417996	421	0	418417	1.00	1,583
PNMD	10,000	194	30	45	1350	0.74	0.26	42	0.67	9,806.00	420,000	411852	4027	2137	418016	1.00	1,984
LNML	10,000	143.1	10	61	610	1.00	0.00	42	0.62	9,856.90	420,000	413990	3726	0	417716	0.99	2,284
PNMD	10,000	194	30	61	1830	1.00	0.00	42	0.67	9,806.00	420,000	411852	5459	0	417311	0.99	2,689
LNMH	10,000	167	30	45	1350	0.74	0.26	42	0.32	9,833.00	420,000	412986	1656	1840	416482	0.99	3,518
LNMH	10,000	167	30	61	1830	1.00	0.00	42	0.32	9,833.00	420,000	412986	2244	0	415230	0.99	4,770
LNML	10,000	668	10	30	300	0.49	0.51	42	0.62	9,332.00	420,000	391944	8555	14258	414757	0.99	5,243
LML	10,000	1861	10	36	360	0.59	0.41	42	0.21	8,139.40	420,000	341855	9685	32027	383566	0.91	36,434
LMH	10,000	3578	10	61	610	1.00	0.00	42	0.45	6,422.00	420,000	269724	67624	0	337348	0.80	82,652

displacement	Total Acres	ZOI acres	sum groups /day	sum days disturbed	sum vis days			HV	RF	sum remaining AC	HU	sum remaining HU	sum days no dis HU	sum days dis reduced HU	sum remain HU	% total	sum red HU
DNML	10,000	13	10	23	230			42	0.99	9,987.00	420,000	419,454	204	340	419,998	1.00	2
DNMH	10,000	13	40	53	1130			42	0.98	9,974.00	420,000	418,908	467	618	419,993	1.00	7
DNMH	10,000	11.1	70	98	2480			42	0.98	9,962.90	420,000	418,442	804	740	419,986	1.00	14
DNML	10,000	497	80	128	2780			42	0.99	9,465.90	420,000	397,568	10,967	11,348	419,883	1.00	117
DNMH	10,000	497	110	143	3230			42	0.98	8,968.90	420,000	376,694	15,998	27,089	419,780	1.00	220
LML	10,000	71.56	120	158	3380			42	0.21	8,897.34	420,000	373,688	16,153	29,355	419,197	1.00	803
LNML	10,000	71.6	130	219	3990			42	0.62	8,825.74	420,000	370,681	18,017	29,355	418,054	1.00	1,946
LMH	10,000	119.3	160	249	4890			42	0.45	8,706.47	420,000	365,672	19,126	31,901	416,699	0.99	3,301
LML	10,000	47.71	170	310	5500			42	0.21	8,658.76	420,000	363,668	19,547	31,901	415,116	0.99	4,884
PNMD	10,000	194	200	355	6850			42	0.67	8,464.76	420,000	355,520	23,574	34,038	413,132	0.98	6,868
LNML	10,000	143.1	210	416	7460			42	0.62	8,321.66	420,000	349,510	27,300	34,038	410,848	0.98	9,152
PNMD	10,000	194	240	477	9290			42	0.67	8,127.66	420,000	341,362	32,759	34,038	408,159	0.97	11,841
LNMH	10,000	167	270	515	10640			42	0.32	7,960.66	420,000	334,348	34,415	35,878	404,641	0.96	15,359
LNMH	10,000	167	300	568	12470			42	0.32	7,793.66	420,000	327,334	36,660	35,878	399,871	0.95	20,129
LNML	10,000	668	310	628	12770			42	0.62	7,125.66	420,000	299,278	45,214	50,136	394,628	0.94	25,372
LML	10,000	1861	320	664	13130			42	0.21	5,265.06	420,000	221,133	54,899	82,163	358,195	0.85	61,805
LMH	10,000	3578	330	710	13740			42	0.45	1,687.06	420,000	70,857	122,523	82,163	275,543	0.66	144,457

Results of Grizzly CEM:
Test Scenario

DISPLACEMENT	ZOI (m)	ZOI (acres)	RC	HV	RHV	Total AC	R Acres	HU	new HU	R HU	Total HU	difference HU	Percent HU	rank
LNML	300	70	0.62	42	26.04	100,000	99,930	4,200,000	4,197,060	1,822.80	4,198,882.80	1,117.20	1.00	1
LMI	300	70	0.53	42	22.26	100,000	99,930	4,200,000	4,197,060	1,558.20	4,198,618.20	1,381.80	1.00	2
LNMH	300	70	0.32	42	13.44	100,000	99,930	4,200,000	4,197,060	940.80	4,198,000.80	1,999.20	1.00	3
LML	300	70	0.21	42	8.82	100,000	99,930	4,200,000	4,197,060	617.40	4,197,677.40	2,322.60	1.00	4
PMND	500	194	0.67	42	28.14	100,000	99,806	4,200,000	4,191,852	5,459.16	4,197,311.16	2,688.84	1.00	5
DNML	0	10000	0.99	42	41.58	100,000	90,000	4,200,000	3,780,000	415,800.00	4,195,800.00	4,200.00	1.00	6
LMH	500	194	0.45	42	18.9	100,000	99,806	4,200,000	4,191,852	3,666.60	4,195,518.60	4,481.40	1.00	7
PNM24	500	194	0.38	42	15.96	100,000	99,806	4,200,000	4,191,852	3,096.24	4,194,948.24	5,051.76	1.00	8
DNMH	0	10000	0.98	42	41.16	100,000	90,000	4,200,000	3,780,000	411,600.00	4,191,600.00	8,400.00	1.00	9
PML	1000	776	0.67	42	28.14	100,000	99,224	4,200,000	4,167,408	21,836.64	4,189,244.64	10,755.36	1.00	10
aircraft	1610	2012	0.79	42	33.18	100,000	97,988	4,200,000	4,115,496	66,758.16	4,182,254.16	17,745.84	1.00	11
PMH	1000	776	0.38	42	15.96	100,000	99,224	4,200,000	4,167,408	12,384.96	4,179,792.96	20,207.04	1.00	12
PM24	1000	776	0.38	42	15.96	100,000	99,224	4,200,000	4,167,408	12,384.96	4,179,792.96	20,207.04	1.00	13
explosives	1610	2012	0.5	42	21	100,000	97,988	4,200,000	4,115,496	42,252.00	4,157,748.00	42,252.00	0.99	14
DML	0	10000	0.84	42	35.28	100,000	90,000	4,200,000	3,780,000	352,800.00	4,132,800.00	67,200.00	0.98	15
DMH	0	10000	0.48	42	20.16	100,000	90,000	4,200,000	3,780,000	201,600.00	3,981,600.00	218,400.00	0.95	16
developed	5000	19407	0.08	42	3.36	100,000	80,593	4,200,000	3,384,906	65,207.52	3,450,113.52	749,886.48	0.82	17

DISPLACEMENT	ZOI (m)	ZOI (acres)	RC	HV	RHV	Total AC	R Acres	HU	sum HU	sum r HU	total HU	difference HU	Percent HU	rank
LNML	300	70	0.62	42	26.04	100,000	99,930	4,200,000	4,197,060	1,822.80	4,198,882.80	1,117.20	1.00	1
LMI	300	70	0.53	42	22.26	100,000	99,860	4,200,000	4,194,120	3,381.00	4,197,501.00	2,499.00	1.00	2
LNMH	300	70	0.32	42	13.44	100,000	99,790	4,200,000	4,191,180	4,321.80	4,195,501.80	4,498.20	1.00	3
LML	300	70	0.21	42	8.82	100,000	99,720	4,200,000	4,188,240	4,939.20	4,193,179.20	6,820.80	1.00	4
PMND	500	194	0.67	42	28.14	100,000	99,526	4,200,000	4,180,092	10,398.36	4,190,490.36	9,509.64	1.00	5
DNML	0	10000	0.99	42	41.58	100,000	89,526	4,200,000	3,760,092	426,198.36	4,186,290.36	13,709.64	1.00	6
LMH	500	194	0.45	42	18.9	100,000	89,332	4,200,000	3,751,944	429,864.96	4,181,808.96	18,191.04	1.00	7
PNM24	500	194	0.38	42	15.96	100,000	89,138	4,200,000	3,743,796	432,961.20	4,176,757.20	23,242.80	0.99	8
DNMH	0	10000	0.98	42	41.16	100,000	79,138	4,200,000	3,323,796	844,561.20	4,168,357.20	31,642.80	0.99	9
PML	1000	776	0.67	42	28.14	100,000	78,362	4,200,000	3,291,204	866,397.84	4,157,601.84	42,398.16	0.99	10
aircraft	1610	2012	0.79	42	33.18	100,000	76,350	4,200,000	3,206,700	933,156.00	4,139,856.00	60,144.00	0.99	11
PMH	1000	776	0.38	42	15.96	100,000	75,574	4,200,000	3,174,108	945,540.96	4,119,648.96	80,351.04	0.98	12
PM24	1000	776	0.38	42	15.96	100,000	74,798	4,200,000	3,141,516	957,925.92	4,099,441.92	100,558.08	0.98	13
explosives	1610	2012	0.5	42	21	100,000	72,786	4,200,000	3,057,012	1,000,177.92	4,057,189.92	142,810.08	0.97	14
DML	0	10000	0.84	42	35.28	100,000	62,786	4,200,000	2,637,012	1,352,977.92	3,989,989.92	210,010.08	0.95	15
DMH	0	10000	0.48	42	20.16	100,000	52,786	4,200,000	2,217,012	1,554,577.92	3,771,589.92	428,410.08	0.90	16
developed	5000	19407	0.08	42	3.36	100,000	33,379	4,200,000	1,401,918	1,619,785.44	3,021,703.44	1,178,296.56	0.72	17