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Author(s): David J. Mattson, Stephen Herrero, R. Gerald Wright and Craig M. Pease
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Science and Management of Rocky Mountain Grizzly Bears

DAVID J. MATTSON,* STEPHEN HERRERO,† R. GERALD WRIGHT,* AND CRAIG M. PEASE‡

*National Biological Service, Department of Fish and Wildlife Resources, University of Idaho, Moscow, ID 83843, U.S.A.

†Faculty of Environmental Design, The University of Calgary, 2500 University Drive NW, Calgary, AB T2N 1N4, Canada

‡Department of Zoology, University of Texas at Austin, Austin, TX 78712, U.S.A.

Abstract: *The science and management of grizzly bears (*Ursus arctos horribilis*) in the Rocky Mountains of North America have spawned considerable conflict and controversy. Much of this can be attributed to divergent public values, but the narrow perceptions and incomplete and fragmented problem definitions of those involved have exacerbated an inherently difficult situation. We present a conceptual model that extends the traditional description of the grizzly bear conservation system to include facets of the human domain such as the behavior of managers, elected officials, and the public. The model focuses on human-caused mortality, the key determinant of grizzly bear population growth in this region and the interactions and feedback loops among humans that have a major potential influence on bear mortality. We also briefly evaluate existing information and technical methods relevant to understanding this complex human-biophysical system. We observe not only that the extant knowledge is insufficient for prediction (and in some cases for description), but also that traditional positivistic science alone is not adequate for dealing with the problems of grizzly bear conservation. We recommend changes in science and management that could improve learning and responsiveness among the involved individuals and organizations, clarify some existing uncertainty, and thereby increase the effectiveness of grizzly bear conservation and management. Although adaptive management is a promising approach, we point out some key—as yet unfulfilled—contingencies for implementation of a method such as this one that relies upon social processes and structures that promote open learning and flexibility in all facets of the policy process.*

Ciencia y Manejo de los Osos Pardos de las Montañas Rocallossas

Resumen: *La ciencia y manejo de los osos pardos (*Ursus arctos horribilis*) en las montañas rocallosas de Norte América han producido considerables conflictos y controversias. Mucho de esto puede ser atribuido a los divergentes valores públicos, así como a reducidas percepciones e incompletas y fragmentadas definiciones de los involucrados, lo cual ha exacerbado la ya dificil situación. Presentamos un modelo conceptual que expande la descripción tradicional del sistema de conservación de los osos pardos para incluir facetas del dominio humano como son la conducta de los manejadores, los oficiales elegidos y en publico. El modelo se enfoca en la mortalidad causada por humanos, clave determinante del crecimiento de las poblaciones de osos pardos en esta región y las interacciones y retroalimentación entre los humanos que tienen un mayor potencial para influir en la mortalidad de los osos. Brevemente evaluamos la información existente y los métodos técnicos relevantes para entender este complejo sistema humano-biofisico y observamos que no solo el conocimiento actual es insuficiente para predecir (y en algunos casos para describir), sino también que la ciencia positivista por si sola no es adecuada para enfrentar los problemas de la conservación del oso pardo. Recomendamos cambios en la ciencia y manejo que pueden mejorar el aprendizaje y responsabilidades entre los individuos y las organizaciones involucradas, clarificar algunas incertidumbres existentes y por lo*

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tanto incrementar la efectividad del manejo y conservación del oso pardo. Mientras que el manejo adaptativo es una aproximación que promete, indicamos algunos puntos clave, tales como contingencias de implementación de un método como este, no abordadas en su totalidad, método que se basa en procesos sociales y estructuras que promueven un aprendizaje abierto y otorgan flexibilidad en todas las fases de los procesos políticos.

Introduction

Grizzly bear (*Ursus arctos horribilis*) conservation is a complex and messy business. It challenges biologists and managers, who gather, interpret, and apply scientific information, and transcends the definitions and understanding offered by biology alone (Primm 1993; Mattson & Craighead 1994). Successful grizzly bear conservation requires broad thinking that includes a range of problem-solving approaches encompassing all of the many facets of real-world bear management. The involved players explicitly need to move beyond traditional disciplinary boundaries, conventional paradigms, and rigid organizational frames of reference if they are to implement durable solutions (Miller 1985; Funtowicz & Ravetz 1993; Shrader-Frechette & McCoy 1993; Miller et al. 1994; Clark & Minta 1994; Clark et al., this issue).

We describe a working definition of key problems facing grizzly bear conservation in the Rocky Mountains of the United States and southern Canada. Our emphasis is on a pragmatic definition of the problem rather than a given disciplinary or scientific paradigm (Weiss 1989). We accordingly have not limited ourselves to the view imposed by disciplinary biology, which construes "problems" in terms of biological systems and theory, lack of complete knowledge, and the ever-present view that more research is needed. Rather, we describe a conceptual model focused on grizzly bear mortality, which is really a model of the interface between humans and the natural system. We argue that such complex systems have defied human cognition and an approach to management that waits upon replicable empirical studies. The model raises larger questions about how we create and use relevant information to define and solve conservation issues (Clark 1992, 1993; Clark et al., this issue) and leads to suggestions for improving science and management.

We premise our analysis upon a societal commitment to preserve Rocky Mountain grizzly bear populations and their habitat in a wild state as codified in several laws and policies (e.g., the U.S. Endangered Species Act) (Keiter & Locke, this issue). This has not always been society's goal, nor will it necessarily be a goal in the future (Storer & Tevis 1955; Brown 1985). A different premise (e.g., the sufficiency of preserving grizzlies in a highly modified environment or as captives) would lead to a different diagnosis and conclusion. Our approach to grizzly bear conservation reflects our backgrounds. We have been trained in the positivistic, scientific tradition of the biological sciences (Schön 1983), as field biologists, behavioral ecologists, modelers, demographers, and systems and quantitative ecologists.

A Model of Human-Caused Grizzly Bear Mortality

The problem of conserving Rocky Mountain grizzly bears can be viewed as ensuring that the finite rate of growth for wild populations is at least 1.0 over some appropriate period. Although there is a theoretical basis for assuming that inbreeding and demographic and environmental stochasticity will affect small, isolated grizzly bear populations (Allendorf et al. 1991; Burgman et al. 1993), history has shown that grizzly bears were extirpated because people killed them (Storer & Tevis 1955; Brown 1985; Clark & Casey 1992). Despite controlled hunts and various legal protections, grizzly bear deaths in the Rocky Mountains continue to be caused almost exclusively by humans (Mattson et al. 1995). Although bears killed by humans may have been over-sampled, this bias would have to be several orders of magnitude greater than we currently assume to avoid the conclusion that human-caused mortality is the greatest threat to the survival of grizzly bears in the southern Rocky Mountains. Our conception of the problem therefore follows that of Caughley (1994) and focuses on deterministic (i.e., human-related) causes of mortality rather than stochastic phenomena.

Human-caused grizzly bear mortality is determined by the rate of encounter between humans and grizzly bears and by the probability that such an encounter will result in a grizzly bear's death (Fig. 1). These rates are not immutable and are influenced by the number of humans in occupied grizzly bear habitat, their behavior when present (e.g., human abilities to avoid encounters and conflict, and responses to encounters once they occur [Herrero 1985]), the amount and dispersion of human access to private and public lands (Chester 1980; Mattson et al. 1987; Aune & Kasworm 1989; Nagy et al. 1989; Servheen 1989; McLellan 1990; Schoen 1991), grizzly bear behavior (i.e., aggressiveness and levels of habituation to humans or conditioning to human foods

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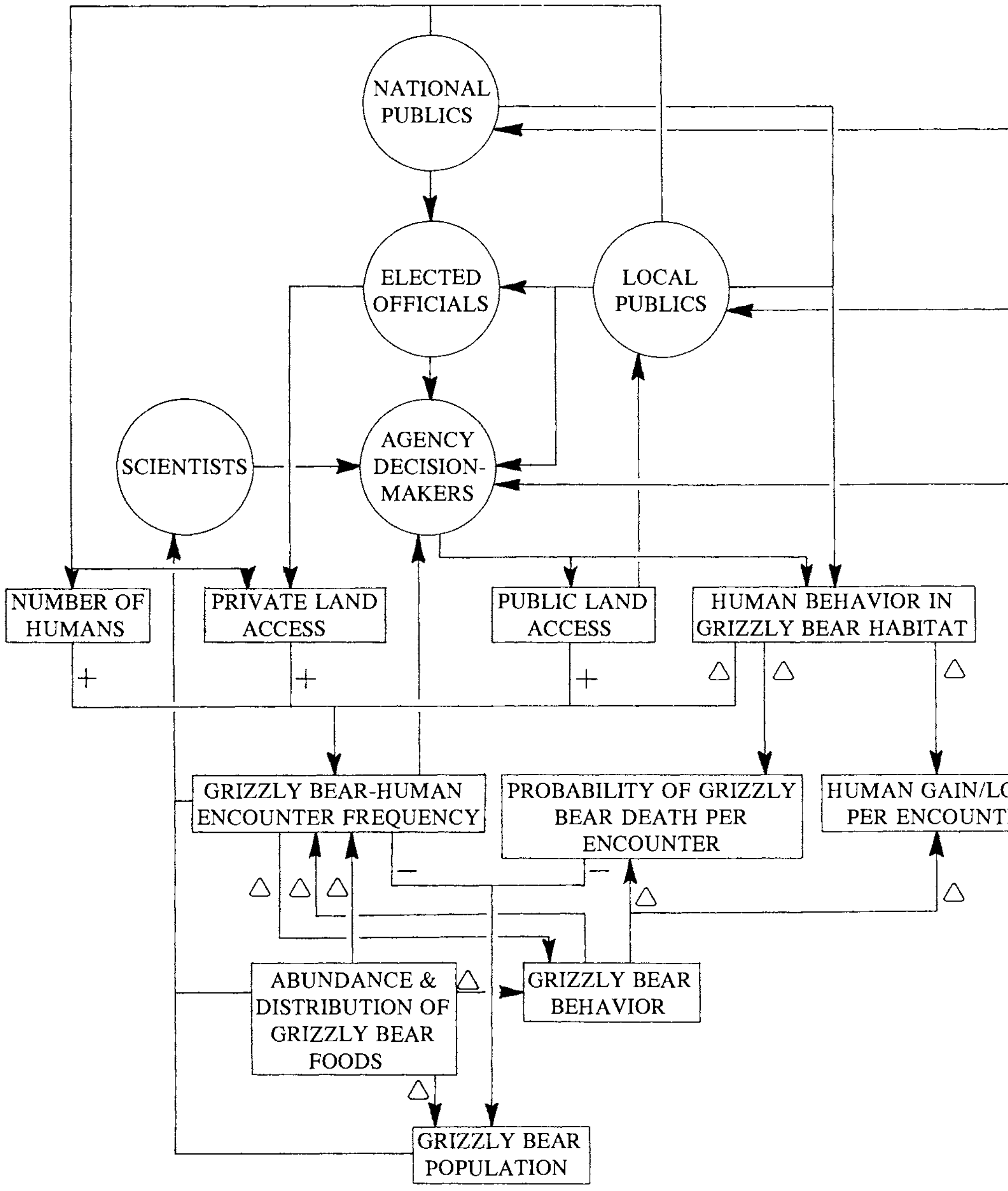

Figure 1. A simplified model of interactions between humans and grizzly bears, emphasizing factors in both the human and grizzly bear domains with greatest effects on the frequency with which bears encounter humans, the probability that a given encounter will result in the bear's death, and the rate at which humans directly or indirectly gain or lose from encounters with bears. Arrows indicate the direction of information flow or physical effects; + and – indicate the nature of response (increase and decrease, respectively) in the dependent state or rate to increased levels of a given factor; and Δ denotes potential for increase or decrease.

[Herrero 1985, 1989]), grizzly bear population size, the distribution of bear foods (Mattson et al. 1992), and the distribution of dominant bears or bears otherwise dangerous to the survival of cubs and subordinates (Mattson et al. 1987; McLellan & Shackleton 1988; Wielgus & Bunnell 1994). Finally, human behavior, access, and numbers are determined by a complex of individual and cultural factors. Of these factors we emphasize political agents (elected officials and other policy formulators), agency decision makers (the ostensible implementors), and the public (Kellert & Clark 1991).

Our effort is best viewed as a simplified, linear heuristic that serves to identify and relate many key elements affecting human-caused grizzly bear mortality. This model diagram does not depict many of the complexities (e.g., all participants or all conceptual variables) or weight the differential effects of model elements. Such modeling details are beyond the scope of this paper (see

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Primm 1993). Nonetheless, our model serves as a useful hypothesis, an "overture" problem definition (Weiss 1989), that we anticipate will lead to other, more complete models as understanding and testing of this system advances.

Feedback Loops

Synergism, or self-reinforcing cycles created by feedback, often dominates the behavior of models and, indeed, natural systems. There are a few feedback loops with this potential in grizzly bear conservation, either because they promise to overshadow other feedback or because they dominate existing science, management, or policy debates. By these criteria, two sets of nested loops stand out that reflect on the net benefits of restricting human access and the influence of biological information in management implementation.

THE RELATIONSHIP OF ACCESS RESTRICTION TO HUMAN BEHAVIOR

There is uncertainty over the efficacy of restricting human access as a means of enhancing grizzly bear habitat, especially in areas such as northern Idaho and northwestern Montana, where much recreation and most timber harvest has been traditionally contingent upon roads (Keating 1995; Oliveria 1995). The cumulative evidence of numerous studies shows a positive correlation between human access and deaths of and reduced habitat use by bears (Mattson 1990; McLellan 1990). The overwhelming support of the data for this correlation notwithstanding, reduced human access may sometimes have unexpected negative consequences if the remaining encounters become more lethal to bears (Kellert 1994*b*).

The public is affected by access management and related changes in industrial and recreational activities, and by changes in well-being that directly or indirectly arise from encounters with bears. This feedback can modify public perceptions and can potentially change human behavior and related risks to bears, or even change legal mandates, such as the U.S. Endangered Species Act, through influences on elected officials. Thus, a potentially positive action, such as restricting human access, could take on negative manifestations by adversely affecting legislation or people's tolerance of bears. It is thus vital to understand this feedback loop and circumstances that lead to increased grizzly bear survival.

Consider, for example, the situation in Idaho, where planning is underway to reintroduce grizzly bears into the Selway-Bitterroot Recovery Area, and where road management is being reevaluated in the Selkirk and Yellowstone ecosystems. We predict that the frequency of human-bear encounters will decline if access is restricted and regulations are more stringent in greater portions of the grizzly bear's range (Fig. 2a). But increased restrictions will likely increase the antipathy of the local public toward bears and government. Under conditions in which humans are freely armed with rifles (as on private lands or most multiple-use public lands) and industrial or recreational opportunities are reduced, lethal encounters could increase. On the other hand, in settings such as national parks, where the visiting public is largely unarmed and mostly nonlocal, lethality may remain unchanged.

When changes in human behavior (≈ lethality) are factored with changes in access (≈ encounter frequency) to derive an index of grizzly bear mortality rate, several general predictions result (Fig. 2b). First, access reduction promises the greatest gains where people are unarmed visitors (i.e., in a park setting). Second, in areas where people are armed and antagonized, there may be no gains by restricting access if those restrictions are relatively ineffective (i.e., when road closures don't work). Third and most important, where the number of people willing to kill bears increases as a function of reduced access, mortality may actually increase under even modest restrictions and may decline only when substantial areas are protected well away from where most humans would likely operate without motorized access. In short, because little of Idaho's grizzly bear recovery areas consist of national parks, successful conservation of grizzlies may depend largely upon the level of support and acceptance that exists or that can be recruited among local residents and their elected representatives (Maguire & Servheen 1992; Clark & Reading 1994; Kellert et al., Primm, this issue).

INPUT TO AGENCY DECISION MAKERS

Another important feedback loop centers on agency decision makers—district rangers, forest supervisors, or park wardens—who are charged with implementing management policy. These officials mediate the conflicting demands of a host of mandates and publics. The decisions they make regarding access and management of human behavior are thus affected by diverse influences other than laws and regulations, including budgets, personal history, direct contact with elected officials, agency culture, and values of the public where they live (Sabatier 1978) (Fig. 3).

Agency decision makers also receive information about grizzly bears from scientists and agency biologists, but this information and the individuals who communicate it will often have little effect on management decisions for three important reasons: (1) effects on grizzly bear demography are less immediate than the influence of the sociopolitical domain (Mattson & Craighead 1994); (2) reliable information on grizzly bear population trends takes years to collect (Miller 1990) and is further diffused by the 3- or 6-year running means commonly employed by the U.S. Fish and Wildlife Service (1993); and (3) measurement techniques and the treatment of uncertainty are controversial (Mattson & Craig-

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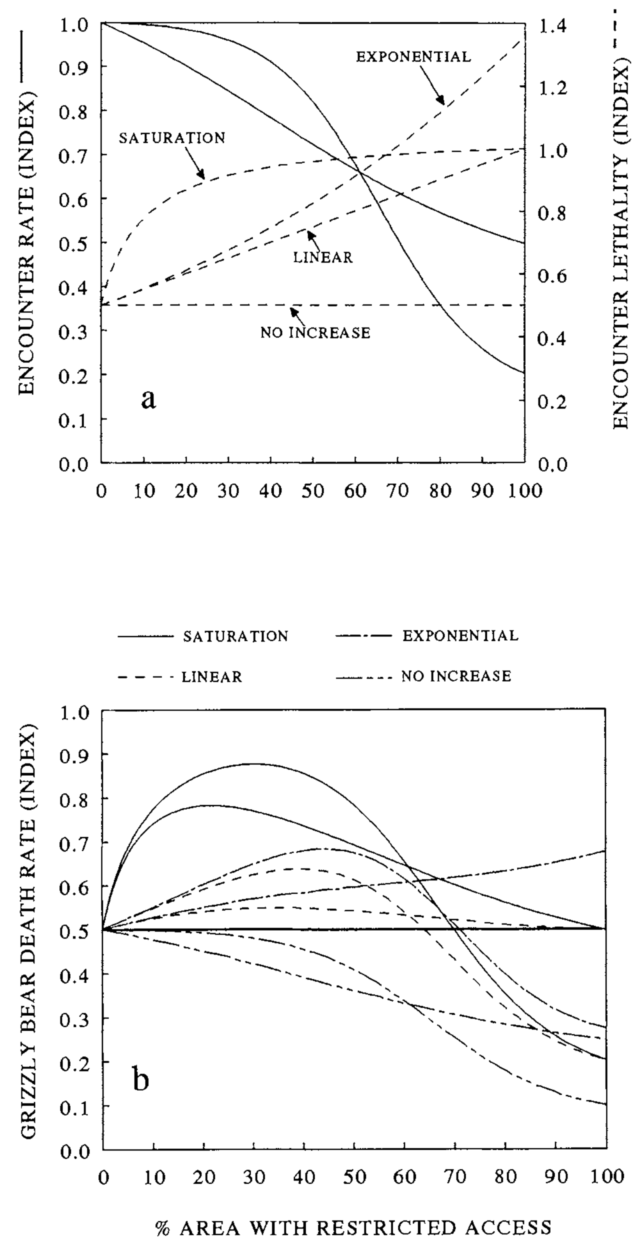

Figure 2. Hypothesized relationships of encounter rate, probability of grizzly bear death per encounter, and a derived index of overall human-caused death rate (d(N)$_H$) *to levels of habitat protection expressed as the percentage of a recovery area that is protected by restricted access, and the effectiveness of those restrictions: encounter rates (solid lines) are assumed to decline sigmoidally as a function of area protection and to reflect the distances humans will range from convenient motorized access (expressed as two levels of effectiveness); lethality of encounters to grizzly bears (dashed lines) is assumed to vary one of four ways (without change or linear, exponential, or asymptotic increases) (a). There are eight combinations of human-caused death rate, varying with the size of protected area, that derive from these eight scenarios (b). All levels of protection result in reduced* d(N)$_H$ *when lethality does not vary with protection; all other scenarios result in increased* d(N)$_H$ *under modest levels of protection, by area or effectiveness. Substantial declines in* d(N)$_H$ *are expected only when there is effective protection over very large areas.*

head 1994). A manager may suffer the negative political consequences of his or her actions overnight, but may never have to deal with the career-damaging consequences of a decision that is immediately popular but will be detrimental to grizzly bears years in the future. In such situations it is clearly rational to expect that some people will minimize perceived personal risk (Heinen & Low 1992; Michael 1995), even at potential cost to the greater social good (Shrader-Frechette 1991) and to grizzly bears.

Thus, grizzly bears may be given little consideration in management decisions if the biological information available from scientists is at odds with powerful and immediate sociopolitical input (Bella 1987; Primm 1993; Mattson & Craighead 1994). This syndrome is likely common because of the prevalent dominionistic and utilitarian values among residents near or within areas occupied by grizzly bears (Reading & Kellert 1993; Reading et al. 1994; Kellert et al., this issue). Traditional reliance upon "prohibitive" management tactics to implement grizzly bear conservation almost certainly antagonizes people holding such values (Yaffee 1982, 1994). This local antagonism can lead agencies to interpret information and uncertainty in ways that favor status quo approaches to using public and private resources (Ingram 1973; Bella 1987; Ludwig et al. 1993). Thus, even with legal mandates such as the Canadian National Parks Legislation or the U.S. Endangered Species Act (Keiter & Locke, this issue), if money is not allocated to institute needed management, if agency culture does not value the task of grizzly bear conservation, and if the local public is hostile, little to nothing may actually be done to protect grizzly bears (Houck 1993; Primm 1993; Mattson & Craighead 1994).

The Importance of Uncertainty and Error

It is the perceived status of grizzly bears and their relationship to humans that influences human choices. Thus, human perceptions and the associated errors introduced in science and management by measurement, sampling, analysis, and human bias are important to understanding how humans influence grizzly bear populations. Variation in perceptions from some fundamental reality, such as numbers of bears, is normal. The degree to which humans engaged in studying and managing grizzly bears acknowledge their uncertainty and bias is

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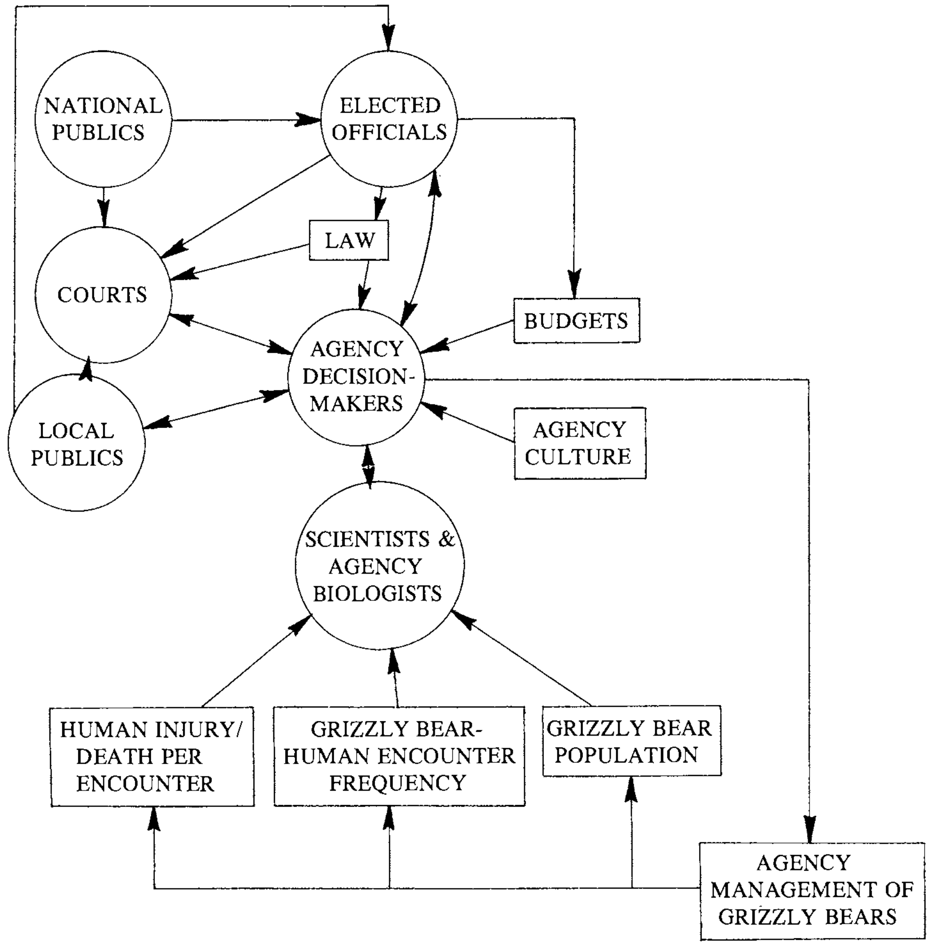

Figure 3. A simplified model of the factors and associated information impinging on key agency decision makers responsible for the management of grizzly bears. Arrows indicate the preponderant direction of sometimes reciprocal information flow.

important to grizzly bear survival. An unduly optimistic estimate (e.g., of population growth rate) that is assumed to be accurate and precise could easily lead to a relaxation of management (e.g., greater allowable mortality), which could lead to more dead bears.

Not all error is of equal consequence (Shrader-Frechette 1991; Reckhow 1994). The costs of a poor estimate of population growth may be either extirpation of bears or the necessity of managing more grizzly bears than were anticipated. But grizzly bears are especially vulnerable to over-estimation of population growth and size because their low fecundity prevents a quick recovery from unintentional over-killing even if mortality rates are reduced (Miller 1990). Put simply, the societal costs—failure to meet conservation policy aims—of unintentional over-kill will be greater than the costs of unintentional population increases. Furthermore, the former is without immediate remedy if it leads to extirpation.

The problems of erratic or chronic bias and unequal error costs are potentially addressed through allocating burden of proof, determining acceptable risks, choosing which bound of certainty to use, and varying the emphasis on type I and type II errors (Shrader-Frechette 1991; Shrader-Frechette & McCoy 1993). The implications for grizzly bear management are enormous, depending on whether society requires that agencies prove that proposed actions will or will not harm bears, or that managers operate on the basis of upper or lower confidence limits of, for example, an estimate of population growth rate (Bella et al. 1994; Weaver et al., this issue). Managing for a high probability of grizzly bears surviving 1000 years will similarly be much different from managing for a modest probability of survival over 100 years (Mattson & Craighead 1994).

Allocating burden of proof and determining acceptable risk are major policy issues (Shrader-Frechette 1991). Under strong statutes such as the Canadian National Parks Legislation or the U.S. Endangered Species Act, scientists and managers are ostensibly directed to minimize risk to grizzly bears. But even these statutes do not clearly specify parameters of risk, and clarification is still needed from experts, the courts, or elected officials (Mattson & Craighead 1994; Keiter & Locke, this issue). Agencies find it hard to reach clarification of these matters on their own, primarily because of their cultural predisposition (Yaffee 1982, 1994). Where there is not an unequivocal legal mandate, as in most of Canada, acceptable risk and burden of proof need to be established through a more local social process that involves the public and stakeholders (Gregory & Keeney 1994; Keiter &

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Locke, this issue). In either case, acceptable risk and proof have not yet received concerted management attention (U.S. Fish and Wildlife Service 1993).

This issue is aggravated by a problem of scale (Ruggiero et al. 1994). Because grizzly bears and their sign exist at such low densities in the Rocky Mountains, data are almost always collected from very large areas. Sample sizes from a specific locale are rarely adequate for scientifically "defensible" inferences. Management, on the other hand, assesses proposed actions typically at the scale of a few square kilometers, if not hectares. Whereas monetary economic gains are quite often tallied with great precision and even accuracy, effects on grizzlies are typically estimated only by extrapolation or other questionable deduction. Information on grizzly bears is almost certain to be uncertain (especially in contrast to information on commodities) as a chronic outcome of the scale at which agencies normally manage grizzly bear habitat. Thus, where the burden of proof has not been clarified or where the burden is placed upon those favoring grizzly bear conservation, management often leads to incrementally greater risk of decline and extirpation for vulnerable bear populations (Weaver et al. 1986; Primm 1993; Mattson & Craighead 1994).

Knowledge of Model Parameters

There is considerable uncertainty about most factors likely to determine the number of grizzlies that die, which affects our ability to answer questions concerning the frequency with which humans will kill grizzlies under different scenarios and whether this level of mortality will allow for grizzly bears to persist. We clarify the nature and extent of this uncertainty with a brief review of relevant biological information. We have limited direct knowledge about sociological information and techniques, and we do not address the higher-order factors and feedback that are also central to grizzly bear conservation policy.

Relationships

Some definitive qualitative information does exist for model parameters. With few exceptions, we can confidently predict that grizzly bear mortality will increase as the frequency or lethality of encounters with humans increases. Population growth rate or even population size and probability of persistence will correspondingly decline. A few select circumstances aside (e.g., McNeil River Falls in Alaska, where the number and distribution of human visitors are tightly controlled [Aumiller & Matt 1994] and certain historical bear feeding grounds in Yellowstone Park [Schullery 1992]), history and research are replete with observations that support this prediction. Although grizzly bear populations can survive despite some increased contact with humans (e.g., McLellan 1989), the historical rule has been that extirpation and death are caused almost solely by humans (Storer & Tevis 1955; Brown 1985; Mattson 1990; Clark & Casey 1992; Mattson et al. 1995).

There are similarly conclusive results regarding the consequences of human access, whether measured in terms of road densities or permanent residential facilities. Researchers have consistently found that black bears (*Ursus americanus*) and grizzly bears underutilize habitat near roads or other human facilities (Mattson 1990; McLellan 1990). This has been ascribed either to bears avoiding humans or to the selective over-harvest of human-habituated bears that would otherwise more fully use this heavily human-influenced niche. Although some people would argue with this interpretation (that, for example, we may be erroneously ascribing selective underuse of habitats correlated with human features to the effects of humans themselves), the consistency of this result across a spectrum of conditions, its repetition at several spatial scales (global, regional, and local), and the corroborating association of dead bears with roads and other human facilities argues convincingly for the detriment to grizzly bears of access and permanent human facilities (Mattson 1990; McLellan 1990; Schoen 1991).

We also know quite a bit about how bear behavior affects human safety and the mortality rates of bears. Habituated and food-conditioned grizzly bears are a paradox to humans, posing the greatest threats to tourists (especially campers) and yet providing most of the viewing opportunities (Herrero 1985). Similarly, human-habituated grizzly bears are much more likely to be killed by humans than are wary bears (Meagher & Fowler 1989; Mattson et al. 1992). Bear deaths are also far more likely to occur when bears forage near humans, either because annually varied distributions of rich foods take them there (Mattson et al. 1992) or because human facilities and inherently rich habitats are superimposed. There is also some evidence that wary adult males may usurp more secure back-country habitats and force adult females or subordinate younger bears into more frequent contact with humans (Mattson et al. 1987; McLellan & Shackleton 1988), with increases in the probability that they will be killed (Mattson et al. 1992). Conversely, excessive mortality among adult males, especially in the periphery of occupied habitat, may allow high immigration of subadult and young adult males that, in turn, displace reproducing females and kill their cubs (Wielgus & Bunnell 1994).

Although we understand the basic nature of these relationships—whether they contribute to or detract from grizzly bear persistence—there is not enough information about how changes in human behavior and numbers alone explicitly affect grizzly bear mortality and how these factors interact with access and general habi-

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tat conditions to allow precise and accurate predictions (Weaver et al., this issue). Similarly, we know little of practical import—or at least available information and theory have not yet been exploited—about how human values or behavior change on a large scale, or, more important, how those changes specifically modify bear survival (Clark & Reading 1994; Kellert 1994*a*, 1994*b*; Kellert et al., this issue). We need to know more about relevant aspects of the human domain and apply as yet unexploited information that may be available from sociology and psychology (Brewer & Clark 1994).

Problems with Measurement

Despite considerable effort, either the availability or knowledge of techniques for measuring most model features are still deficient. Our expertise and the expertise of most other grizzly bear researchers do not embrace the techniques available or needed to measure the human attributes we have described (Kellert & Clark 1991; Kellert 1994*a*). Human behavior cannot be usefully related to population persistence unless some consensus exists upon the definition and measurement of these parameters, in addition to widely accepted techniques for estimating the variance and mean of such parameters as grizzly bear population size and growth.

A substantial part of grizzly bear research has focused on measuring either population size or vital rates, and from these estimating population growth rate. Although techniques have been developed with promise for estimating population size in either the relatively open habitats of Alaska (Miller et al. 1987) or where there are relatively high densities of forest-dwelling grizzly bears (Mace et al. 1994; variations on mark-recapture techniques using intensive aerial surveys or remote cameras), researchers have been unable to obtain useful annual estimates for the size of an entire Rocky Mountain grizzly bear population in its typically forested haunts. Despite long-term research and monitoring, low densities, wary behavior, and low visibility seem to defy reliable measure (Mattson & Craighead 1994). Alternately, estimation of growth rate from the vital rates of radio-marked bears requires many years of data collection and attention to the numerous biases that can be introduced by unequal sampling of months, years, or types of bears, as well as errors ascribable to deficient analytical technique. Improvements in management will continue to depend on new concepts, better analysis methods and data, and development of organizational structures to ensure that new information is incorporated into management techniques and that results are adequately monitored.

The Limitations of Traditional Science

The traditional positivistic approach to addressing these shortcomings in information and methods would entail either or both of two methods. The first is replication of studies over numerous areas embracing a spectrum of human attitudes, densities, and access, as well as grizzly bear densities and population compositions, in different habitats with different major foods. The studies should be conducted over a period of time sufficient to capture endemic annual variation in habitat use, if not the effects of catastrophic habitat changes. The second is systematic control of all factors extraneous to the one of interest, factor by factor, with subsequent reconstruction of the system by specification of increasingly complex interactions (Romesburg 1981; Carpenter et al. 1995). We will probably not live to see such a scientific program either begun or concluded. There isn't enough money, bears, or even time to conduct such research, nor are scientists at liberty to manipulate the behavior and distribution of humans on such a scale simply for the convenience of research design (Rousch 1995; Weaver et al., this issue).

Not surprisingly then, the classic approach to science of hypothesis and deduction (Romesburg 1981) has been remarkably ineffective at posing questions and addressing similar problems arising from an intersection of the human social domain with complex, nonlinear ecological systems (Clark 1993; Bunnell & Dupuis 1995). Chaos, emergent complexity, and narrowly bounded and unfruitful problem definitions are characteristic, as are persisting uncertainty despite large data-gathering efforts and large monetary investments (Barnthouse et al. 1984; Miller 1993; Shrader-Frechette & McCoy 1993).

The amalgam of biophysical and social factors controlling grizzly bear mortality has defied scientifically reliable predictions and will likely continue to do so (Kravtsov 1993; Bella et al. 1994; Funtowicz & Ravetz 1994). This is not to say that scientists will be unable to inform our insight or judgment by analyzing broad historic patterns of grizzly bear population survival or to identify indicators of various system attributes (e.g., grizzly bear population size and trend), or that we will be unable to characterize the system in ways that are directly helpful to management. Rather, this information will not likely give us the ability to predict changes in, for example, grizzly bear mortality to a standard that most scientists and managers would consider reliable science—with a 90–95% chance of not being wrong. Without denying the beneficial applications of traditional methods, other means of coping with this uncertainty and lack of knowledge are needed.

These epistemological problems have major implications for grizzly bear management and human social processes. An implicit and fundamental understanding common among grizzly bear researchers and managers is that given enough time and resources researchers will provide scientifically reliable answers to the managers' questions (Bella et al. 1994). Accordingly, managers wait for delivery of their answers and, lacking data that indicate the harm of a proposed action to grizzly bears, understandably accom-

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modate the immediate, compelling sociopolitical demands that favor the creation of economic wealth from natural resources (Ludwig et al. 1993; Primm 1993; Reading & Kellert 1993; Mattson & Craighead 1994).

The implicit contract between researchers and managers will likely never be fulfilled, not for lack of effort and ingenuity but because of a complex and irreducible system. Managers are asking researchers what they will probably never know with certainty—the exact density and types of roads that are compatible with grizzly bear persistence in a given area, for example, or whether an expanded campground at Norris Junction in Yellowstone Park or an expanded ski area near the Town of Banff in Banff National Park will be the straw that breaks the camel's back. The unspoken contract and its attendant unrealistic expectations need to be corrected (Shrader-Frechette & McCoy 1993), and the corrections are partly contingent upon the people involved reaching a new understanding of science and management (Clark 1992, 1993; Gunderson et al. 1995).

Improving Grizzly Bear Science and Management

Our diagnosis of problems impeding effective grizzly bear conservation naturally leads to the identification of measures that could help save grizzly bears. We offer these only as guides to action, not as an official position; they presuppose a societal commitment to grizzly bear conservation. Despite the temptation to cast conservation as an objective scientific endeavor, it is fundamentally a business defined by value-laden goals and, at best, guided by "reliable" scientific information. It is also a process, like most, strongly influenced by our epistemologies and the models by which we understand our places in the world (Primm & Clark, this issue).

Adaptive management (Walters 1986; Gunderson et al. 1995) and "post-normal" science (Funtowicz & Ravetz 1993) are concepts with roots in positivistic science that can nonetheless contribute to redefining the relationship between science and management and thereby facilitate our investigation and understanding of complex relationships between humans and natural systems. Both concepts more explicitly integrate social values and norms into establishing goals and acceptable risks and propose new protocols for using information. Adaptive management, in particular, emphasizes the importance of learning at the personal, professional, organizational, and societal levels (Gunderson et al. 1995; Parson & Clark 1995). Together, these emerging concepts offer potential ways to reduce current debilitating fragmentation of information, authority, and interests among managers, scientists, stake-holders, and the public (Lasswell 1971; Brewer & Clark 1994; Clark & Reading 1994).

Adaptive management is frequently touted because it provides a dynamic rational process, derived from traditional positivistic science, for developing the most defensible (or "likely") model to explain available information and then uses this model to direct management. For example, this approach could be used to anaylze systematically all information relevant to the relationship of road densities to grizzly bear persistence and to derive a model that is most consistent with the observed—albeit uncertain—patterns. This model could then provide a rationale for site-specific road-management objectives or standards. Monitoring would inform researchers and managers whether local mortality and population responses were consistent with expectations. If deviations were observed, then corrective changes in the model and management would need to be taken. Most important, management could act and be continually updated in response to currently available biological information and could serve to generate otherwise unavailable information (Ludwig et al. 1993).

Movement in this direction, however, is predicated upon three critical assumptions: (1) that we can adequately monitor and integrate information about humans and grizzly bears; (2) that agencies can expeditiously incorporate information gained from monitoring into their management; and (3) that managers and scientists can engage each other and the public in developing coordinated, satisfactory management and science (i.e., that expectations and values will be adequately incorporated into the process). All of these conditions are contingent, in turn, upon land and wildlife management agencies with adaptive open-learning mechanisms (Clark 1993; Brewer & Clark 1994) and with sufficient resources, authority, and incentives. The history of grizzly bear management in the United States and Canada suggests that there is considerable room for agency improvement in all of these critical regards (Nagy & Gunson 1990; Primm 1993; Clark & Minta 1994; Mattson & Craighead 1994). A fundamental redesign of management agencies will likely be a key part of any effective long-term management of the fragmented grizzly bear populations typical of the contiguous United States and parts of southern Canada (Kellert 1994*a*). More than anything else, however, improved management of grizzly bears may be contingent upon managers understanding the policy process (including organizational and personal behavior) well enough to allow effective problem definition, program implementation, and adaptive responses at all 'panarchical' levels (Clark 1992, 1993; Gunderson et al. 1995; Clark et al., this issue).

The following specific measures we recommend could change science and management in ways that reduce complexity, uncertainty, and conflict, and, thus, promote the survival of grizzly bears.

First, grizzly bear conservation would benefit from continued and more comprehensive mapping of its problems at all relevant scales and domains. Without adequate understanding of the problems, including their

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relationships to processes and participants at all temporal and spatial scales, we will be unable to mobilize or allocate limited resources to achieve the most effective management possible (Clark et al., this issue). This type of in-depth, interdisciplinary effort is inherently difficult given institutionalized obstacles to learning and our inherently limited cognitive capabilities (Gunderson et al. 1995; Michael 1995; Parson & Clark 1995; Primm, this issue). Thus, even this important foundational step may be contingent on a sufficient understanding of *its* confounding problems among policy elites, managers, and scientists so that wide-ranging interdisciplinary problem definition can be fostered by effective incentives.

Second, grizzly bear conservation would benefit from the integration of research and management not just into an adaptive management framework but also as part of a larger policy-making and management system with increased learning capabilities at all levels (Clark 1993; Gunderson et al. 1995; Parson & Clark 1995). This would entail the classical tenets of adaptive management (Walters 1986), as well as increased incentives and improved mechanisms throughout the policy process for democratically resolving conflicts and expressing values in ways that are attentive to scientific information about biological and social systems (McDougal et al. 1988). Partly for reasons discussed in the first recommendation, however, the practicality and particulars of implementing these changes are open to question, at least given the extent of this analysis.

Third, natural resource management agencies would better accomplish any complex task if they were redesigned (Kellert 1994*a*; Westrum 1994). It is virtually certain that agencies would be much more effective at conserving grizzly bears if they were more creative and open to learning from the entire system they were managing (Miller et al. 1994; Yaffee 1994). This logically entails encouraging the free flow of ideas and information, regardless of bureaucratic hierarchies, and increasing the permeability of agency boundaries (Westrum 1994). In addition, because other sociopolitical input is so powerful, the incentives influencing key agency decision makers need to be modified so that these individuals are naturally led to encourage the survival of grizzly bears. In particular, there should be incentives to weight information about grizzly bear populations and their habitat heavily, given the extent to which this information is otherwise inherently made unreliable by delayed feedback (i.e., future discounting) and contentious uncertainty (Costanza & Daly 1992; Mattson & Craighead 1994). This would admittedly be a difficult task given investments by some non-agency special interests in the status quo and the strength and rigidity of agency traditions (Westrum 1994).

Fourth, management would be more effective if assessment of human impacts emphasized a scale commensurate to policy goals and the limitations of grizzly bear investigations (Ruggiero et al. 1994; Paquet & Hackman 1995). These considerations clearly highlight the population as an appropriate level of analysis, with attention to the cumulative impacts—or the "total load"—imposed by humans on grizzly bears and their habitat. This level of analysis could be tied to site- or project-specific analysis through the assignment of objectives, required for meeting ecosystem-level goals, to home-range-sized areas (in the United States to strata called Bear Management Units; Weaver et al. 1986). But such a shift would require bolstering currently weak or inappropriate incentives for managers to support, if not give priority to, transjurisdictional management.

Fifth, grizzly bear conservation could benefit from clarification of the burden of proof on agencies managing grizzly bears and their habitat (Shrader-Frechette 1991; Mattson & Craighead 1994). Is the burden to prove that there will or will not be injury to bears from proposed and existing human activities, or is judgment contingent merely on the balance of evidence? Similarly, policy makers could help by clearly specifying whether we use the most likely, worst, or best case suggested by research (i.e., the central tendency, the conservative bound, or the liberal bound) to guide management. A more clearly articulated prescription would facilitate any policy implementation and evaluation. If, however, society rates grizzly bear conservation above other values where the bears currently survive, then management would logically employ the conservative bounds of scientific uncertainty and require the proof of benign effects. Having said this, national constituencies with special interests antithetical to these views will no doubt seek to thwart consensus on this issue.

Sixth, science and management could also benefit from a clear statement of acceptable risk and relevant time frames for management (Shrader-Frechette 1991; Funtowicz & Ravetz 1993; Mattson & Craighead 1994). This is a policy decision that cannot be made by scientists which will specify the extent to which society values grizzly bears. This determination would help establish the level of confidence researchers employ in scientific estimates as well as the risk and time frame specified in population modeling. We can make no recommendations here, other than to suggest that any time frame shorter than 100 years is trivial for an animal as long-lived as a grizzly bear, which can live up to 30 years. We also suspect that, for the same reasons, resolution of this issue will be as difficult as for that of the fifth recommendation.

Seventh, following from recommendations one through three, researchers could contribute by their pursuit of reliable (Romesburg 1981) means to monitor trends and sizes of grizzly bear populations. In addition, and perhaps as important, managers and researchers would benefit by systematically monitoring the human dimensions of grizzly bear habitat: the numbers, armament, values,

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and behavior of people, as well as dynamic biophysical attributes such as grizzly bear food and shelter. Continued research on trends will probably be easy because of historical emphasis on this topic, whereas systems to monitor humans will likely be complicated by uncertainty over good quantitative metrics and because of traditional antipathy to keeping records on certain types of public activity.

Finally, grizzly bears could benefit by the widespread adoption of management strategies known to be effective but not always implemented. This program would emphasize: (1) sanitation of human facilities wherever humans and grizzly bears come in contact so that conditioning of grizzlies to human foods is minimized (Herrero 1985; Herrero & Fleck 1990); (2) location or relocation of human facilities in or to areas that are likely to receive little grizzly bear use, either for travel, bedding, foraging, or security from other bears, to minimize conflict and habituation of grizzly bears to humans (Herrero et al. 1986); (3) limitation of human activity and numbers in occupied grizzly bear habitat, again to minimize conflict and habituation; (4) limitation of human access to grizzly bear habitat by road and trail; (5) reduction in number of armed people in grizzly bear habitat (other than during legal hunting seasons), especially in combination with foods or odors that attract grizzly bears (Herrero & Fleck 1990); (6) a balanced management of mortality that favors the survival of females (e.g., the sex-weighted point scheme used in the Yukon [Smith 1990]), but at the same time does not result in excessive mortality of adult males; and (7) education of back-country users and other local residents to minimize undesired conflicts with grizzly bears. We do not identify explicit thresholds or standards for these recommendations because the specifics need to await more rigorous analysis of data from each grizzly bear population. The standards will also be contingent upon the degree to which recommendations one through six are implemented.

We have not explicitly considered two factors that are perhaps as important as any to the ultimate survival of grizzly bears in the Rocky Mountains: (1) the degree to which politicians and managers involve the public in developing conservation strategies and corresponding ownership of the process by affected citizens (Gregory & Keeney 1994; Kellert 1994*b*; Wondolleck et al. 1994; Primm, this issue), and (2) the life-styles and values of humans in Canada and the United States. If grizzly bears are resented and consistently held in lower regard than other resources that we demand from their remaining habitat, then wild grizzly bears in the southern Rocky Mountains will almost certainly disappear, and their descendants will survive only as penned and catered relics. The survival of grizzly bears and other wild things in the Rocky Mountains might simply follow from the extent to which we can peacefully resolve conflicts among ourselves and adopt more tolerant and less acquisitive life-styles (McDougal et al. 1988; Daly & Cobb 1989).

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