BACKGROUND AND PROPOSED STANDARDS FOR MANAGING GRIZZLY BEAR HABITAT SECURITY IN THE YELLOWSTONE ECOSYSTEM

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INTRODUCTION

The Endangered Species Act requires that managers anticipate and minimize negative human effects on threatened and endangered species to the extent necessary for insuring viability. This stipulation is especially relevant to grizzly bears (*Ursus arctos horribilis*) given that direct human-caused mortality is the arguable cause of virtually all grizzly bear population declines and extinctions (see Storer and Tevis 1955, Craighead and Mitchell 1982, Brown 1985, Servheen 1989a, and Mattson 1990), and that human access is a primary mediator of this mortality (Mattson 1990, McLellan 1990, Mattson and Knight 1991a).

A wealth of information concerning the responses of grizzly bears to humans has accumulated especially within the last 10 years. During this same time the Interagency Grizzly Bear Study Team, National Park Service, and Wyoming Game and Fish have collected information that is specific to bear behavior and survival in the Yellowstone ecosystem. However, there has not been a recent summary or interpretation of this information in terms relevant to grizzly bear management and, more importantly, in terms applicable to derivation of road density standards. I have attempted to serve these purposes in this paper.

This paper is organized into four sections. The first constitutes a review and summary of literature pertaining to the responses of grizzly bears to humans. The second provides a rationale and parameters for what I call "micro-scale" security areas - areas that are functional at the scale of individual foraging bouts. The third section provides methods for calculating standardized road densities in a way that reflects access by motorized vehicles and the presence of cover. The fourth and last section provides a rationale and parameters for grizzly bear road density standards in the Yellowstone area and, in addition, sets forth a conceptual frame-work for relating Yellowstone-specific standards to the global situation.

SECTION 1 -- Grizzly Bear Responses to Human Activities: A Summary and Interpretation

This section presents a summary and interpretation of existing literature concerning the responses of grizzly bears to humans. I have organized this information first as basic observations, and then as direct inferences that integrate and reconcile these observations. I included not only information concerning the immediate behavioral responses of grizzly bears to humans, but also population-level responses that were mediated through direct human-caused mortality. I limited the scope of my review to North American grizzly bears, although I have included results from Eurasian brown bear studies where there was some compelling relevance.

Basic Observations

Immediate Responses.--

- Some grizzly bears readily habituate to humans, especially if humans are associated with high quality human-origin or natural foods (Braaten and Gilbert 1990; Warner 1987; Fagen and Fagen, in press; McArthur Jope (1983); Jope (1985); Olson et al. 1990; Tracy 1977; Herrero 1985).

- Proportionally more of resident grizzlies habituate to humans when human use is spatially and temporally predictable, and the bear population protected from hunting (McArthur Jope 1983, Jope

1985, McLellan and Shackleton 1989, Kendall 1983, Jope and Shelby 1984).

- Grizzly bears are more likely to use roads, recreational trails, and areas near human residences (campsites or front-country facilities) at night or when unoccupied (Nadeau 1989, Harting 1985, McLellan and Shackleton 1988a, Gunther 1990, Hoak et al. 1983, Zager 1980).

- Grizzly bears are more prone to flight from humans in the back-country than most other large vertebrates (Chester 1980).

- Flush distances vary from 44m to 370m, on average, primarily depending on whether the bear is in or out of cover and whether the bear or human(s) approach prior to the bear detecting the human(s). Flush distances tend to be closer in cover or when the bear approaches people unaware of their presence (Jope 1985, McLellan and Shackleton 1989, Schleyer et al. 1984, Haroldson and Mattson 1985).

- Grizzly bears move away or flee from people during 25-100% of encounters, primarily depending on whether the bears population is hunted, they encounter people on foot, whether the bear is in the open, or whether the encounter is near facilities receiving high levels of predictable human use. Flight is less frequent when bears are in cover compared to in the open, part of a protected-unhunted population, near human access that has higher levels of spatially and temporally predictable human use, or when encountering humans in moving vehicles rather than on foot (Jope 1985, Gunther 1990, McLellan and Shackleton 1989, Chester 1980, Albert and Bowyer 1991).

- Grizzly bears tend to flee farther (>1km, and up to 1.4-3.0(8.6)km) after relatively unpredictable encounters with humans on foot in back-country areas, especially in the open (McLellan and Shackleton 1989, Schleyer et al. 1983, Haroldson and Mattson 1985, Gunther 1990).

- Flight from encounters in open areas is consistently towards cover (Gunther 1990, McLellan and Shackleton 1989, Schleyer et al. 1984, Haroldson and Mattson 1985, Smith 1978).

- Aggressive responses to encounters are more likely when a female with dependent young is involved, when the population is unhunted, and when the encounter occurs in areas where there is less human activity that tends to be less spatially and temporally predictable (McArthur-Jope 1983, Jope 1985, Herrero 1985, Jope and Shelby 1984, Gunther 1990, McLellan and Shackleton 1989, Albert and Bowyer 1991, Olson et al. 1990).

- Most of this variation in flight response and aggression is ultimately attributable to the degree of wariness or human-habituation among bears in the respective study area, with habituated bears exhibiting less flight response and less aggression in day-light encounters (Braaten and Gilbert 1990, Warner 1987, McArthur-Jope 1983, Jope 1985, McLellan and Shackleton 1989, Albert and Bowyer 1991, Kendall 1983, Jope and Shelby 1984, Olson et al. 1990).

- Fewer bear conflicts and human-injuries occur when human use is regulated so that it becomes more temporally and spatially predictable, and restricted to specified levels (Warner 1987; Fagen and Fagen, in press; Albert and Bowyer 1991; Dalle-Molle and Van Horn 1989).

- A large portion of human fatalities caused by grizzly bears is attributable to human-habituated and food-conditioned bears; and a substantial portion of these fatalities occur at campsites during the night (Herrero 1985, Herrero and Fleck 1990).

Population-Level or Demographic Responses.--

Conflicts and Mortality.-

- Number of conflicts between grizzly bears and humans is positively correlated with levels of human use as it changes seasonally or among years, especially in areas where human activity is unregulated and/or where the bear population is protected from hunting (Fagen and Fagen, in press; Mattson et al. 1992; Keating 1986; Titus and Beier 1992; Albert and Bowyer 1991; Kendall 1983; Smith et al. 1989; Dalle-Molle and Van Horn 1989).

- Number of human-caused grizzly bear mortalities is positively correlated both spatially and temporally with increased human access and activity, and the resulting increased contact between bears and humans. This relationship is evident in both protected and hunted populations, but is most pronounced where hunting is allowed (Mattson et al. 1992, Mace et al. 1987, Titus and Beier 1992, Mattson and Knight 1991a, Smith et al. 1989).

- Known human-caused mortality occurs disproportionately more often within 1.5-1.6km of a road compared to areas more remote from roads, or is negatively correlated with distance to the nearest road (Mattson and Knight 1991a, McLellan and Shackleton 1988a, Dood et al. 1986, Aune and Kasworm 1989).

- Few grizzly bear population ranges include major town-sites or recreational developments, however those populations that do exhibit disproportionately the greatest mortalities in association with these features (Servheen 1989b, Mattson and Knight 1991a).

- Habituated or food-conditioned grizzly bears are much more likely to be killed by humans than bears that remain wary, especially where human activity is relatively unregulated and/or hunting allowed. Conversely, survival of habituated bears is relatively high in more remote but unhunted areas where human activity is highly controlled (Mattson et al. 1992, Meagher and Fowler 1989, Dau 1989, Braaten and Gilbert 1990, Warner 1987, Albert and Bowyer 1991, Olson et al. 1990).

- Subadults and adult females with young are disproportionately common among habituated bears that range near humans, with the exception of Glacier National Park's back-country. In a few studies females with young tended to avoid areas near humans, probably because they were avoiding the adult males concentrated on high quality food sources that were also located near the human facilities (as at Brooks River Falls) (Braaten and Gilbert 1990; Warner 1987; Fagen and Fagen, in press; Mattson et al. 1992; Jope 1985; McArthur Jope 1983; Tracy 1977; Olson et al. 1990; Dau 1989).

- Subadult males were disproportionately killed by humans in most study areas, most often by hunters, in conflicts over livestock, or as a consequence of risks posed to humans (Dood et al. 1986; Dood and Pac 1993; Nagy and Gunson 1990; Mace et al. 1987; McLellan and Shackleton 1988b; Bunnell and Tait 1980, 1985). This vulnerability is partly attributable to wider-ranging movements (Bunnell and Tait 1980) and long-range dispersal into unfamiliar habitats (Blanchard and Knight 1992, Mattson 1990).

- Proportionately more bears from hunted populations are killed illegally or to resolve conflicts in areas that contain or are near more resident humans (McLellan and Shackleton 1988b, Mace et al. 1987, Nagy and Gunson 1990).

- Ungulate hunters accounted for a large portion of defense-of-life-and-property (DLP) kills in several study areas (Titus and Beier 1992, Smith et al. 1989), including the Yellowstone ecosystem since 1988, or most illegal kills occurred during the big-game hunting season (Knick and Kasworm 1989).

Distribution and Behavior.-

- Habituated bears are proportionately most active and most common near human facilities such as roads, viewing areas, and recreational developments, especially in unhunted populations (Braaten and Gilbert 1990; Warner 1987; Fagen and Fagen, in press; Mattson et al. 1992; Jope 1985; McArthur Jope 1983; Albert and Bowyer 1991; Tracy 1977; Olson et al. 1990; Dau 1989; Herrero 1985).

- Grizzly bears consistently under-use habitat within 100-500(914)m of roads. This under-use does not vary substantially with use levels or whether the road is paved or unpaved, and is exhibited at very low levels of traffic (0.5-1.9 vehicles hr^{-1})(Aune and Kasworm 1989, Kasworm and Manley 1990, Mace and Manley 1993, Archibald et al. 1987, McLellan and Shackleton 1988a, Mattson et al. 1987). Similarly, grizzlies under-use habitat where open road densities exceed 1 $mile/mile^2$ (Mace and Manley 1993), and observations of bear sign are negatively correlated with km of road (Elgmork 1978).

- Grizzly bears under-use habitat within 400-2000m of occupied back-country campsites and cabins by

40-67% (Gunther 1990, Elgmork 1983). Bear also tend to use back-country foraging areas at different times than humans where human activity is not highly controlled (Olson et al. 1990, Gunther 1984).

- Grizzly bears substantially under-use habitat near town-sites and major recreational developments in the Yellowstone ecosystem. This under-use extends out to between (1)4-5km, and impairs daytime use by between 46-94% within this zone, depending on the season, food, and development (Mattson et al. 1987, Mattson and Knight 1992, Reinhart and Mattson 1990).

Inferences and Implications

- Immediate responses of grizzly bears to humans are arguably a function of the bear's wariness/habituation, the setting (whether in cover or at an atypical site), whether the encounter is with a vehicle, and whether the bear or human approached immediately prior to detection. Encounters between wary bears and humans on foot, especially in the open and in atypical situations, will likely result in a more extreme response by the bear characterized by either aggression or long-range and rapid flight. Aggressive responses are more probable if this type of encounter involves a female with dependent young.

- Habituation will be more common among bears in any given area or population if the bears are unhunted and protected, if levels of human use are high, and if that human use is spatially and temporally predictable.

- Habituation allows grizzly bears to more fully use habitat that is near human facilities, and lessens the probability of an extreme response during encounters with humans. However, the fact that an habituated bear is more likely to range near people will predictably result in a much higher rate of close encounters with humans. Habituated bears will pose the least threat to human safety where there is the tightest control of human activity with the intent of creating consistent and highly predictable spatial and temporal distributions.

- Because habituated bears are more vulnerable to hunting and poaching, and are often perceived to be a threat to human safety, they are typically killed at a higher rate than wary bears. Thus, habituation typically increases mortality risk for individual bears except where human activity is closely regulated and the bear population is unhunted.

- Areas near human facilities can constitute short-term refuges for females with young and subadults, with the attendant condition that these animals become habituated to humans. This refuge effect will have varying beneficence to the population depending on how lethal habituation is to individual bears. In turn, lethality will be a function of whether hunting is allowed and how closely regulated humans are.

- Under-use of habitat near human facilities will predictably be a function of individual range sizes, harvest rates, and the distribution of human facilities with respect to productive habitat; and would be greater in populations that have larger ranges and are well below ecological carrying-capacity because of historically high harvest rates, and where human facilities are located in the poorest habitat. Greater under-use would ultimately be attributable to a lower frequency of habituated bears and more opportunities for the remaining warier bears to meet their energetic needs without using habitat near humans. This interpretation suggests that hunting might reduce human-bear conflicts not so much by instilling fear in bears, but by selecting for the survival of wary bears and by providing more individual foraging space for the bears that survive.

- Proportionately more of sustainable harvest rates will be attributable to illegal causes or control actions as the numbers of resident humans in or near occupied grizzly bear habitat increases. Thus, as populations of resident or recreating humans increase, proportionately more bear mortality will be irreducible or resistant to ready management. In this type of situation, management will be much less responsive to population declines than where the majority of mortality is caused by legal hunting. There appears to be trade-off between hunting opportunities and management flexibility on the one-hand and numbers of resident or recreating humans on the other.

- Over-all mortality risk will increase as miles of open roads and numbers of town-sites or major recreational developments increases in occupied grizzly bear habitat. This risk could be substantially reduced by termination or reduction of hunter-harvest. If mortality risk implicit to these human facilities is at or below sustainable levels, then exhibited under-use of habitat should remain stable. If attendant mortality risk is greater than sustainable levels, then under-use would predictably increase, with a possible attendant decrease in human-bear conflicts. Thus, declining levels of human-bear conflict that might be attributed to successful management could alternatively be attributed to over-harvest.

- If habituation is lethal to bears, as in the Yellowstone area, and current levels of non-hunting mortality are at or near sustainable levels, then the bear population's future prospects will likely be determined simply by the over-all frequency of contact between bears and humans, mediated through the level, dispersal, and predictability of human use. Greater numbers of unpredictably dispersed and armed humans will result in higher mortality risk for the population given the same levels of over-all human use.

- Mortality risk for bears will increase substantially as the number of big-game hunters in grizzly bear habitat increases. Risk attributable to big-game hunters is disproportionately high because hunters are armed, often dispersed in an unpredictable way across the landscape, and typically associated with animals remains that attract bears.

SECTION 2 -- Micro-Scale Security Areas for Yellowstone Grizzly Bears

Rationale

Historically, North American grizzly bears did not persist in areas with even moderate densities of humans or domestic livestock (Mattson 1990). Grizzly bears continue to be killed by humans for numerous reasons, most commonly because of conflict over common resources (e.g., livestock and other human foods) or because the bear is perceived as a physical threat (Craighead et al. 1988). Human-bear conflicts often revolve around bears habituated to humans as they pursue natural or human-food related feeding opportunities near humans (Meagher and Fowler 1989; Mattson et al. 1992; Section 1). By inference, as human access and activities increase in an area, increasing numbers of bears are forced to come into contact with and tolerate humans as they use their natural habitat. Circumstantial evidence suggests that this results in an increased frequency of bears habituated to humans (McArthur-Jope 1983; Mattson 1990; Mattson et al. 1992; Section 1), and increased bear mortality either because of chance encounters with humans, where humans claim self-defense, or because management agencies judge the bear's tolerance to be a risk to humans (Mattson et al. 1992).

History has demonstrated that grizzly bear populations survived where frequencies of contact with 19th and 20th-century technological humans were very low (Storer and Tevis 1955; Brown 1985; Servheen 1989). Although grizzly bear mortality can be regulated and influenced by changes in human attitudes, it seems unlikely that humans will generally tolerate much contact with an animal, like the grizzly bear, that is a direct competitor for foods (Mattson 1990) and a potential hazard (Herrero 1985). Thus there is a strong case for preserving areas where grizzly bears will be secure from encounters with humans; where bears can meet their energetic requirements while at the same time choosing to avoid people. Such areas would foster the wary behavior in grizzly bears that most managers consider to be desirable. In conjunction with management of attractants around human facilities and town sites, security areas could help to significantly reduce the incidence of poached bears, and bears killed out of self-defense or killed by management agencies because of undesirable behavior.

In this section I describe the rationale for parameters and identification of what I call "micro-scale" security areas. These areas are functional at the scale of individual foraging bouts, as distinguished from security more directly relevant at the scale of a bear's life-time range. By implication, managers need to provide security not only at the "micro-scale" but also somehow relate these security areas to the goals of viability and recovery. By the conceptualization presented here, this linkage can be achieved through access standards and security area networks (Section 4).

Parameters

Existing analyses of telemetry data from radio-collared grizzly bears provide a basis for postulating dimensions and spacing of security areas, suitable for the scale of an individual bear's home range. Wary bears consistently avoid areas within 2 km of major roads and 4 km of major human developments or town-sites (Mattson et al. 1992), while bears that use areas near roads and developments exhibit disrupted foraging behavior out to these same distances (Mattson et al. 1987). By implication, micro-scale security areas would consist of a 2-4 km wide buffer surrounding a core area corresponding in size to the average 24-48 hour foraging radius of a Yellowstone grizzly bear. This would hypothetically allow a grizzly bear the space to forage while concurrently maintaining its wariness of humans. Results of a 1984-1985 study where grizzly bears were radio-relocated on an hourly basis for periods of 48-96 hours (Schleyer et al. 1984; Haroldson and Mattson 1985) suggested that the average 24-48 hour foraging radius of Yellowstone grizzlies was ca. 0.96 km. Thus, micro-scale security areas should be an absolute minimum of 6 km in diameter or 28.3 km^2 (ca. 7,000 acres). If these areas were roughly pentagonal in shape, radii would vary from a maximum of 3.4 to a minimum of 2.8 km.

Ideally, spacing of these security areas would allow for safe and unimpeded movement of wary bears among secure habitats. Thus, one hypothesized configuration of security areas would place them on average ca. 2x the mean 48-hour foraging radius apart. After accounting for angular irregularities, this distance averages 1.8 km. If an entire analysis area or bear home range (averaging 884 km^2 for an adult female life range [Blanchard and Knight 1991]) were apportioned by these guidelines, ca. 57% would be in security areas. Under less favorable conditions, existing or planned security areas would ideally be contiguous and part of a functional network rather than scattered and isolated.

Identification

For practical reasons security areas should have identifiable characteristics, in addition to dimensions and spacing, that relate to the level and nature of human use within. The literature review in Section 1 and the experimental conditions under which relevant data were collected are logical points of reference for identifying these characteristics. First, there should be minimal dispersed use by armed humans, especially associated with attractants such as animal remains. Encounters between humans and bears under these conditions are potentially most lethal to bears (Section 1). Second, there should be no open roads and only low densities of closed roads and/or trails within a security area. This is in accord with the study area conditions during which the data were collected that were used to derive security area dimensions. Unfortunately, there is no readily accessible basis for empirically estimating the densities of trails/closed roads that are compatible with maintaining adequate security within a security area. However, this issue is potentially addressed indirectly through road density standards, and the identification of related allowable densities of trails and closed roads (Section 4).

To facilitate use and recognition by bears, security areas should logically be secure for some minimum period of time. Optimally, a security area would remain secure indefinitely. In situations where management necessitates spatially and temporally varied human activity, then the duration of security areas should arguably relate to the time required for a female to mature and replace herself (i.e., one generation length) without habituating herself or her cubs to humans. This can be calculated as $\Sigma x l_x m_x / \Sigma l_x m_x$, and averages ca. 11 years for wary female Yellowstone grizzly bears (unpublished data).

Whatever the criteria, security areas can be identified by a series of map overlays done either manually or by a GIS. The optimal sequence would be (1) an initial screening with respect to existing open roads, (2) a subsequent screening to identify high-priority security areas containing high-quality bear habitat, and (3) a final screening to identify candidate areas where sufficient road-closures could create a security area. Furthermore, these areas should be evaluated to determine the temporal sequencing of networks given schedules of planned human activities.

SECTION 3 -- Conversion Factors for Standardized Calculations of Road and Trail Densities

Rationale

Human access has varying impacts on grizzly bears depending on the presence of hiding cover, the intensity of use by humans, and whether motorized vehicles are employed (Kasworm and Manley 1990; Archibald et al. 1987; Schleyer et al. 1984; Haroldson and Mattson 1985; McLellan and Shackleton 1989; Chester 1980; Gunther 1990; and others, see Section 1). These varying degrees of impact are reflected in the zones of influence (ZOI) and "disturbance coefficients" (DC) defined for different types of human activities and access in the publication: *Cumulative Effects Analysis Process for the Yellowstone Ecosystem* (USDA For. Serv. 1985).

Road density standards have become an important part of grizzly bear management in the contiguous United States. Usually only one standard has been applied in any given area. However, as pointed out above and in Section 1, the impacts of any given mile of road will vary according to the amount of associated hiding cover, the level of use, and whether the road is closed to motorized traffic. Trail systems are also commonly ignored in road density calculations, despite the fact that these features also facilitate human access and have demonstrated or likely impacts on resident bears. We need to have some means of accounting for these variables, as well as recreational trail systems, in conjunction with road density standards.

The Cumulative Effects Analysis (CEA) handbook referenced above (USDA For. Serv. 1985) provides a means of dealing with these complexities. By using the ZOIs and DCs for different types of access and activities we can calculate conversion factors that can render miles of road or trail under various conditions into a common standard. Thus, we can add up "equivalent miles" of trails and roads subject to different management and cover to compare to a road density standard derived with respect to the same common standard. In the following section I detail the calculations used to derive conversion factors and give factor values for roads and trails with and without associated hiding cover. I have treated "closed roads" as trails in this approach, thereby giving a more realistic means of dealing with closed roads rather than dropping them from consideration as soon as they are barricaded. This approach is in accord with the direction specified in the CEA handbook (USDA For. Serv. 1985).

Methods and Parameters

I used the latest revised summer values for ZOIs and DCs from the CEA handbook, as follow:

Activity Group	ZOI Distance	Cover DC	Noncover DC
Motorized linear low use	0.5 mile	0.90	0.71
Nonmotorized linear low use	0.25 mile	0.92	0.83

Total relative habitat alienation (HA_{ij}) associated with each of the above categories was calculated as:

$$HA_{ij} = ZOI_i * (1-DC_{ij}).$$

Using either roads with cover or a weighted average of roads with and without cover as a standard (i.e., CF = 1.00), equivalencies or conversion factors (CF_{ij}) were calculated as follows:

$$CF_{ij} = HA_{ij}/HA_{motorized\text{-}cover}; \text{ or}$$

$$CF_{ij} = HA_{ij}/(0.75*HA_{mot.\text{-}cover} + 0.25*HA_{mot.\text{-}noncov.}).$$

The calculated CF_{ij}s are as follows:

Access Type	CF Mot.-cover as standard	CF Wgt. ave. as standard
Roads in cover	1.00	0.70
Roads in noncover	2.80	1.90
Trails or closed roads in cover	0.40	0.30
Trails or closed roads in noncover	0.80	0.60

It is very important to realize that use of the 2 different equivalency standards depends on how road density standards were derived for any given area. In the Yellowstone ecosystem the proposed road density standard (see Section 4) was developed in the context of an environment with ca. 75% cover. Thus the CFs based on 3/4 weighting cover would be most appropriate.

These CFs should be used as weighting factors for total miles (TM_{ij}) added under each category. After weighting, equivalent miles would be added across all categories to calculate "standardized road density" (SRD), which would then be compared against the road density standard, where:

$$SRD = (CF_{11}*TM_{11}) + (CF_{12}*TM_{12}) + (CF_{21}*TM_{21}) + (CF_{22}*TM_{22}).$$

These CFs should be updated as our conceptualization of the problem improves and new information becomes available that allows us to more accurately specify impacts associated with different types of human access.

SECTION 4 -- Perspective and Rationale for Proposed Road Density Standards in the Yellowstone Ecosystem

Management of human access is currently viewed by most managers as the most critical element of grizzly bear habitat conservation. Road density standards have consequently become a key part of most grizzly bear management plans. In this capacity, road density standards logically identify thresholds of acceptable change in grizzly bear habitat. These thresholds ideally reflect acceptable levels of habitat alienation and mortality risk that in turn fulfill objectives for population persistence mandated by the federal Endangered Species Act.

However, most grizzly bear road density standards have until very recently been based on elk (*Cervus elaphus*) models (for example, see Lyon 1979, 1983), and none of these standards have demonstrated ties to explicit population persistence or viability objectives. These are important issues for at least two reasons. First, the hypothesis that elk-based road density standards are adequate to insure security for grizzly bears is implicitly not as defensible as the alternate hypothesis that elk-based standards are deficient in this regard. This conclusion is suggested by the following observations: (1) elk are generally more fecund, (2) consistently exist at higher densities, and (3) are extant in a larger portion of their former range compared to grizzly bears in the contiguous United States. Second, viability-based road density standards are critical because no other standards exist to insure that grizzly bear habitat is not degraded beyond some level compatible with long-term population persistence (Mattson and Knight 1991b; Servheen 1992). Grizzly bear population status is currently monitored strictly through demographic indices (Servheen 1992) that are inherently insensitive to habitat conditions because of the explicit metric and implicit somatic averaging that affects them. Thus, it is imperative that methods be developed for deriving road density standards that are specific to grizzly bears and that can be explicitly tied to population demography. This section presents an initial effort to reach these ends.

Concerns and Considerations

Habitat Alienation and Mortality Risk. -- Most people accept that road density *per se* has little impact on grizzly bears. Only a trivial amount of any landscape is directly obligated to road prisms and surfaces. In fact, some research results have suggested that the physical road structure may, in a proximal sense, enhance bear habitat; by increased foraging opportunities associated with roadside seedings of clover (*Trifolium* spp.) and graminoids (Jonkel and Cowan 1971), and by facilitating the travel of individual bears that are willing to use roads, typically at night (Zager 1980; McLellan and Shackleton 1988a). Rather, most managers and researchers emphasize road density because it is assumed to be highly correlated with more critical factors such as frequency of human-bear contact (Bunnell and Tait 1980; Section 1).

Human-bear contact is typically thought to manifest primarily in two negative ways: (1) habitat alienation or avoidance and (2) mortality risk. Numerous studies have documented under-use of habitat near roads that is typically attributed to avoidance (Section 1), while fewer studies have associated higher levels of grizzly bear mortality either with areas near roads or areas impacted by higher road densities (Section 1). I argue that these two factors are inter-related and that mortality risk is the more important consideration (1) because of its direct and substantive manifestation in population demography and (2) because of the likelihood that habitat alienation is largely a direct function of differential mortality rates that are selective against human-habituated (i.e., less wary) bears that would otherwise be able to fully use habitat near roads (Mattson et al. 1992; Section 1).

If my contentions are correct, then behavioral-based results (i.e., under-use or alienation of habitat near humans) may be a compromised basis for deriving road density standards unless coupled with some estimate of the role that habituation played among the sampled bears. Based on this hypothesis, I would predict that habitat alienation and mortality risk are not linearly correlated in space, and that because of this nonlinearity, behavioral-based density standards will be higher than mortality-risk based standards. This is to be expected because mortality risk is not realized instantaneously, and as a consequence areas near humans would be used at proportionately higher rates than expected by mortality risk, especially given that a relative surplus of resources in these areas would predictably recruit new resident bears. Thus preliminary spatial results of behavioral-based studies such as Mace and Manley (1993) may over-estimate road densities that are compatible with long-term population persistence.

Scale of Analysis. -- The documented responses of grizzly bears to human facilities will predictably be strongly scale dependent. This derives from the fact that most results are relative in nature (e.g., proportional use of habitat strata) and consequently prone to change as study area bounds are changed. For example, the larger perspective involving mortality risk gradients associated with transitions from wildlands to settled agricultural lands has not been explicitly captured in any study to date and has consequently not been used in conceptualizing road density standards. Furthermore, most analyses that have addressed the hypothesis of habitat alienation have focused on scales of <1-5 km, within the range where habituated or less wary bears may be prevalent (Mattson et al. 1992). The full spatial pattern of mortality risk is likely to manifest only at much broader scales, including areas >1-5 km from road access, where encounters with humans are likely to be infrequent, and wary bears consequently more common (Mattson et al. 1992).

Inclusion of these more remote areas is critical because most under-use of habitat attributable to lower survivorship of habituated or less wary bears will be manifest as the differential in use of habitat compared to that expected between areas far from humans, where wary bears are more numerous, and areas nearer humans where unwary bears are predictably more common. This differential would be a direct reflection of higher mortality risk associated with human access played out primarily through the loss of fear among vulnerable bears.

Results from the Yellowstone ecosystem suggest the appropriate scale of analysis for capturing broader scale phenomena is approximately 10x the size of the average female life range. In Yellowstone, patterns of mortality risk, habitat use, and distribution by behavior were not fully expressed in an area <9,000 km^2 (e.g., Mattson et al. 1987; Mattson et al. 1992); approximately equal to 10 x 884 km^2 average female life ranges (Blanchard and Knight 1991).

However, at this broader scale, analysis is potentially confounded by several important factors. For one, differences in habitat productivity or support capability need to be explicitly accounted for in estimates of "expected" bear use in any given zone (i.e., area alone is not a good indicator of expected use). Trapping effort should also not be biased towards more accessible, potentially more impacted areas; and trapping success should not be biased towards more habituated animals. In either case, behavioral data will likely under-estimate impacts associated with access, while demographic data will be unduly pessimistic with respect to the entire population. A spatially structured analysis using trapping effort as a covariate may address spatial biases, while a behaviorally-spatially structured demographic analysis may address some effects attributable to trapping bias with respect to bear behavior or accessibility.

Variable Road Density Standards. -- There are at least four hypothesized reasons why road density standards should vary among ecosystems or bear management units in accord with differences in attendant risk to individual bears.

First, allowable road densities should logically vary with average bear range sizes. All other things equal, a wider-ranging bear is predictably at greater risk from a given road density compared to a less mobile bear (Bunnell and Tait 1980). Thus, road density standards should compensate for this greater implicit risk, and be lower in areas with wider-ranging typically lower density (see Nagy and Haroldson 1990) bear populations.

Second, road density standards should vary with local human attitudes and levels of traffic. Again, all other things equal, an individual bear will predictably be at greater risk at a given road density where humans are more hostile towards grizzly bears and/or where there are higher levels of human traffic. Local attitudes could be readily determined through surveys, although the exact relationship between attitudes thus determined and bear demography would be difficult to establish. Furthermore, it could be argued that there is a subsidiary but important positive relationship between hostility and restrictiveness of road density standards that could modify the simple proposed relationship superficially suggesting that lower road density standards are needed where humans are more hostile.

Third, unless some means of incorporating the presence of cover into road density calculations can be achieved, mortality risk will predictably vary with the amount of cover at the same road densities, with bear populations with less cover at greater risk. This follows from the greater apparent vulnerability of bears in the open, and their orientation towards cover for security (Section 1).

Fourth, unless some means of incorporating trails and closed roads into road density calculations can be achieved, mortality risk will predictably vary with the additional miles of this type of access at the same open road density, with bear populations in areas of greater closed road or trail densities at greater risk. This follows from the fact that many bears are killed by armed humans during hunting season, and from the general proposition that area access for these people is facilitated not just by open roads, but in some areas more importantly by trails and closed roads (see Section 1).

Propositions

For reasons expounded above, I offer the following 5 propositions related to derivation of road density standards for grizzly bear management:

(1) Road density standards should vary among ecosystems as a function of bear range sizes and local human attitudes, with lower allowable densities where ranges are larger and/or human attitudes more negative.

(2) Road density standards should reflect mortality risk more than habitat alienation; and if behavioral data are used as a basis for road density standards then the spatially explicit effects of habituation and/or intra-specific spacing on mortality risk should be accounted for.

(3) Road densities should be calculated so as to account for the effects of variable cover and road closures (Section 3).

(4) Trails should also be incorporated into road density calculations on the basis of pro-rated equivalencies (Section 3).

(5) Studies of the relationships between road densities and bear behavior or demography should ideally encompass an area equivalent to ca. 10 female life ranges, including areas not impacted by roads, and should include enough data to allow spatially structured analyses of life expectancy and population growth rate.

Proposed Approach

In this section I outline an approach to deriving road density standards for grizzly bear habitat in the Yellowstone Ecosystem that is attentive to the previous 5 propositions. Given the paucity of relevant empirical data, my approach is more conceptual than empirical in nature. It also relies upon the methods presented in Section 3 for calculating equivalent miles of roads and trails in a way that reflects the presence of cover and road closures; thus all road densities are expressed in terms of equivalent miles.

Rationale. -- Mortality risk in the Yellowstone ecosystem is much higher for bears that are habituated to humans, regardless of whether bears are seeking out natural or human-origin foods near humans (Mattson et al. 1992). Furthermore, habituated bears are disproportionately common within 2 km of roads and 4 km of major developments. Following the logic for micro-scale security areas, the spatial extent of "secure" habitats will largely be a function of the area that is sufficiently buffered to maintain wariness, which is apparently key to preserving high survivorship (Mattson et al. 1992). Thus, it is reasonable to postulate that long-term persistence of the Yellowstone grizzly bear population will be contingent upon the proportion of the recovery zone that is >2 km from an open road and >4 km from a major development or town site (cf. Craighead 1980; Mattson 1990).

The extrapolation of results primarily from bears responding to major roads in Yellowstone Park to secondary road systems on National Forest lands is potentially problematic. However several results support the hypothesis that such results are extrapolable, and may even be conservative with respect to areas impacted by secondary road systems. First, behavioral responses of bears to road traffic seem to reach an asymptote at very low traffic levels; bear responses appear to be much the same whether traffic frequency is 0.5 or 100 vehicles per hour (Section 1). Even though the relative importance of different mortality causes varies between parks and National Forests (Mattson and Knight 1991a), it is arguable that many of these causes are compensatory. In other words, many of the bears that exhibit habituation around primary roads in Yellowstone Park are killed at or near developments by managers, while this same type of bear is killed near secondary roads in National Forests, more often by poachers or in DLP (Mattson and Knight 1991a). Thus, park roads and developments, in combination, are similarly lethal as Forest Service road systems to less wary or habituated bears; and, indeed, this hypothesis seems to be borne out by the available data (Mattson and Knight 1991a). Accordingly, we would expect under-use of habitat near secondary roads on National Forests and primary roads in parks to be similar, given the assumption that this under-use as well as the spatial distribution of habituated bears is an artifact of both mortality rates and the degree to which mortality is selective against habituation (see above).

Open Road Density Standards. -- This approach assumes that micro-scale security areas are the building blocks important to preserving wariness among bears and the higher survivorship associated with this behavior. Accordingly, if an entire Yellowstone Bear Management Unit (see Weaver et al. 1986) were apportioned to minimum-sized (ca. 28 km^2) security areas, approximately 10% of the unit would be sufficiently buffered to meet criteria for maintaining high levels of wariness among resident bears. This level of security would correspond to a road density of approximately 0.4 km/km^2 or 0.6 $miles/mile^2$. This is arguably the highest road density compatible with retaining resident bears in any area for any substantive period of time. To achieve 50% security, road densities would have to be approximately 0.16 km/km^2 or 0.26 $miles/mile^2$. The general relationship between percent secure habitat (PSH) and road density (RD in km) would be negative, and for the range RD = 0.04-0.40 km/km^2 would be approximated by:

$$\arcsin(PSH) = 90 - 119RD^{0.538}.$$

Given that the "population" growth rate exhibited by Yellowstone's habituated bears is highly negative, and exceeding in degree the slightly positive growth rate of the wary bear "population" (manuscript in preparation), it is reasonable to postulate that road densities at the scale of an adult female's life range (ca. 884 km^2 [Blanchard and Knight 1991]) should be less than 0.26 $miles/mile^2$. In other words, at least 50% of available habitat should be adequately buffered to preserve wariness and provide security in any given Bear

Management Unit. Accordingly, I recommend the following road density standards for the Yellowstone ecosystem: open road densities should not exceed 0.6 miles/mile^2 over some fraction of a bear's life range, and furthermore average no greater than 0.26 miles/mile^2 over the entire range. In other words, some areas could have road densities averaging 0.6 miles/mile^2, but other areas comprising the bear's range would have to compensate with average densities substantially less than 0.26 miles/mile^2.

Spatial Frame-Work for Calculating Road Densities.-- There have been many problems associated with spatial referents for road density calculations, given that densities will vary if roads are non-randomly distributed and analysis areas are delineated with regard to road aggregations. Fundamentally, there is concern that density calculations will be capricious if analysis boundaries change for each analysis, and that calculations will be arbitrary with respect to the needs of bears. These concerns can be resolved by permanently fixing the boundaries of analysis areas according to criteria that reflect discontinuities in habitat use by bears, and by sizing analysis areas such that they capture the scale at which grizzly bears operate. In other words, these concerns can be alleviated by making the spatial referents as attentive as possible to the scales and patterns of bear movements, rather than to management concerns defined by a particular project.

The Yellowstone ecosystem has already been stratified in a way that directly reflects documented patterns and scales of grizzly bear movements. These strata constitute the Bear Management Units (BMU) and Subunits (BMUS) used in Cumulative Effects Analysis (Weaver et al. 1986). Each BMU was delineated according to observed discontinuities in the distributions of radio-marked grizzly bears, and roughly corresponds in size to an adult female's life range (ca. 200,000 - 400,000 acres). Each BMU is characterized by high observed fidelity (70-90% [Mattson 1987]) by individual adult females and captures the spatial range of options available to females that reside there. Thus, from a grizzly bear's perspective, it makes the most sense to calculate road density by BMU and to apply road density standards at this scale; with the proviso that these standards provide sufficient security to insure long-term population persistence, or, at a minimum, $r > 0$. **In this context, I propose that road densities should average less than 0.26 miles/mile^2 at the scale of a BMU.**

BMU subunits typically delineate finer-scale discontinuities in habitat, often areas of seasonally important habitats. However, virtually all grizzly bears range over areas larger than a BMUS during their life-time, and exhibit lower fidelity to these strata. Thus it is reasonable to postulate that bears could co-exist with higher road densities within a given BMUS as long as road densities in other BMUSs of the same BMU were low enough to keep the BMU average within its more restrictive standard. **In this context, I propose that road densities could average as high as 0.6 miles/mile^2 within a given BMUS, but only as long as the BMU average remained less than 0.26 miles/mile^2.**

Closed Road and Trail Densities. -- As pointed out earlier, trails and closed roads also facilitate human access to grizzly bear habitat. Accordingly, their impacts need to be considered when assessing the adequacy of management and the sufficiency of habitat security. Unfortunately, there are few empirical results that relate to the impacts of these linear features on mortality risk for bears. The results of Mace and Manley (1993) based on behavioral responses of bears, suggest that absolute densities of open roads, closed roads and trails should be cumulatively no greater than twice the absolute densities of open roads. Given the conversion factors presented in Section 3, **this result suggests that total densities of open roads and closed roads or trails, expressed in terms of equivalent miles, should be no more than 1.38x open road density standards at both the BMU and BMUS scale; or 0.36 miles/mile^2 and 0.8 miles/mile^2, respectively.**

Relationship of Proposed Standards to Actual Densities. -- Road densities discussed here are expressed in terms of standardized miles (see Section 3). Standardized miles will deviate from actual miles of roads or trails on the landscape depending on the amount of cover and whether roads are open or closed. As a consequence, actual miles will rarely equal standardized miles and actual densities will rarely equal standardized densities. Thus, any given BMU subunit may meet road density standards with varying milage of linear features. Figure 1 illustrates the potential

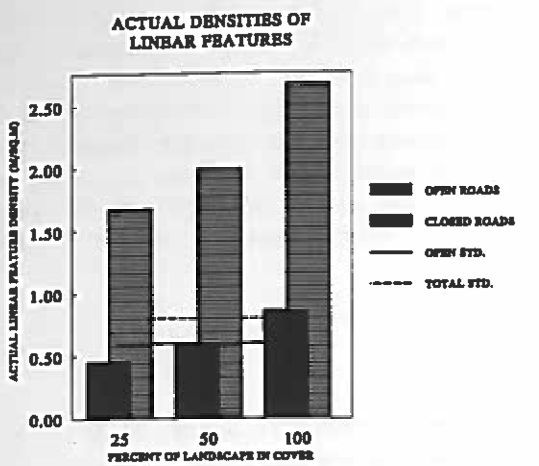

Figure 1. Range of actual linear feature densities possible when meeting proposed BMU subunit standards, given varying levels of cover and open road densities.

range of actual linear miles that could exist in a given area, and meet density standards, depending on the level of cover and road closures. For example, with 100% cover and closure of all roads to motorized traffic, a total density standard of 0.8 miles/mile^2 could be met with many as 2.67 miles/mile^2 of existing closed roads and trails. At the other extreme, if there were 25% cover and open roads were maintained at maximum allowable densities (e.g., 0.6 miles/mile^2), total density of linear features would have to be approximately 0.87 miles/mile^2 to meet density standards.

Variation in Road Densities Among Ecosystems. -- At a given road density (RD), miles of road intersected by a bear's range (MR) would increase approximately by the power of -2 (square root) of home range size (HR) as follows:

$$MR = 2 * HR^{-2} * RD.$$

We can postulate a similar relationship between range size and mortality risk, assuming that they are linearly and positively related. Correspondingly, road density standards would hypothetically decrease as average range sizes increase approximately according to:

$$RD = MR / (2 * HR^{-2}).$$

Thus, road density standards proposed here are not likely to be applicable in other ecosystems unless the scale of bear movements is similar. However, this formulation constitutes a hypothesis that is testable if risk-based road density standards are derived for several ecosystems characterized by different bear range sizes. Similarly, it provides a rational frame-work for comparing road density standards from different ecosystems.

Figure 2 illustrates the potential differences in road density standards among ecosystems as a function of female life range size expressed in square miles. It is important to note that range sizes of Yellowstone females are among the largest described for grizzly bears in North America. It is also important to note that average life range size of Yellowstone's adult female grizzlies was 3.1x larger than average annual range size (Blanchard and Knight 1991).

Mace and Manley (1993) are the only other researchers to relate levels of grizzly bear habitat use to different densities of open and closed roads. They found under-use of habitat in areas with open road densities >1 mile/mile^2. They also estimated average annual range size of adult females to be 48 miles^2. Assuming that the same relationship between life and annual range size documented in the Yellowstone area holds in their study area, then predicted average life range size would be 151 miles^2. This corresponds to a

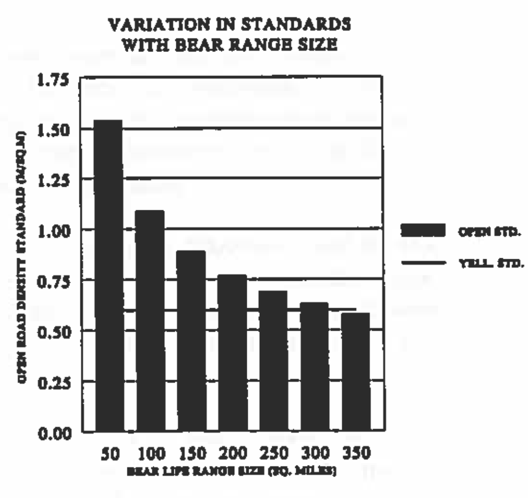

Figure 2. Predicted variation in open road density standards as a function of adult female life range size. The proposed Yellowstone standard (YELL. STD.) is also indicated.

predicted open road density standard (0.9 miles/mile^2[Fig. 2]) that is in remarkable accord with the apparent tolerances of grizzly bears (<1 mile/mile^2) documented during their study to date. This single comparison supports my hypothesis that (1) road density standards will vary among ecosystems, (2) standards will be higher in areas where bears exhibit smaller ranges, and (3) standards will vary inversely to 2*HR^{-2}.

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