Habitat-based Criteria For Grizzly Bear Recovery And Management:

What body of scientific information should these criteria be based on?

What methodology should be used to set habitat-based recovery thresholds?

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Introduction and Overview

Wildlife managers, ecologists and conservation biologists widely understand that no species can persist in the wild without adequate habitat. To ensure grizzly survival one must protect its habitat. This overarching prescription begs many important details that must be confronted in developing and implementing habitat-based recovery criteria.

First, I review what we currently know about the habitat requirements of grizzly bears. The major theme of this discussion is that humans are the central component of grizzly habitat: Grizzly bears in the lower-48 states live on several habitat islands surrounded by human activities; most grizzly mortality in the lower-48 is associated with roads, human developments, grazing allotments and other human features of the landscape; and humans pose the major threat to critical grizzly foods. The habitat-based recovery criteria should focus on these three aspects of grizzly habitat, all of which could be measured easily, objectively, and with small error. Moreover, data already gathered and available to the USFWS could be used to quantify how various human habitat features such as roads and grazing allotments increase grizzly mortality rates.

Second, I turn my focus from grizzly habitat itself to the methods the USFWS should use in identifying grizzly habitat needs. I accomplish this by providing a methodology for the USFWS to employ in setting habitat-based thresholds for grizzly recovery. This discussion is motivated by my concern that the USFWS will use an ad hoc or arbitrary argument to justify the habitat-based recovery thresholds it chooses. This is unnecessary. Grizzly bear data already gathered by the U.S. government could, when fully analyzed, be used set these thresholds in a rational manner. In particular, the USFWS should set these thresholds so as to ensure that the number of grizzly bears will be stable or increasing, and the population size will be large enough to ensure survival in the face of chance events. In comparison to recovery criteria that seek to directly measure grizzly population size and growth rate, habitat-based recovery criteria should be less expensive and time-consuming to measure, as well as being easier to measure objectively and with small error. To exploit these benefits, the USFWS must develop a quantitative argument explaining the connection between the habitat-based recovery thresholds it sets, and grizzly population size and population growth rate.

Third, I continue the discussion of appropriate methodology for setting habitat-based recovery criteria by discussing two generic scientific issues that the USFWS must explicitly confront. All scientific results contain error, bias and uncertainty. Importantly, at least at a broad level, there is near universal agreement among scientists concerning the appropriate methods for confronting these problems. I am concerned that the the USFWS will fail to employ these standard statistical methods when setting the habitat-based recovery criteria and when analyzing associated data sets. Additionally, science demands that all results be tentative, and subject to change in light of improved information. I am concerned that the revised recovery plan will not contain administrative procedures sufficient and specific enough to ensure that continued improvement of our scientific understanding of grizzly bears will lead to continued management advances.

Grizzly Bear Habitat

Humans Are The Central Feature Of Grizzly Habitat

Wildlife habitat is conventionally, but perhaps often implicitly, viewed as being the natural factors needed for a wild animal to survive, including food, water, native vegetation, denning and nesting sites, etc. This narrow definition is inadequate for grizzly bears. Humans are the most important feature of grizzly habitat.

The current grizzly bear distribution in the lower-48 states shows that grizzly bears are found only in areas with very low human densities. That is, in wilderness, broadly defined. The ensuing discussion brings out three specific mechanisms by which humans degrade areas that would otherwise be suitable grizzly habitat.

Any grizzly bear population living on a habitat island is subject to a substantially elevated risk of extinction. The theory of island biogeography is one of the best established scientific findings in ecology. Extinction rates are higher on islands than on the mainland (MacArthur and Wilson 1967); this is true not only of oceanic islands, but also of habitat islands (Brown 1971, 1978; Galli et al. 1976; Karr 1982; Blake and Karr 1984, 1987; Soule et al. 1979, 1988; Newmark 1987, 1995, 1996; Lomolino et al. 1989; Friesen et al. 1995). This broad pattern holds no less for grizzlies; within the last century numerous grizzly bear populations confined to small habitat islands have gone extinct (Mattson et al. 1995).

Humans are the most important and prominent cause of grizzly mortality. Either directly or indirectly, humans are responsible for the vast majority of grizzly bear deaths in Yellowstone (Knight et al. 1988; Mattson et al. 1996). To understand grizzly bear habitat needs, we must understand and quantify how humans change grizzly mortality rates.

Compelling qualitative, and in some cases quantitative, evidence documents that grizzly bear mortality rates are altered by human habitat features such as garbage dumps; roads and trails; towns, campgrounds and other developments; grazing allotments; the number of human residents and visitors; and number of hunters and other armed individuals present. As discussed below the rate at which grizzly bears condition to humans is also an important demographic parameter; the evidence is that it is also heavily influenced by these human features of grizzly habitat.

Although good qualitative evidence is available documenting how these human habitat features affect grizzly bears, quantitative estimates of their effect on grizzly mortality rates are generally unavailable. And as discussed below, the estimates that are available focus on the effect of these habitat features on grizzly behavior and spatial distribution, rather than directly quantifying their effect on mortality rates and other demographic parameters. As developed below, data are available to enable the USFWS to quantitatively determine the effect of each of the above human habitat features on grizzly mortality rates, and to compare their relative importance on grizzly mortality of these human habitat features. Such an analysis could enabie the USFWS to reallocate scare management dollars to areas with the potentially largest impact on grizzly mortality, as well as assist in identifying the proper human habitat features for the recovery criteria to focus on.

Grizzly bear feeding sites are important because of the opportunity for humans to interact with bears at these sites, and because of the probable relation between the availability of certain food resources and grizzly bear fecundity. Several excellent grizzly bear foods are concentrated at specific known locations. This includes whitebark pine, carcasses on ungulate winter ranges, army cutworm moths, and spawning trout (Mattson et al. 1991). The habitat-based recovery criteria must ensure that there will be sufficient quantities of these food resources to support a viable grizzly bear population---that is, a population whose size is large enough to be considered recovered.

Obviously, if overall food availability declines, grizzly bear population size will decline also. At minimum, the USFWS needs to develop criteria to monitor the abundance of critical grizzly bear foods, and to make grizzly bear recovery contingent on grizzly bear food resource base that is overall stable or increasing. Even better, the

USFWS should determine the relation between grizzly food abundance and grizzly population size, and set the habitat-based recovery criteria so as to ensure a population that is large enough to not be significantly subject to extinction from chance events.

Recommendations for Habitat-based Recovery Criteria

As compared to demographic recovery criteria, habitat-based recovery criteria should be relatively inexpensive and quick to measure, with small error and bias. By contrast the three demographic recovery criteria in the current recovery plan are subject to sampling biases and estimation errors not disclosed therein; these sampling biases are so severe that one can not make a confident inference about grizzly bear population growth rate or size from knowing only the values and trends of these three criteria (Craighead et al. 1995; Mattson 1997*a,b*). Additionally, direct measures of Yellowston grizzly bear population growth rate are subject to large sampling error (Eberhardt 1995; Boyce 1995; Pease and Mattson 1997), and all available estimates of Yellowstone grizzly bear population size have large errors (Craighead et al. 1995) and use non-standard estimation methodologies. It is with this background that I consider possible habitat-based recovery criteria.

Is the grizzly bear population being considered for delisting living on a habitat island? If so, the USFWS should presume that the population has not recovered, and uncertainty and lack of data should be interpreted pessimistically. This presumption of non-recovered status could perhaps be overcome with specific, compelling evidence to the contrary. This recommendation is based on the overwhelming evidence showing that island populations have elevated extinction rates, and the position of island biogeography as one of the best-supported results in ecology.

Monitoring roads and other landscape features that indicate grizzly mortality levels. Recovery should be contingent on demonstrating that the number, density per unit area, and spatial distribution of roads, trails, developments, residents and visitors, grazing allotments, and armed individuals is such as to ensure that the grizzly bear population growth rate is stable or increasing, and that the grizzly bear population size will meet its recovery target.

Is the grizzly bear food base stable or increasing? A grizzly bear population cannot be considered recovered if its food base is decreasing. This question could be answered by considering each major food separately. Potentially, a more sophisticated analysis could consider the trend in overall food availability, thereby combining trends in individual foods.

The criteria the USFWS uses to monitor grizzly bear food availability must be sensitive to known threats to these resources. That is, the criteria must be constructed to that if one of these known threats caused a significant impact on a grizzly bear foods, this would be reflected in the criteria. For example, whitebark pine is threatened by global warming (Romme and Turner 1991), white pine blister rust (Kendall 1995), by suppression of the fires needed to regenerate stands (Keane et al. 1990). The recovery criteria also must account for the 100 year lag between a fire and production of cones by new whitebark pines (Mattson and Reinhart 1994).

Are enough grizzly foods available to support a grizzly bear population whose size is large enough to be recovered? Recovery should be contingent upon demonstrating that sufficient grizzly bear foods are available to support a population that is large enough to be recovered. Before this can occur, the USFWS needs to promulgate a recovery criteria that unambiguously states what grizzly bear population size is necessary for recovery. None of the current recovery criteria accomplish this.

Habitat-based recovery criteria to be avoided. There are several approaches to developing habitat-based recovery criteria that are deficient. (1) In developing habitat-based recovery criteria, the USFWS should not simply assume that current grizzly habitat conditions and food resources are sufficient to allow recovery. I know of no evidence demonstrating that this is so. As one particular manifestion of this, I know of no evidence showing that the current recovery zone is large enough to support a recovered population. (2) The USFWS should not propose habitat-based recovery criteria that are independent of the recovery criteria involving population growth rate and population size. Rather, the USFWS must provide a defensible argument demonstrating that when the habitat-based recovery criteria are met, the population will be stable or increasing, and population size will be large enough for recovery to occur. (3) The USFWS should not arbitrarily decide to base the recovery criteria on some human habitat features, while ignoring others (e.g. base recovery on number of grazing allotments, while ignoring road density). The human habitat features chosen must be justified using a defensible argument.

Data Available To The USFWS For Use In Setting Habitat-based Recovery Thresholds

The best available raw data that I am aware of on the relation between grizzly bear demography and habitat features in Yellowstone consist of: (1) The raw hard copy unpublished Flight Report data set from 1975-1997 held by the Interagency Grizzly Bear Study Team (IGBST), (2) the unpublished Individual Grizzly Bear Histories data set held by the IGBST, the (3) the published Annual Reports of the IGBST, the (4) the raw hard copy trapping forms data set held by the IGBST, and (5) the Craighead et al. (1988) mortality data set. These five data sets will have to be used in conjuntion with GIS data layers showing the locations of road, developments, grazing allotments, food resources, etc.

The above data sets need to be vetted before being used to develop habitat-based recovery criteria. First, I recommend that the USFWS not base their habitat-based recovery criteria on the electronic version of the Flight Report data compiled by the IGBST, and that they instead use the hard copies; while completing a demographic analysis of the Yellowstone grizzly bear population I discovered substantial errors in this electronic file (Pease and Mattson 1997). Second, the Flight Reports, Individual Grizzly Bear Histories data set, IGBST Annual Reports, and Craighead et al. (1988) are sometimes inconsistent as to the date particular bears died or dropped their collars. Evidently, these data sets sometimes do not carefully distinguish between some or all of: the actual date of death or collar drop, the last time a bear was definitely seen alive with an active radio collar, the last time a bear could have been alive with an active radio collar, the most probable date of death or collar drop, and the date a death or collar drop became known to humans. Third, in a small percent of the cases, the available data are inadequate to determine whether a particular bear died or dropped its collar. Any analysis must account for this uncertainty. Fourth, the Flight Reports occassionally misreport the age of offspring accompanying radio-collared females.

The USFWS needs to resolve these discrepancies before relying on these data sets. If the USFWS decides to base the habitat-based recovery criteria on new analyses of the above data sets, or on analyses already published (Eberhardt et al. 1994; Eberhardt 1995; Boyce 1995), they must state in writing the procedures used to correct the above errors, or alternatively present information showing that these errors have negligible effect on the conclusions. More generally, the documents the USFWS uses to support the habitat-based recovery criteria need to explicitly state the procedures the USFWS has implemented to resolve descrepancies between the above five data sets, to ensure that all electronic files accurately represent the underlying hard copy data, and to ensure that future data will be gathered and compiled with adequate accuracy.

Other data sets that the USFWS might potentially draw on in developing habitat-based recovery criteria also contain errors. For example, ground-truthing has uncovered discrepancies between both total and open road densities in Forest Service records and the actual situation on the ground (Predator Project 1995). Additionally, many roads purportedly closed are in fact open to some vehicle traffic (Predator Project 1995). When evaluating whether a habitat-based recovery criteria has been met, the USFWS should rely on data showing the actual situation on the ground, not on inaccurate records and optimistic assumptions about road densities and the effectiveness of road closures.

Any analysis of the above data sets that the USFWS undertakes to estimate the effect of habitat features on grizzly demographic parameters must account for several sampling biases and estimation difficulties. First, the radio-collared bears in the available data set oversample some time periods and bears, and undersample others. This sampling bias is a problem, because, unless it is quantified and accounted for, one could easily make mistake low sampling intensity for low mortality, or vice versa. Before one can estimate mortality rates, one must account for the varying intesity at which certain bears, time periods, and spatial locations were sampled. Second, not all cubs are seen each time their mother is, and some cubs die between emergence from the den and when they are first seen. If uncorrected, these biases will cause fecundity estimates to be too pessimistic. Third, the exact date each bear in this sample died or dropped its collar is often unknown, and can only be determined to within a time interval. The data analysis must account for this. Fourth, some previous analyses (Knight and Eberhardt 1985; Eberhardt et al. 1994) have underestimated the mortality rate by incorrectly including certain uncollared bears in the denominator of the mortality estimator (Eberhardt 1995; Hovey and McLellan 1996).

The USFWS has not yet undertaken a comprehensive analysis of the Yellowstone data sets identified above, to quantify the extent to which the human habitat features such as distance to road affect grizzly bear mortality rates, and to provide direct estimates of how these human habitat features affect grizzly bear population growth rate. Such an analysis would provide a non-arbitrary basis for setting habitat-based recovery criteria. Specifically, it would enable recovery criteria to be set to ensure that fecundity would exceed mortality. Such an analysis sould also quantify the standard errors in our estimates of how these human habitat features impact grizzly bear mortality rates and in the population growth rate estimate.

Because these are radio-telemetry rather than mark-recapture data, because of the large number of parameters that must be estimated, and because of the need to remove various sampling biases, standard data analysis packages (e.g., Pollock et al. 1990) cannot be used to analyze them. Methods such as Cox regression (Cox and Oakes 1984; Boyce 1995) are inadequate for estimating grizzly mortality because they can not be readily modified to address some of the above sampling biases and estimation difficulties. I recommend estimating the demographic parameters quantifying the effect of roads and other human habitat features on grizzly mortality using a maximum likelihood or similar method (Edwards 1992) in conjunction with the Akaike Information Criterion or closely aligned method (Akaike 1973; Burnham and Anderson 1992; Lebreton et al. 1992; Burnham et al. 1995).

A Methodology For Setting Habitat-based Recovery Thresholds

The Relation Between Habitat and Demography

Two central demographic parameters: population size and population growth rate. Scientists are near unanimous in agreeing that to assess the status of a rare species, you must know its population size and population growth rate. This is no less true for grizzly bears. A declining population will eventually go extinct if this decline is not halted, regardless of its current size. Similarly, it is well established that small populations are at considerably greater risk of extinction than large ones (Tuljapurkar and Orzack 1980; Tuljapurkar 1982). The extent of this risk is determined by the levels of environmental and demographic stochasticity (Tuljapurkar and Orzack 1980; Tuljapurkar 1982; Lande 1988, 1993*a,b*), and by the extent to which the population's genetic structure is altered unfavorably at low population sizes by inbreeding depression and similar genetic processes (Lande and Barrowclough 1987; Hedrick and Miller 1992), among other factors. One cannot assess grizzly bear habitat needs independently of grizzly bear population size and growth rate.

Before establishing grizzly bear habitat-based recovery criteria, the USFWS first needs to develop a recovery criteria that specifically states what population size a recovered population will have. The USFWS also needs to develop a recovery criteria stating what population growth rate a recovered population will have, and the time span over which this population growth rate will be measured. The three recovery criteria in the current recovery plan are not acceptable surrogates of recovery criteria directly measuring population size and growth rate. They are subjective, subject to large sampling biases of unknown magnitute, and/or have not been directly related to population size or growth rate (Craighead et al. 1995; Mattson 1997 *a,b*).

Grizzly bear population growth rate is itself determined by grizzly bear birth and death rates, and the rate at which wary bears become conditioned to humans. The relation between population growth rate and the birth and death rates is obvious. More subtly, the Yellowstone grizzly bear population is structured into one subpopulation that is wary of humans and another that is habituated to humans and/or conditioned to human foods (Meagher and Fowler 1989; Mattson et al. 1992; Boyce 1995; Eberhardt 1995). Human-conditioned bears have approximately double the mortality rate of wary bears (Pease and Mattson 1997), implying that the Yellowstone population has a source/sink (wary/human-conditioned) population structure. A complete demographic analysis needs to account for this structuring by estimating the rate at which wary bears become conditioned to humans (Pease and Mattson 1997). Once a bear is human-conditioned, it appears that neither it nor its offspring will ever become wary (Herrero 1985; Meagher and Fowler 1989; Mattson et al. 1991). Consequently, the overall population growth rate is roughly equal to the population growth rate of the wary subpopulation minus the rate at which wary bears become conditioned to humans.

The structuring of these grizzly bear populations into wary and human-conditioned subpopulations is important to developing habitat-based recovery criteria. Roads, developments, grazing allotments and other human features of the grizzly bear's habitat identified below determine the extent to which humans and grizzly bears interact. The more interaction between humans and grizzly bears, the faster the rate at which wary bears will become conditioned to humans, causing a lower grizzly bear population growth rate and reduced probability of persistence. Human habitat features such as roads and developments decrease grizzly bear population growth rate via two distinct pathways. First, they directly increase grizzly mortality rates. Second, they increase the rate at which wary bears become habitatutated to humans. Both of these effects need to be estimated quantitatively for the USFWS to have a rational basis for setting road density standards.

Why Not Make The Recovery Criteria Solely Demographic?

As mentioned above the basic problem is that available estimates of of birth and death rates and population size have large errors (Craighead et al. 1995; Eberhardt 1995; Boyce 1995; Pease and Mattson 1997). By contrast, many habitat features can be measured more easily, and should have small measurement error.

Moreover, because of long time lags, if we monitor birth and death rates only we may not demonstrate that the population is in trouble until it is too late to take remedial action. Moreover, because of subtle and complex interactions between different age, sex and behavioral classes of bears, it may be very difficult to detect the impact of habitat deterioration on demographic parameters, even if such an effect is in fact present and large. In short, monitoring demography alone gives one inadequate ability to detect habitat deterioration.

We Should Monitor Both Demography and Habitat

By monitoring habitat, we are well positioned to reconstruct the causes of population increases or declines. For example, grizzly habitat monitoring that was carried out over the period 1975-1997 was not as through as it could have been, as exemplified by the current effort to improve it. This means we have limited ability to reconstruct the causes of any changes in population size oberved via demographic monitoring over this time period, at least in comparison to what we would have been able to infer with more historically complete habitat data.

What has been done. Nearly all current studies of the effects of roads and developments on grizzly bears in Yellowstone describe how they alter bear behavior and spatial distibution (Mattson et al. 1987; Mattson 1993; Mattson et al. 1996). These studies are an excellent first step. However, they are not equivalent to directly quantifying how roads and developments alter grizzly bear demographic parameters. We are interested in roads and other habitat features because of their effects on how quickly bears die and are born.

It is not trivial to describe how changes in grizzly bear foraging and other behavior patterns translate into changes in mortality and fecundity. For example, one of the most prominent behavioral consequences of roads is that they lead to habituation and human-conditioning of wary bears. This has severe, but non-immediate mortality consequences. Similarly, roads and developments are acting as mortality sinks in the landscape (Knight et al. 1988). The available analyses showing the distance at which roads and developments affect grizzly bears may in fact be measuring the width of the zone around roads that is depauperate of bears, because of excess bear mortality. Although this is an interesting number, it is not equivalent to directly estimating the impact of the roads and developments on population growth rate. In short, describing how bear behavior and spatial distribution are altered by roads and developments is an indirect surrogate for describing the actual demographic variables of ultimate interest.

What should be done: Making the connection between habitat and demography. The habitat-based recovery criteria should be closely tied to demographic recovery criteria involving population size and population growth rate. The five data sets discussed above, in conjunction with available GIS data layers, contain sufficient information to allow one to quantitatively describe the relation between, on the one hand, human habitat features (such as road densities) and on the other, the birth, death and habituation rates of Yellowstone ecosystem grizzly bears. However, the analyses of the available data are generally sufficient only to describe the relations qualitatively. To fully exploit the best available data from Yellowstone, it will be necessary to further analyze these data. This analysis would establish quantitative relations between (1) critical human features of grizzly bear habitat such as roads, trails, developments, number of human visitors and residents, and grazing allotments, and (2) demographic parameters such as grizzly bear fecundity, mortality and habituation rates, and population growth rate. It would enable the USFWS to quantitatively predict the impact on grizzly bear population growth rate of changes in these human features of grizzly bear habitat.

Statistics, and Ensuring That Scientific Progress Leads to Management Progress

Scientific Procedures to Account for Error, Uncertainty, and Bias

Statistics. Scientists have developed a huge body of knowledge useful for accounting for error, uncertainty and bias when drawing inferences from data. This is conventionally known as statistics. Stuart and Ord (1987, 1991) nicely summarize the major results of classical statistics.

The USFWS has available to it a variety of potential habitat-based recovery criteria, and a variety of data sets that could be potentially analyzed or gathered towards the end of determining whether these recovery criteria have been met. Given this circumstance, rather than recommending specific statistical analyses, I will outline several broadly applicable tenants of good statistical practice. Whatever habitat-based recovery criteria the USFWS chooses, they should have the following general properties:

Point estimates do not constitute the best available science. A point estimate is a number computed from a data set, with no measure of uncertainty or error reported. Point estimates are undesirable because they fail to quantify, or even acknowledge, the error and uncertainty associated with a parameter estimate. All measurements are subject to error and uncertainty.

The USFWS should compute the 95% confidence interval associated with all parameters estimated as part of the recovery criteria. The recovery plan should be explicit in stating that this will be done, and in explaining the methods to be used. Confidence intervals can be computed using standard formulas (Hoel 1971), approximate analytic methods (Stuart and Ord 1987: chpt 10), or a bootstrap (Efron 1982). Snedecor and Cochran (1978: pp. 5-10) discuss the critical distinction between point estimates and interval estimates.

Each and every recovery criterion should state how the USFWS will account for the sampling uncertainty inherent in measuring it. Will recovery be based on assuming that the most pessimistic parameter estimates hold, or on the most likely parameter estimates?

The USFWS should identify in writing all significant sampling biases affecting each habitat-based recovery criterion. It is very difficult, if not simply impossible, to gather any scientific data that are not contaminated to some extent by sampling biases. However, it is deceptive and contrary to standard statistical and scientific practice to analyze data without explicitly acknowledging their limitations. The new habitat-based recovery criteria should not suffer from sampling biases to the extent that the current recovery criteria do (Mattson 1997*a*). Both intentional and unintentional biases must be considered (Pease and Bull 1996; Pease and Fowler 1997).

Ensuring that Scientific Advances Lead To Management Advances

The habitat-based recovery criteria must be explicitly tied to grizzly bear management. At the very core of the scientific method is the idea that scientists revise their models in light of data showing that they are not working (Pease and Bull 1996). It is now widely recognized that good resource management involves dynamic feedback that continually revises and improves management in the light of new scientific information (Walters 1986).

It is not enough for the recovery plan to simply state, as the current one does, that management will be revised if the recovery criteria are not met. The recovery plan must provide a specific and identifiable administrative mechanism to ensure that this will happen. There are a number of administrative and political hurdles that can prevent this from occurring (Pease and Lande 1995: Table 2).

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