Identification of potential linkage zones for grizzly bears in the Swan-Clearwater Valley using GIS

Per Lennart Sandstrom
The University of Montana

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IDENTIFICATION OF POTENTIAL LINKAGE ZONES FOR GRIZZLY BEARS
IN THE SWAN-CLEARWATER VALLEY USING GIS

by

Per Lennart Sandstrom

B.S. The University of Montana, 1990

presented in partial fulfillment of the requirements

for the degree of

Masters of Science

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Approved by:

Chairperson

Dean, Graduate School

Date 5-30-96
Loss and fragmentation of habitat which leads to isolation of wildlife populations is considered the primary cause of species extinctions. The primary causes of habitat fragmentation are human activities associated with roads, timber harvesting, and residential and recreational developments. Using Geographical Information System's modeling techniques, I created a method that evaluates degrees of habitat fragmentation, and evaluates whether an area has the potential to serve as a linkage zone for grizzly bears in the Swan-Clearwater valley in Western Montana. Without focused management in specifically described, carefully selected areas (linkage zones), the Mission Mountain grizzly bear sub-population would likely become extinct within a few decades. The amount and spatial distribution of human activities in the Swan-Clearwater valley (and many similar areas in the region) determines which areas grizzly bears can use and survive in. Based on this knowledge, I selected 3 layers of information directly or indirectly associated with human activities (roads, developed sites, and cover conditions) and 1 layer of vegetational information (riparian extent) for the model. I manipulated these 4 layers for input in the model and assigned different values for different categories of conditions based on the perceived impact a particular condition is expected to have on habitat quality. The 6 assigned impact values ranged from a "beneficial" impact on habitat quality to a "high" negative impact on habitat quality. After creating raster maps of individual impact levels for the 4 layers, I combined these individual impact maps to one new map which displayed the combined impact on habitat quality.

Results revealed that a high proportion (67%) of the study area had road densities > 2 mi/mi² which were distributed unevenly among the different landowners. Road densities and developed sites were distributed along the center of the valley floor creating a habitat fracture zone. This spatial distribution makes moving across the valley dangerous for grizzly bears. Based on the spatial distribution of the combined impact levels, I delineated 4 linkage zones across the valley, occupying 42% of the study area. Because of the valley's mostly checkerboard ownership of alternate mi² sections, all major landowners - Flathead and Lolo National Forests, Department of State lands, Plum Creek Timber Company, and private, non-corporate landowners - had land within the linkage zones. Identification and maintenance of potential linkage zones both between and within designated grizzly bear recovery areas play an important part in the overall recovery effort of grizzly bears in the region.
ACKNOWLEDGEMENTS

My thesis project was supported both economically and logistically by the U.S. Fish and Wildlife Service's Grizzly Bear Recovery Program and is part of a larger evaluation of the extent of habitat fragmentation and its effects on grizzly bears. I feel very fortunate and am extremely thankful to have been able to carry out this project in conjunction with my regular job with the Grizzly Bear Recovery Program.

This project would not have been possible without the support of my committee chair, Dr. Christopher Servheen, also the Grizzly Bear Recovery Coordinator with the U.S. Fish and Wildlife Service. He not only provided funding for my project, but also lent his assistance throughout the project with his patience, encouragement, and expertise. I want to also thank Dr. Roland Redmond, both as a very helpful committee member and as the Director of the Wildlife Spatial Analysis Laboratory, to which my computers are plugged in and my plots are made. I want to thank my third committee member Dr. Daniel Pletscher, not only for the time and thinking he gave to this project, but also for the faith he has shown in me since my undergraduate beginnings. My whole committee should serve as role models to other faculty in how seriously they have taken their jobs as thesis advisors.

Steve Mietz contributed greatly both as a work partner, friend, and ARC/INFO tutor. Additionally, he worked hard on getting files and output maps ready. Thank yous are also due to Dr. Zhenhui Ma for assistance in developing my ideas for prediction of riparian extent, and for providing his software and
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I. INTRODUCTION

The brown bear (*Ursus arctos*) is found in a wide variety of environments, from some of the driest deserts in Asia, to the Arctic tundra of North America. The brown bear, known in North America as the grizzly bear (*U. arctos horribilis*), has a circumpolar distribution with high numbers in Alaska, northern and western Canada, much of the Russian Federation, and parts of eastern Europe. Grizzly bears originally existed in a relatively continuous population throughout most of western North America (Fig. 1a), with higher concentrations in major river valleys and in the Rocky Mountains (Storer and Tevis 1978, Brown 1985). Currently in the conterminous U.S., the grizzly bear has been eliminated from more than 98% of its historical range and today exists only in 5 relatively isolated populations (USFWS 1993). Loss of habitat and declining populations prompted listing of the grizzly bear as a threatened species south of the 49th parallel under the Endangered Species Act in 1975 (USFWS 1982, 1993). Today, 6 grizzly bear recovery areas have been designated by the USFWS (1982, 1993) in the conterminous 48 states (Fig. 1b). Four of these areas - the Northern Continental Divide Ecosystem (NCDE), the Cabinet/Yaak Ecosystem, the Selkirk Ecosystem, and the Northern Cascades Ecosystem - are connected with larger Canadian bear populations, and movements of grizzly bears across the international boundary have been documented in each ecosystem. Though some of the grizzly bear's habitat in the United States is connected to larger populations in Canada, and though the grizzly bear has protected status, populations in the
Figure 1. Historical distribution of grizzly bears in North America and present recovery areas in the United States.

a) Approximate historical distribution of grizzly bears (gray) (IGBC 1987) with grizzly bear recovery areas (black).

b) Grizzly bear recovery areas with Canadian portions approximated.
conterminous 48 states are still threatened. This threat is primarily the result of excessive mortalities, habitat disturbance, and ongoing habitat fragmentation associated with human presence (Servheen 1990, USFWS 1993).

Loss and fragmentation of habitat, leading to isolation of wildlife populations, is considered the primary cause of species extinctions and consequent loss of biodiversity both in the temperate zone (Wilcove et al. 1986) and worldwide (Wilcox and Murphy 1985). Among many potential causes of fragmentation of once pristine landscapes into smaller and more isolated patches, the primary causes are human activities associated with roads, residential and recreational developments, and timber harvesting. For this study, I defined habitat fragmentation as the division of once contiguous habitat into smaller patches, which are separated from each other by human activities. Healthy populations of large, wide-ranging mammals which exist at low densities become increasingly difficult to maintain as habitat becomes more fragmented (Wilcox 1980, Bennett 1990). While this description of species landscape distribution fits many large carnivores, the grizzly bear was the focus of this study.

Identification and maintenance of corridors or linkage zones may help to minimize some of the negative effects associated with habitat fragmentation (Noss 1987, Saunders and Hobbs 1991, Soule and Gilpin 1991). Though the importance of corridors in general has been questioned (Simberloff and Cox 1987), maintaining natural connectivity of a landscape and thereby avoiding
isolation of populations can be important for both demographic and genetic reasons (Noss 1989). Biologists most commonly use the term "corridor" to identify the intervening areas between habitat fragments which are suitable for the movement of animals. The term "corridor" appears better suited for species with a more migratory and predictable movement pattern than grizzly bears have. However, to describe the intervening areas that are suitable for low levels of occupancy as well as movements, I will instead use the term "linkage zone".

In the case of grizzly bears, distances between populations are often too great to expect that intervening areas (linkage zones) will function for movement only. Low levels of grizzly bear occupancy are expected throughout the linkage zones, and in some cases the potential linkage zones contain low elevation, spring habitat which is necessary for the long term persistence of grizzly bears (Craighead et al. 1982, Dood et al. 1986).

The degree of negative effects of fragmented grizzly bear habitat may depend more on the spatial arrangement of human activities than the actual amount of human activities. A linear arrangement of human activities along the center of valley floors separating mountainous habitats from each other termed "habitat fracture zones" (Servheen and Sandstrom 1993) often occurs in the Rocky Mountains of Montana and Idaho. Such habitat fracture zones are usually associated with low elevation, mixed land ownership and are found both between and within grizzly bear recovery areas (Fig. 2). In Montana, examples of habitat fracture zones within recovery areas include the valleys of the North
Figure 2. Fracture zones (yellow lines) exist both between and within grizzly bear recovery areas. Fracture zones are usually associated with low elevation and private land ownership.
and Middle Forks of the Flathead River, the Swan and Clearwater Rivers in the NCDE, and the Kootenai River in the Cabinet/Yaak Ecosystem. Examples of fracture zones between recovery areas are the valleys of the Clark Fork and St. Regis River, the Tobacco Valley, and the Evaro Hill area. The linear arrangement of human activities in these and other fracture zones creates increasingly effective barriers which isolate grizzly bear populations. The Grizzly Bear Recovery Plan (USFWS 1993) calls for an evaluation of potential linkage zones, both within and between existing grizzly bear recovery areas. There is a need to develop a repeatable approach to assess habitat fragmentation and to evaluate the potential for linkage zones.

To evaluate the degree of fragmentation and whether an area has the potential to serve as a linkage zone for grizzly bears, I created an assessment tool using GIS modeling techniques. I used the Swan-Clearwater valley as the pilot study area, where human activities threaten to isolate the grizzly bears in the Mission Mountains from the rest of the NCDE population. If linkage zones are not maintained across the Swan-Clearwater valley, the Mission Mountains could become completely isolated. The Mission Mountains by themselves are too small to support a grizzly bear population over time, and local grizzly bear extinction would be likely.

II. STUDY AREA

The Swan-Clearwater Valley is located in Western Montana at latitude 47
north and longitude 114 west. The 158,362 ha analysis area is bounded on the east by the Swan Front roadless area (part of the Bob Marshall Wilderness complex) and on the west by the Mission Mountains Wilderness Area (Fig. 3). The lands of the study area are of mixed ownership, which are managed according to different goals. Mountain ranges on both sides of the valley reach more than 3000 m, with the timberline at approximately 2100 m (USFS 1994). The Swan Valley, the northern portion of the analysis area, is a gently sloping valley less than 12 km wide and is bisected by the Swan River flowing northward. Valley elevations vary from 940 m at Swan Lake to 1450 m at the Swan-Clearwater divide. At the southern portion of the study area is the Clearwater River valley and Seeley Lake (elevation 1220 m).

Millennia of glacial activities molded the U-shaped Swan-Clearwater valley. Receding glaciers left behind a valley floor with a complex system of forest wetlands intermingled with upland forests. The resulting topographic variation created strong climatic gradients which lead to great diversity in vegetation. Such wet micro-sites in combination with topographic diversity undoubtedly contributed to very productive grizzly bear habitat.

Except for wetland and riparian areas, the valley was originally covered with coniferous forests. Today, major cover types include lodgepole pine (Pinus contorta), Douglas-fir (Pseudotsuga menziesii), Engelmann spruce/subalpine fir (Picea engelmannii/Abies lasiocarpa), western larch (Larix occidentalis), grand fir (Abies grandis), and ponderosa pine (Pinus ponderosa) (Hart 1994).
Figure 3. Study area boundary (red) and land ownership in the Swan-Clearwater valley.
common species include western red cedar (*Thuja plicata*), western white pine (*Pinus monticola*) hemlock (*Tsuga heterophylla*), and whitebark pine (*Pinus albicaulis*).

Fires and logging have had a major influence on characteristics of the landscape. Landscape patterns left by decades of extensive logging activities are easily distinguishable in satellite images which also makes the valley's mostly checkerboard ownership of alternate square-mile sections easily discernible. Major land owners include Flathead National Forest (35.7 %), Plum Creek Timber Company (30.2 %), Lolo National Forest (13.7 %), Montana Department of State Lands (10.5 %), private non-corporate land owners (8.2 %), and the US Fish and Wildlife Service (< 1 %). Residential development is rapidly expanding on the 13,026 ha of private, non-corporately owned land in the valley.

**III. DESCRIPTION OF SELECTION CRITERIA AND METHODS**

Most evaluations of grizzly bear habitat emphasize vegetation, particularly vegetation as potential food resources (Mace and Jonkel 1980, Craighead et al. 1982). Although distribution of food is clearly an important determinant of grizzly bear use and movement, human presence in areas such as the Swan-Clearwater is most important. Historically, grizzly bears existed throughout much of western U.S. with highest concentrations along river valleys in the Rocky Mountains (Storer and Tevis 1978, Brown 1985). As humans moved into these river valleys, grizzly bears were displaced. This pattern of displacement
has become apparent in the Swan-Clearwater valley, where the number of
grizzly bears using the valley has declined in the last 15 years while the amount
of human activities has increased. Consequently, the number of grizzly bears in
the adjacent Mission Mountains appears to have declined during this time (C.
Servheen, pers. commen.).

I compiled an extensive GIS database for the Swan-Clearwater valley and
adjacent Mission Mountains to evaluate possible causes of the declining
numbers of grizzly bears in this area. This database included 29 different layers
of information (Appendix 1). After viewing these data layers, I determined that
human activities are a major factor in determining which areas grizzly bears use
and survive in. Use and movements by grizzly bears throughout the valley floor
appears to be limited by human activities (USFS 1994a, 1994b). To help
address the apparent problem of habitat fracture zones in the valley, I developed
a model to site-specifically assess habitat quality based on a combination of
human impacts and vegetational qualities. When the model identifies an area
with little human impact which is continuous and spanning across the valley floor,
the area can potentially function as a linkage zone.

To enable such an assessment, I selected those data layers which are
directly or indirectly associated with human activities. The data layers which
were included in the model because of their association with human activities
were roads, developed sites, and cover conditions. These were selected
because increases in the amount of roads and/or developed sites, and
reductions in vegetative cover reduce the quality of grizzly bear habitat. Also necessary to the analysis is some positive measure of vegetational quality. However, other than information that delineates riparian areas (indicates high quality habitat), no specific vegetational mapping has been done for the Swan-Clearwater valley. I included the riparian data layer as a positive measure of habitat quality. As other sources of vegetational maps become available (USFS 1996) incorporation of such information can further improve this modeling process. Not included in the model, but included in the final evaluation, was information about land ownership and topography.

An important feature of this model is its ability to cumulatively assess an area with regards to various human impacts and vegetational qualities to identify potential landscape linkages. To develop a cumulative assessment tool, I categorized and assigned values for each type of condition (different road densities, cover conditions, developed sites etc.) according to the perceived level of impact that the particular condition is expected to have on habitat quality (Christiansen 1982, Weaver et al. 1986, USFS 1990, 1994, IGBC 1994, C. Servheen pers. commen.). The assigned values for the individual types of conditions ranged from "beneficial" impact on habitat quality to "high" negative impact on habitat quality (Table 1).

When assigning values I considered variations of impacts within a particular condition, for example establishing different values for different road densities. I also considered variation of impacts between different conditions, for
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<tr>
<td>RD 1.01-2.00 mi/mi², inside SCA</td>
<td>Minimal</td>
</tr>
<tr>
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^ Secure Core Area (SCA) were areas > 500 m from an open road or a road with use restricted by a gate or sign, or a trail receiving high use (IGBC 1994).
example establishing values for cover conditions in relation to developed sites. Almost exclusively, the studies I used information from to help assign values have evaluated how one single condition affects grizzly bears. For example, numerous studies have evaluated the effect roads have on grizzly bears (see next section), or the effect cover conditions have on grizzly bears (see next section). Very seldom have researchers examined how combinations of factors affect habitat quality. Researchers have generally examined effects of different types of human activities on grizzly bear use qualitatively, but seldom have such relationships been assessed quantitatively. Lack of quantitative information regarding the relative difference in impacts on habitat quality makes assignment of values for impact on habitat quality difficult. Lack of quantitative information was also the reason I used relative values instead of real numbers in this model.

Below follow explanations of why the layers of information were chosen, and how the data were manipulated and used in the model.

**Roads**

Roads can have a major influence on grizzly bear populations and habitat use patterns (McLellan and Mace 1985, Kasworm and Manley 1990, Mace and Manley 1993). Grizzly bears are occasionally killed by vehicles on roads (Knight et al. 1981, 1986), but the primary impact of roads is the access they provide hunters, poachers, and the general population (McLellan and Mace 1985). Grizzly bears may be displaced trying to avoid roads (Kasworm 1985, Mace and
Manley 1993), or conversely grizzly bears may become habituated to roads which can later lead to higher mortality rates (Meagher and Fowler 1989). The effects roads have on grizzly bears can be divided into 4 categories: 1. avoidance/displacement; 2. habituation; 3. habitat loss and fragmentation; 4. direct mortalities (IGBC 1987). A combination of these effects determine how grizzly bears respond to roaded areas. Studies investigating the influence of roads on grizzly bears have looked at the distances to roads at which bears appear to show avoidance (Mattson et al. 1987, McLellan and Shackleton 1988, Aune and Kasworm 1989, Kasworm and Manley 1990) and at road densities in relation to grizzly bear habitat use (Mace and Manley 1993). Such studies consistently point out that as the density of roads increases in an area, the use by grizzly bears declines. In fact, according to many researchers, management of motorized access may be the most powerful tool for securing grizzly bear habitat (Mace and Jonkel 1980, Mattson et al. 1987, USFWS 1993, IGBC 1994).

Because of the impact that roads have on grizzly bears, I included roads information in the assessment of potential linkage zones.

Road density has usually been calculated by delineating an area, measuring total length of roads present, and dividing length by area. With this approach the same road density (i.e. average road density) is ascribed to every point within the area. Mace and Manley (1993) indicated that such a technique for calculating road densities did not adequately address grizzly bears' response to roads. To evaluate potential linkage zones, I used a GIS technique that has
been referred to as moving window analysis (Gardner and Turner 1990, Mace and Manley 1993). To calculate the exact length of roads within a predefined radius of each point, I used a variation of the moving window technique which I called "moving circle" analysis. This technique provided precise road density values for each pixel of the map.

Road data for the Swan Valley portion of the study area was acquired in vector form from Flathead National Forest (NF), current as of 1994, whereas the data for Clearwater Valley portion was developed from cartographic feature files current as of 1992 (Hart 1994) updated by Lolo NF personnel.

From this road information, I created 2 road files for my analysis. The first file depicted "total motorized access routes" (TMAR), which included all open roads, restricted roads, and motorized trails (IGBC 1994). Restricted roads included roads on which motorized use was restricted seasonally or throughout the year by a physical obstruction such as a gate, berm, rocks, or logs. Total motorized access routes were used in the model because the "open roads" category by itself does not give a complete measure of how grizzly bears are affected by roads (Mace and Manley 1993). The second file depicted all open roads, roads with motorized use restricted by a gate or a sign, and trails receiving high use (more than 12 parties per week, USFS 1992). Studies which analyze distance to roads at which bears appear to demonstrate avoidance behaviors provide a range of distances (100 - 914 m) (Mattson et al. 1987, McLellan and Shackleton 1988, Aune and Kasworm 1989, Kasworm and Manley
1990). Based on this range of values, IGBC (1994) proposed a distance of 500 m as the most reasonable average distance beyond which grizzly bears appeared to be less affected by access routes and termed those areas Secure Core Areas (SCA).

To perform the moving circle analysis, I converted the file depicting TMAR from vector into raster form, where each pixel (30 x 30 m) representing a road had the value of 1, and each pixel not representing a road had the value of 0. The moving circle, GIS routine was carried out in ERDAS using the command SCAN (ERDAS 1991). I calculated road density in mi$^2$, rather than metric units (km$^2$) because miles have become a standard (IGBC 1994). For road density calculation, I used a moving circle with a 900 m (30 pixels) radius, which yielded a 0.98 mi$^2$ circle (Appendix 2). Each pixel on the map, whether it was a road pixel or not, was the center pixel of a particular moving circle. The number of pixels represented as roads in the surrounding 1 mi$^2$ circular area (each pixel representing a 30 m road segment) was assigned to the corresponding center pixel in a new layer. This value represents the road density in miles of roads per mi$^2$ for that point (Appendix 2). The completed computer run yielded a map with continuous, precise road densities for the 1 mi$^2$ surrounding each pixel. I grouped the different road density values into 4 categories of road densities, 0 mi/mi$^2$, 0.01 - 1 mi/mi$^2$, 1.01 - 2 mi/mi$^2$, and > 2 mi/mi$^2$, based on Mace and Manley (1993). The use of these road density categories have become a standard in road management with regards to grizzly bears (IGBC 1994). Mace
and Manley (1993) found that all sex and age classes of grizzly bears used areas with road densities > 2 mi/mi² less than expected. Because no investigation of the effects of specific road densities categories > 2 mi/mi² have been carried out, I assumed an equally strong, negative effect on habitat quality for any road densities > 2 mi/mi².

To complete the road impacts map for use in the linkage zone assessment, I buffered all open roads, roads restricted by a gate or a sign, and trails receiving high use by 500 m (IGBC 1994). Areas remaining after establishment of this buffer are SCAs. By combining the outputs from TMAR densities and SCAs I was able to further refine the impacts of roads on habitat quality. Because human presence is more likely outside SCA than inside, I gave areas inside SCA a one category better impact value than areas outside SCAs. For example, if the TMAR density was in the 1.01-2.00 mi/mi² road density category and the area was inside an SCA (meaning that all roads in the area had road use restricted by a permanent physical obstruction) I assigned the area to the "minimal" impact category. On the other hand, if an area with the same TMAR density was outside an SCA (meaning the area contained open roads, or roads restricted by a gate or a sign, or high use trails) I assigned it to the "low" impact category. The better relative value in the first example is represented by the fact that all the access routes in the area had use restricted by a permanent physical obstruction and therefore human presence in the area would be less likely. To develop the final layer for road impacts, SCAs were included
independent of their size. The final layer had 5 categories of road impacts values ranging from "beneficial" for areas with 0 mi/mi² road densities, inside a SCA to "moderate" impacts on habitat quality for areas with > 2 mi/mi² road densities outside SCA (Table 1). For other linkage zone analysis areas where specific information about road restriction is not available and SCAs cannot be determined, I recommend using the road density scores from Table 1 for the "outside SCA" category.

Developed sites

Intensive human activities found particularly around developed sites affect how grizzly bears use and survive in an area. Other than acting neutral, grizzly bears respond to developed sites in 2 ways. First, the developed site attracts animals because of the presence of garbage, drawing them in and habituating them to humans, often resulting in bear mortalities. The other possible response is that the grizzly bear avoids the developed site, leading to a net loss in habitat. Both the latter outcomes have negative consequences for grizzly bears.

Increases in grizzly bear mortalities have been documented in the vicinity of garbage dumps (Schullery 1980), major campgrounds (Knight et al. 1984, Mattson et al. 1987), small campsites (Schleyer et al. 1984), and areas with active resource extraction activities (McLellan and Mace 1985, McLellan and Shackleton 1989). Numerous studies have documented avoidance by grizzly bears of developed sites with consequent loss of habitat area (Elgmork 1983,
Knight et al. 1984, Haroldson and Mattson 1985). While the single most common
type of developed site in most fracture zones is human residences (seasonal or
permanent), very little specific information is available about grizzly bear's
response to residences in North America. In southern Norway, Elgmork (1978,
1983) found a significant decrease in brown bear occurrence as the number of
holiday cabins increased.

Because most of the various developed sites have become permanent
features in the landscape, they usually have to be accommodated by wildlife
managers rather than removed. Only on rare occasions is it an option to remove
a developed site from a critical habitat area. Instead, the developed site
becomes something to manage around. Because of their permanence in the
landscape and the direct association with human presence, developed sites may
be the most important consideration in an evaluation of habitat quality and
potential linkage zones.

A process called Cumulative Effects Modeling (CEM) was developed in an
try to evaluate the effects that developed sites and other forms of human
activities have on habitat use by grizzly bears (Christiansen 1982, Weaver et al.
1986, USFS 1990). The CEM process was designed to do 2 things. First, the
model predicts individual and collective effects of land uses and activities in
space and through time on grizzly bears. Secondly, use of CEM allows
evaluation of alternative land-use scenarios relative to grizzly bear recovery
goals and objectives. This effort is ongoing at different stages for all grizzly bear
recovery areas.

Input data for this layer consisted of point and polygon features of developed sites. Polygon features represented campgrounds, livestock operations, communities, and other objects which cover an area too large to be represented by a point. The information was already digitized by the Flathead NF for the Swan Valley. For the Clearwater Valley, I digitized developed sites from aerial photos taken in 1993 and visited each site to determine the type.

Each developed site represented a "human influence zone" (Servheen and Sandstrom 1993), which was sized depending on what type of human activity the site represented. To determine which type of developed site should have the largest, medium, and smallest sized human influence zones, I used information from the CEM process. The categorization of different developed sites for the CEM process was based on best judgements of experienced bear biologists (Table 2). Limited quantitative data exist for exact distances of such influence. If available, such information would vary both by individual bear and by season. Because of lack of empirical data, the actual size of human influence zones for input to this model was based on best judgement estimates (C. Servheen pers. commen.). The larger the influence zone surrounding the developed site, the greater the potential to either attract or deter grizzly bears (Table 2).
Table 2. Size of influence zone around different developed sites.

<table>
<thead>
<tr>
<th>Influence zone radius (m)</th>
<th>Type of developed site</th>
<th>CEM danger category</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 2</td>
<td>Fishing access, Boat launch, Trail head, Miscellaneous structure</td>
<td>low</td>
</tr>
<tr>
<td>120 4</td>
<td>Campsite, Picnic site, Work station, Outfitter camp, Viewpoint</td>
<td>medium</td>
</tr>
<tr>
<td>210 7</td>
<td>Residence, Livestock operation, Community, School, Manufacturing business, Church, Campground, Garbage dump, Restaurant, Summer camp, Guest lodge</td>
<td>high</td>
</tr>
</tbody>
</table>

A CEM danger categories are determined for 5 different seasons (USFS 1994). The categories listed here represents the most common CEM danger category for that activity.

Influence zones surrounding developed sites are areas most dangerous to grizzly bears and were therefore assigned the strongest individual impact value ("high"). This indicates that a human influence zone represented a greater reduction in habitat quality than if an area were in the highest road density category or lacked hiding cover. There are 2 reasons behind the assumption that developed sites cause the greatest decline in habitat quality. First, a developed site often represents permanent human presence, whereas roads or lack of hiding cover only represents an increased possibility of human encounters. Secondly, because of reduced land management opportunities, a developed site has a more long term, permanent, negative impact on habitat quality. Managers have more opportunities to change the amount of roads or change the cover conditions in an area than they have to relocate already established developed sites.
As the distance to developed sites increased, I assumed improvements in habitat quality. This was represented in the model by 2, 120 m (4 pixels wide) concentric zones around each human influence zone with lower impact values assigned ("moderate" and "low") indicating less reduction in habitat quality than within human influence zones (Table 1). I assigned a "neutral" value, for distances > 240 m from the outer boundary of a human influence zone.

Cover conditions

The concept of hiding cover has been discussed frequently in the literature (Lyon 1979, Hillis et al. 1991), and numerous definitions exist. For the purpose of my analysis, I used Flathead NF's (USFS 1992) definition for non-hiding cover, or open areas, which is "vegetation not capable of hiding 90% of an adult grizzly bear at 200 feet." Open areas within the evaluation area occurred naturally as a result of recent fires and of conditions that were too wet or too dry to support sufficient vegetational hiding cover. Human-made open areas were mostly caused by recent logging activities. In the latter case, open areas were often associated with logging roads.

Grizzly bears and other species of large mammals are often reluctant to venture far from hiding cover during daylight hours in areas with frequent human activity. During a 4 year study of 46 radio-collared grizzly bears, Blanchard (1978) found 90% of relocated bears in areas with hiding cover. In a similar comparison, Schallenberger and Jonkel (1980) documented 80% of the
relocated grizzly bears in areas with forest cover. As with most telemetry studies, these findings were mostly based on daytime relocations. Though grizzly bears often stay hidden when humans are present, they seem unaffected by cover conditions in areas that are relatively free from human use (Servheen 1981). In fact, some open areas such as avalanche chutes and alpine areas are preferred by bears during certain times of the year (Servheen 1981).

Open areas where humans are present are usually associated with roads or trails. Bears in direct view of roads and vehicles usually flee, whereas grizzly bears in protective cover are less affected by human presence (McLellan and Mace 1985, McLellan and Shackleton 1989, McLellan 1990). Therefore I assumed open areas to have a negative affect on habitat quality only if the area was within 500 m of an open road, a road with use restricted by a gate or a sign, or of a high-use trail (outside SCAs). On the other hand, open areas at distances greater than 500 m from such access routes (within SCA) were considered to affect grizzly bears equally to areas which provided hiding cover.

Information on presence or absence of hiding cover was available for the Swan Valley from the Flathead NF. To develop this information for the Clearwater Valley, I used a multi-spectral LANDSAT Thematic Mapper image from July 20, 1991. I performed an unsupervised classification using the VISUALIZATION/MAPPING algorithm (Ma 1994). This classification yielded a single band file with 63 different spectral groups (Appendix 3). Using aerial photos and knowledge from field visits to the area, I distinguished pixels
representing areas with hiding cover from pixels representing open areas. The single band file was then recoded into 2 classes - cover and open areas - and merged together with the cover file for Swan Valley.

I then assigned a 30 m (1 pixel) wide edge around the sides of the open areas. I assigned edge to the open side of the forest because grizzly bears are not specifically dependent on interior forest conditions and sometimes use open areas near hiding cover. After completing the cover map for the study area, I coded all open areas the same as areas providing hiding cover when they were within an SCA. In other words, a reduction in habitat quality was only accounted for when open areas occurred within 500 m of an open road, a road with motorized use restricted by a gate or a sign or a high use trail.

I found no evidence in the literature demonstrating differences in grizzly bear's behavioral response to the highest road impact category compared to areas not providing hiding cover (outside SCA). Therefore, I assigned the same impact value ("moderate") for open areas as for the highest road impact category (Table 1). The intermediate impact value ("minimal") for edge areas outside SCA represents only a small reduction in habitat quality compared to areas with hiding cover (receiving a "neutral" impact value).

**Riparian areas**

Grizzly bears use habitat selectively based on a number of factors. Type of vegetation is one important factor, so some measure of vegetational quality is
necessary to include in a landscape evaluation such as this one. Unfortunately, no detailed vegetational mapping has been done in the Swan-Clearwater valley.

Researchers have found that grizzly bears use riparian areas more than expected during all active seasons in the Mission Mountains (Servheen 1983), the North Fork of Flathead river valley (Mealey et al. 1977, Mace and Jonkel 1979), the Rocky Mountain East Front (Aune et al. 1984), the Northern Continental Divide Ecosystem, the Selkirk Ecosystem (Almack 1986), and the Cabinet-Yaak Ecosystem (Kasworm 1985). Riparian areas generally provide more year long predictable food and more security cover for grizzly bears than other habitat types (Craighead et al. 1982).

Because detailed vegetational mapping was not available, I instead used information about the extent of riparian areas as the base vegetational habitat layer in the model. I included wet meadows, seep areas, marshes, and stream and lake-side areas in the riparian area definition. These categories have sometimes been treated separately in grizzly bear habitat classifications (Mealey et al. 1977, Servheen 1983).

In some cases, mapping of riparian areas had already been completed. For areas where specific riparian mapping had not been done, such as in the Swan-Clearwater valley, I developed a model that predicted the extent of riparian areas (Appendix 4). This model evaluated whether an area could support riparian vegetation based the slope of the land adjacent to a water course. For example, an area with small changes in elevation (< 8 m) adjacent to a water
course could have a broad riparian area (210 m was the maximum in this model), while an area with large elevational changes directly adjacent to a stream would have a narrow riparian area.

Three important things should be noted regarding prediction of riparian extent. First, some small, possibly important micro-sites such as seep areas were excluded in the mapping process because of the spatial resolution (1:24,000 and 30 x 30 m pixel size) of this analysis. Secondly, the predictive model should not be considered a replacement for site-specific, field mapping of riparian areas. The predictive model was developed to be used over large areas where minimal field mapping had occurred. Finally, this model does not attempt to determine specific vegetation types of the riparian area. The cover types of the delineated area included open water, rocks, wet grass lands, deciduous scrubs, and coniferous forests, all of which become classified as riparian areas. One merit of this layer was that it demonstrated the linear nature of riparian areas. Minor east/west running riparian areas which feed into the main north/south running riparian areas could secure paths across the main valley floor. In other words, some riparian areas lie perpendicular to the human activities which are linearly arranged along the center of the valley. This spatial arrangement could facilitate animal movement across such valleys.

Once the extent of riparian areas was predicted for the Swan-Clearwater valley, and large bodies of water (> 30 ha) were excluded from the riparian category, I assigned a "beneficial" impact value to riparian areas and a "neutral"
impact value to non-riparian areas (Table 1). It might appear that too little weight is given to the vegetational portion of this model. There were 2 reasons for this. First, if more detailed vegetational information were available, a stronger differentiation between "beneficial" and "neutral" habitat quality could be made. If information on important grizzly bear food types within and outside riparian areas existed, a "more beneficial" impact value would be given to those areas. As it now stands, the riparian delineation includes areas of both high and low vegetational qualities. Lower vegetational quality riparian areas include rocky stream-side areas and open water. Secondly, even if a high quality vegetational area existed and was mapped, a high quality food area is not capable of completely mitigating the negative impacts of intensive human developments.

**Land ownership**

Land ownership patterns in the Western U.S. virtually predicts where fragmentation of habitat is occurring. Highly productive, low elevation areas are often partly or completely privately owned, and the associated human pressures often lead to fragmentation of habitat (Fig. 2). Information about land ownership was not directly incorporated in the model, but I used it in the final analysis. By incorporating the ownership both with the individual layers of the model and the final scored map, I gained important information about the level of fragmentation for the different land owners.

The ownership information was created by updating and redigitizing files
Topography

Topography is by itself another good indicator of where fragmentation of habitat is occurring. Almost all low elevation, mountain valleys in western Montana are facing threats of fragmentation. Historically, these valleys were the most productive areas for wildlife, but also the most sought after by humans. Information about topography was used both in the prediction of riparian area extent and to help in 3-dimensional visualization of the landscape.

I compiled an elevation layer by merging information from 40 1:24,000 digital elevation models provided by the U.S. Geological Survey (1987a).

Combination of input data to final scored map

Once manipulation of each separate layer was completed, I overlaid the 4 individual impact layers into one new layer displaying the combined impact on habitat quality. Careful evaluation of each existing combination of impacts from the 4 map layers allowed me to group the combined impacts into four categories. In general, to be considered in the "minimal" combined impact category, the pixel had to have "neutral" or "beneficial" impact values for all 4 individual layers, or only one condition have a "minimal" or "low" impact value. To be considered in the "low" combined impact category, 2 conditions could be in the "minimal" or "low" category, or 1 condition in the "minimal" or "low" category and/or
1 condition in the "moderate" category while the others had to be "beneficial" or "neutral". To be considered in the "moderate" or "high" combined impact category, the individual impact values had to be different combinations of "low", "moderate", and "high" impact values (Table 3). When interpreting these generalized combinations leading to different habitat quality values, it is important to acknowledge how the different human impacts interact with each other. For example, residences in the valley are always associated with some level of road densities and often with open areas. One could say that the model is indirectly driven by the presence of developed sites, not because they were given the highest impact category (Table 1), but because developed sites almost exclusively occur with roads and open areas.

Table 3. Existing combinations of individual impact levels, and resulting combined impact levels in the "high" and "moderate" category. Categories of human activities and vegetational conditions leading to the individual impacts levels are described in Table 1.

<table>
<thead>
<tr>
<th>Road impacts</th>
<th>Developed site impacts</th>
<th>Cover conditions</th>
<th>Riparian area</th>
<th>Combined impact level</th>
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</table>
**Delineation of linkage zones**

Based on the map displaying the combined impact on habitat quality, I delineated linkage zones. The goal was to identify areas which could link the lower reaches of the Swan Front roadless area at the eastern side of the valley with the Mission Mountain Wilderness to the west (Fig. 3). The wider the linkage zone, the more security is provided for grizzly bears using it. A too narrow linkage zone could be of danger to grizzly bears because it is bounded by human activities. Knowledge of local conditions was important when delineating potential linkage zones. For example, we know the southern portion of the Mission Mountains (south-west of the study area) has the highest topographic and vegetative diversity and contains the most productive grizzly bear habitat in the area. Consequently, the area has the highest density of grizzly bears (Servheen 1983). Because of this information, maintaining linkage zones in the southern portion of the study area are especially important for the persistence of grizzly bears in the area.

Generally, to qualify for inclusion as a potential linkage zone, an area had to be evaluated to be in the "minimal" or "low" combined impact category and to span the valley in a continuous fashion. Whenever possible, riparian areas were included within potential linkage zones. Single, small areas in the "moderate" or "high" combined impact category surrounded by areas in the "minimal" and "low" combined impact categories (usually lone developed sites surrounded by forested areas) could also be included within potential linkage zones. Excluded
as potentially suitable linkage areas were large stretches of land in the "moderate" and "high" combined impact categories. Such areas almost exclusively contained human influence zones.

IV. RESULTS

Roads

The 611 mi² study area contained 1804 mi of Total Motorized Access Routes (TMAR), making the average TMAR density for the study area 3.1 mi/mi² (Table 4). Plum Creek lands had the highest average TMAR density (4.5 mi/mi²) and Department of State Lands (DSL) the lowest (1.9 mi/mi²).

TMAR densities, calculated using the moving circle technique, ranged from 0 mi/mi² to 10.6 mi/mi² throughout the study area. Sixty seven percent of the study area had TMAR densities > 2 mi/mi² (Table 4). The moving circle analysis also demonstrated the variation in road densities depending on land ownership. Private, non-corporate lands and Plum Creek lands had the highest proportion (> 80 %) of their land with TMAR densities > 2 mi/mi², followed by Lolo NF and Flathead NF, while DSL had the lowest proportion (49.5 %).

At the other extreme, 10% of the total study area had TMAR densities in the lowest category (0 mi/mi², i.e. no TMARs within the 900 m search radius of the moving circle). Most of these areas were located along the upper elevation, outer boundary of the study area (Fig. 4). Broken down by individual landowners, the 0 mi/mi² TMAR density category varied between 17.7 % for
Table 4. Distribution of different conditions by land ownership.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Public land</th>
<th>Private land</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flathead NF</td>
<td>Lolo NF</td>
<td>State Lands</td>
</tr>
<tr>
<td>Land ownership (miile^)</td>
<td>218.4</td>
<td>84.0</td>
<td>64.4</td>
</tr>
<tr>
<td>TMAR^ length (miles)</td>
<td>506.2</td>
<td>271.0</td>
<td>121.9</td>
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<td>Percent of functional secure core area (SCA)^</td>
<td>35.8</td>
<td>21.1</td>
<td>33.5</td>
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<tr>
<td>Percent of open area outside SCA (%)</td>
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<tr>
<td>Percent by land owner (%)</td>
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^a TMAR included open roads, restricted roads and motorized trails.
^b Calculated by dividing road length by area.
^c Calculated using the moving circle method. Percentage of area by each landowner.
^d Functional secure core areas were areas > 500 m from an open road, a road with motorized use restricted by a gate or a sign, or a high use trail. Each area also have to be > 1000 ha.
* Used as indicator of patch size. The larger the value the larger the average size of open areas.
Figure 4. TMAR densities for the Swan-Clearwater valley calculated using the moving circle method. SCA boundaries are shown in red.
Flathead NF to only 0.5 % for private, non-corporate lands (Table 4).

The amount of SCA also varied significantly among different landowners. In the study area, 25.1 % of the land was identified as functional SCAs (Table 4) and was located mostly along the upper elevation, outer boundary of the study area (Fig. 4). Flathead NF had the largest proportion of land identified as SCA, while Plum Creek and private, non-corporate lands had the least (Table 4). Proportions of each of 5 categories of road impacts (Table 1), resulting from combining the TMAR density information with the extent of SCAs, ranged from 63.8 % in the "moderate" category, 12.9 % in the "low", 5.4 % in the "minimal", 7.7 % in the "neutral", and 10.1 % in the "beneficial" impact category.

The last measure of roadedness was the distribution of distances to TMAR from any given point. The mean distance to a TMAR for every 30 m pixel in the study area was 374 m (range 0 - 4798 m, s = 527 m). Sixty-five percent of the study area was within 300 m of a TMAR, 82 % was within 600 m of a TMAR, while only 2.3 % was more than 2000 m from a TMAR.

Developed Sites

There were 550 developed sites within the study area, with private residences being the most common type. Influence zones occupy 6419 ha or 4.1 % of the study area, and a large majority of these are located on private, non-corporate lands. Even though this represented only a small proportion of the study area, the spatial distribution of the developed sites could create a
barrier against east to west animal movements across the valley (Fig. 5).

**Cover conditions**

Eighteen percent of the study area lacked hiding cover and was within 500 m of either an open road, or a road with motorized access restricted by a gate or a sign, or a high use trail. Distribution of open areas varied significantly among landowners, with Plum Creek having the largest proportion, about 1/3, of their land in the open category, while Flathead NF, Lolo NF, and DSL had around 10% of their lands in the open area category (Table 4). Open areas were distributed relatively evenly throughout the valley (Fig. 6). With the exception of some high elevation, naturally open areas in the northern part of the study area, open areas were usually associated with TMAR.

The proportion of open area to edge - where a large value indicates a large average size of open areas revealed a combined ratio for the study area of 0.63 (Table 4). Plum Creek had the largest average patch of open area, with a ratio value of 0.71 and Lolo NF had the smallest (0.43).

**Riparian areas**

The model predicting the extent of riparian areas resulted in 30.7% of the study area being classified as riparian (Table 4). This comparatively high proportion of riparian land area can be attributed to the mesic, forested wetland system on the flat valley floor. Because most private, non-corporate lands are
Figure 5. The spatial distribution of human influence zones and associated buffer for the Swan-Clearwater valley. Private, non-corporate land boundaries are shown in black.
Figure 6. Cover conditions in the Swan-Clearwater valley. Land ownership boundaries and associated differences in management strategies can easily be distinguished.
situated along the center of the valley floor, they also contained the highest proportion (57.5 %) of riparian land of any landowner. All other landowners had wider elevational distribution, and therefore had riparian proportions similar to the entire study area (approximately 30 %).

As one measure of fragmentation of riparian areas, I measured the amount of roads within riparian areas. There were 606 miles of TMAR within riparian areas, which equals 32 % of all TMAR.

Combined impact values

The combined "minimal" impact category made up 45.3 % of the study area (Table 4). The amount of land in the "minimal" category varied significantly among the different landowners, with DSL having the largest proportion of their lands in this category and private, non-corporate the smallest proportion. The combined "low" impact category made up 34.6 % of the study area, and ranged from 18.7 % for private, non-corporate lands to 48.6 % for DSL. At the combined, "moderate" impact category, the difference between public lands and private lands was even more apparent. Plum Creek and private, non-corporate lands had 3 to 4 times higher proportions of their lands in this category than the public lands portion of the area (Table 4). Only 3.9 % of the study area was in the combined "high" impact category. As expected, these lands were mostly distributed on private non-corporate lands along the center of the valley floor (Fig. 7). Private, non-corporate lands had 25.5 % of their lands in this category.
Figure 7. Combined impact values for the Swan-Clearwater valley. The spatial distribution of these values was used to delineate linkage zones.
This was also where more than 95% of the human influence zones from the developed site layer were located.

**Land ownership within linkage zones**

Four linkage zones across the valley were identified based on the combined impact value map (Fig. 8). The 4 linkage zones constituted of 42.6% (67,538 ha) of the study area (Table 5). DSL had the highest proportions of their lands (about half) identified as linkage zones, all located in the northern most linkage zone. Almost half of Plum Creek’s land was identified as linkage zones, distributed throughout all 4 linkage zones, while only 12.2% of private, non-corporate lands were located within linkage zones.

The narrowest part of any linkage zone was 800 m (in the southern part of linkage zone B). Within the outer boundary of linkage zone A and B exist some small areas of concentrated development. These areas consist mostly of land with "moderate" and "high" combined impact levels and do not have the potential to function as linkage zones. Because of this, these lands were not included in the linkage zones, even though they were located within the outer boundary of linkage zone A and B (Figure 9).
Figure 8. Four delineated linkage zones (red crosshatch) in the Swan-Clearwater valley.
Table 5. Land ownership in the 4 linkage zones.

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<th>Land owner (ha)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<th>Percent of ownership</th>
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<td>5061</td>
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<td>Lolo NF</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>10206</td>
<td>46.9</td>
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<td>0</td>
<td>8304</td>
<td>8304</td>
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<tr>
<td>Plum Creek</td>
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<td>6854</td>
<td>4580</td>
<td>4004</td>
<td>23419</td>
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</tr>
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<td>Private</td>
<td>1105</td>
<td>268</td>
<td>217</td>
<td>4</td>
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<td>17385</td>
<td>67538</td>
<td>42.6</td>
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*A" represents the southern most linkage zone, progressing northward to "D," the northern most linkage zone.

V. DISCUSSION

Evaluation of habitat fragmentation in the Swan-Clearwater valley

Many studies have been designed to evaluate the effects of roading, developed sites and cover condition on grizzly bear habitat use. Each of these studies has usually evaluated grizzly bear habitat use with regard to only one of these impacts at a time. However, the effect of combined factors will result in a different assessment of habitat quality than the affect of simply evaluating one factor's influence on habitat quality. For example, the effects roads have on grizzly bear habitat use surely differ according to the presence or absence of hiding cover and/or developed sites. I attempted to evaluate habitat potential by considering a number of factors that affect habitat quality. To perform such an evaluation, I needed to assign values to the factors affecting habitat quality. The values assigned to human activities and vegetational qualities were determined
after assessing current literature on grizzly bears and after consulting available experts in the field. The study is limited by its less than ideal assignment of values. Ideally these values would have been assigned based on a larger volume of research that compared the weight of various factors upon habitat quality. Such information does not currently exist. However, as more studies are completed which present such findings, this modelling process can be refined. This type of model will also become more reliable as technologies such as GPS radio collars improve. With adjustment of study design of current and future field research projects, we can increase the knowledge about grizzly bears' behavioral response to different human activities. If new knowledge differs from current knowledge, adjustments can easily be made to input values in my model and new outputs can be produced quickly.

One important output from my modeling effort was partial measurements which demonstrated the level of habitat fragmentation caused by different types of human activities. For example, looking at road densities in just the valley, I compared values found in the Swan-Clearwater valley with threshold values developed for the Flathead NF. In the Swan-Clearwater valley, 67 % of the area had TMAR densities > 2 mi/mi², and only 25.1 % of the area fit the definition of a functional SCA. To put these numbers in perspective, we can look at the grizzly bear habitat goals set by the Flathead NF. Flathead NF managers developed threshold values for levels of road densities that can exist within a female grizzly bears' yearly home range (IGBC 1994, USFS 1995). Information for setting
threshold values and female home range sizes was derived from the South Fork Grizzly Bear Study (Mace and Manley 1993). Flathead NF digitized female home range sizes at about 50 mi$^2$ (USFS 1994c) and set a 10 year goal to limit high density (> 2 mi/mi$^2$) TMAR to no more than 19 % of each female home range area (USFS 1995). This goal of 19 % is much lower then the proportion of 67 % of land in the highest TMAR density category found for the Swan-Clearwater study area.

In terms of SCA, the goal set by Flathead NF is to provide functional SCAs that equal or exceed 68 % of each female home range area within 10 years (USFS 1995), a much higher percentage than the current amount of SCA available in the Swan-Clearwater study area of only 25.1 %. When comparing Flathead NF threshold values with calculated values for the Swan-Clearwater area, we must consider that the threshold values for female home ranges were established for land where more than 75 % was federally owned (USFS 1995), whereas the female home range areas within the Swan-Clearwater valley contain a high proportion of non-federal lands. My analysis was only done for the multiple-use portion of the valley, excluding the portions of predicted female home ranges within wilderness areas. Managers of the Flathead NF can set more ambitious threshold values because of their administrative authority over road management. Providing sufficient SCAs in the Swan-Clearwater where much of the lands are in private hands is more difficult. Still, the large discrepancy between the identified needs of grizzly bears with regards to road
management and what was observed in this area is noteworthy.

Important is not only the amount of human activities in an area, but where the activities occur. The spatial distribution of road densities in the highest category fills the entire center of the valley floor (Fig. 4). Human influence zones occupy only 4.1 % of the valley, but the zones are spatially distributed nearly continuously along the center of the valley floor (Fig. 5). Because of the high likelihood of human presence and because of the spatial distribution of human influence zones, this activity layer is the most important determinant of where grizzly bears can use and cross the valley floor.

My evaluation resulted in a single layer depicting the combined effects of all human activities (presence of roads, developed sites, and cover conditions) and riparian areas. Despite the seemingly low proportion of land in the high danger category (3.9 %), the spatial distribution of poor habitat along the center of the valley creates a broken landscape (Fig. 7). In other words, although much of the area evaluated was considered in the minimal or low danger categories, that habitat was not distributed in a way to provide easy movement from the Swan Mountains to the Mission Mountains. With a paved highway cutting through the center of the valley, and more than 1700 miles of forest roads, a large number of developed sites, and ongoing logging activities, grizzly bears' ability to use the valley floor is currently questionable. Still, based on the combined impact map, I was able to delineate 4 relatively narrow potential linkage zones across the valley.
The importance of linkage zones

Direct demographic threats represent an immediate danger to the survival of the grizzly bear as related to habitat fragmentation. A small, isolated population of grizzly bears is more affected by stochastic events. Bad weather, low numbers of female cubs born several years in a row, a string of poaching, or just bad luck can destroy a small population where a large population could survive. An example of such a combination of deleterious events occurred in 1994 to the Mission Mountain sub-population. The summer and fall of 1994 was dry, which forced bears into closer contact with humans in search for food. An increased number of human/bear encounters led to a reduction of at least 5 grizzly bears from the Mission sub-population (2 killed illegally and 3 removed by agency). With an estimated population size of about 10 -15 grizzly bears (C. Servheen pers. commen.) this constituted a loss of 30 - 50 % of the Mission Mountain sub-population. The highest level of human-caused mortality a grizzly bear population can sustain without population decline is 6 % (Harris 1985). For the grizzly bear recovery goal to be met, the known, human-caused mortality should not exceed 4% of the minimum population estimate (USFWS 1993). For the Mission Mountain sub-population to recover from the losses in 1994 by reproduction alone would take time. Linkage zones can provide a "rescue effect" (Brown and Kodric-Brown 1977) for the bear population. In fact, "rescue effect" is perhaps the most important function of linkage zones, especially in the near future. Later, once a site-specific management strategy is implemented,
permanent seasonal occupancy of low elevation areas can make linkage zones part of the home range of some grizzly bears. This would further facilitate movement of individuals from one side of the valley to another. Once such home ranges are secure enough that grizzly bears can permanently occupy them, then less mobile, adult female grizzly bears will be more likely to move across the valley.

Providing or securing linkage zones can be a practical solution to demographic dangers of fractured habitats. The distribution of grizzly bears in 1922 (Merriam 1922) was disjointed, consisting of 40 distinct bear populations throughout western US. Most of these populations are now extinct due to various human activities in combination with the consequences of isolation (Servheen 1990, USFWS 1993). If no movement between populations can take place, and isolation becomes permanent, local extinction becomes more likely (Hanski and Gilpin 1991), especially if human caused mortality remains high.

Linkage zones can be important not only for the persistence of isolated sub-populations such as that of the Mission Mountains, but for the persistence of whole populations. The most immediate threatening consequence of isolating sub-populations is local extinction. The long term consequence however becomes the eventual isolation of recovery areas. For example, cutting the Mission Mountains off from the rest of the NCDE would in turn isolate the NCDE from the Bitterroot Ecosystem because possible animal movements between the two recovery areas begin with the crossing of the Swan-Clearwater valley (Fig
9). Other areas where sub-populations are threatened by isolation are the Whitefish Range in the NCDE, and the Cabinet Mountains in the Cabinet-Yaak Ecosystem. These areas can only support about 70 - 90 bears each (C. Servheen pers. comm.), which makes extinction due to isolation very likely. In both cases, complete isolation of sub-populations would in turn lead to isolation of recovery areas (Fig. 2).

International cooperation plays an intricate part in recovery of grizzly bears. Linkage zones to the north, which connect US populations with larger Canadian populations, are extremely important to the long term persistence of grizzly bears in the conterminous 48 states. In fact, successful implementation of policies which protect and maintain linkage zones in southern British Columbia and Alberta is one of the keys to long term success for maintaining grizzly bear populations in the conterminous 48 states.

**Finding linkage zones using GIS**

With all the information available to us pointing out the importance of maintaining landscape connectivity, wildlife and land managers need to make informed decisions when determining which areas are best suited to serve as linkage zones. Layering data to manage areas is not a new concept. In the past, biologists attempted to determine key habitats by creating hand-drawn maps of various features, and then layering the maps to determine which areas seemed most ideal for the wildlife species being managed. Though we still use
Figure 9. Potential animal movements from the NCDE to the Bitterroot Ecosystem would include a system of linkage zones between habitat areas. The system would include: 1. Swan-Clearwater linkage zones; 2. The Mission/Rattlesnake habitat area; 3. Evaro Hill linkage zone (Mietz 1994); 4. Ninemile low occupancy area (approximate); 5. Clark Fork linkage zone (approximate).
this technique to assess landscapes, we no longer need to use markers and
drawing boards. By taking advantage of computer technology we can perform
the earlier work of cumulative landscape assessments in much less time. Simply
mapping individual layers of information (roads, houses, open areas, etc.) and
viewing them one at a time does not demonstrate the complexity of identifying
potential linkage zones. Viewing information layers all at once creates a map
that is too complicated to interpret. In my model, values were assigned to each
information layer according to the level of influence on grizzly bears and then the
values were combined to cumulatively display their effect on habitat quality.

A model such as this can evaluate subtle and complicated information that
could not previously be evaluated in a timely fashion. For example, when
assigning impact values, I gave consideration to how permanent a feature was in
the landscape. A residence or a campground received a higher impact value
than the highest road density category or an open area. High road density
received a lower impact value because roads can be removed from an area
more easily than is a developed site. Extremely high road densities may have as
negative an effect on grizzly bears as a residence, but problems associated with
roads can be more easily addressed through management.

Before this project, the only effort to evaluate the landscape connectivity
in the Swan-Clearwater valley resulted in one, about 2 mile wide, "corridor" (M.
Hillis, pers. commen.) This corridor spanned the valley along the Swan-
Clearwater divide, and was identified based solely on continuous federal land
ownership. A successful conservation effort seeking to ensure long term persistence of grizzly bears in the Mission Mountains must needs to maintain more than a 2 mile wide "corridor" across the valley. My assessment looks equally at all lands, independent of ownership. With the complex ownership of the valley floor (Fig 3), there is no single-owner solution to the problem of habitat fragmentation in the area.

Another advantage to using GIS technologies in a project such as this is that the modelling process yields valuable side products. When developing the layers for the assessment, we obtain specific information on the level of fragmentation for the individual layer. This information can help us specify what management option would be most helpful for a given area. If we seek to improve the condition within a linkage zone, we can easily obtain the information by using the GIS data to determine where and on what to focus management. Once the layers have been created, it is also possible to use them for other projects, combining them in a variety of ways. It is possible to build combined impact maps of the past, and to create scenarios of different future management options.

The results of this work can benefit a number of parties. First, researchers looking into any number of issues concerning the Swan-Clearwater area may find the maps helpful. Educators can use these maps when explaining grizzly bear management plans to the public, since the maps are comprehensible to the lay person. Additionally, when managers are required to
make decisions concerning land use, these maps can provide a great deal more information than was previously available. Results from this analysis allow managers to see which initiatives would be most valuable in bear conservation efforts. Managers can determine which improvements will help the situation site-specifically and which will affect the overall picture. And finally, this model can easily be repeated in other mountain valleys facing problems with fragmentation of grizzly bear habitat in a timely fashion.

Linkage zones in the study area

The overall purpose of this study was to identify which portion of what was until recently occupied grizzly bear habitat still has the potential to function as linkage zones in the Swan-Clearwater valley so that the Mission Mountains' grizzly bear sub-population would have a greater chance of persisting. A study of grizzly bear ecology demonstrated the importance of the Swan-Clearwater valley for resident grizzly bears in the Mission Mountains (Servheen 1983). Both during spring and fall seasons, grizzly bears trapped and radio-collared on the west side of the Mission Mountains used the Swan-Clearwater valley habitat extensively. However, current levels of human activity allow grizzly bears little opportunity for permanent occupancy in the Swan-Clearwater valley. For the Mission Mountain sub-population to persist, some habitat must be available on the valley floor to provide for grizzly bear seasonal needs, more habitat than is needed simply for travel, thus, the need to maintain linkage zones.
I have not attempted to provide specific management recommendations. There are other efforts addressing linkage zone management more specifically (Mietz 1994, Conservation Agreement 1995, Swan Private Land Management Recommendations 1995). However, in becoming familiar with the data presented in this study, I have some general recommendations that appear obvious. First, because the resulting 4 linkage zones include all major land owners in the valley, all agencies and land owners must serve as participants in the pending, decision-making processes. When we find that the very high road densities are unevenly distributed among land owners, our goal is not to simply lower overall road densities so that all will be affected equally. Rather the emphasis should be placed on lowering road densities where it is most needed, for example to create secure core areas on the valley floor and to minimize the amount of roads in and near riparian areas.

Secondly, though the grizzly bear recovery effort should be viewed in the long term, actions to prevent extinction of the sub-population should happen immediately. Timber harvesting, for example, should be managed with an eye toward maintaining the connectivity of areas with hiding cover. Timber managers should minimize the occurrence of open areas near roads (Swan Valley Conservation Agreement 1995). Furthermore, involving wildlife managers in the development of zoning regulations could prevent permanent degradation within linkage zones (Swan Private Land Management Recommendations 1995).

The best long term survival strategy for an individual bear is to avoid any
opportunity to confront humans. For grizzly bears using and crossing a valley with varied levels of human activities, their safest route is to stay away from humans. This would be the route of few houses, few roads and few humans. These routes are the linkage zones.
REFERENCES


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APPENDIX 1

Scale and sources for data layers developed for the Swan-Clearwater valley.

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<td>Plat and annexation map (Missoula County)</td>
<td>1:24000</td>
<td>Missoula County</td>
</tr>
</tbody>
</table>


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A U.S.G.S. (U.S. Geological Service)  
B F.N.F (Flathead National Forest)  
C C.F.F (Cartographic Feature Files developed by US Forest Service)  
D E.O.S.A.T. (Earth Observation Satellite Company)  
E D.S.L. (Department of State Lands)
APPENDIX 2

Calculation of Road Densities using the Moving Circle Method

Calculating road densities using "moving window" techniques rather than using traditional road length divided by area calculations is becoming the standard (IGBC 1994). Commonly, a moving square window was used. To further improve the accuracy of this calculation, I used a circular moving window (referred to here as moving circle) for my road density calculations. The use of a moving circle instead of square unfortunately limits the number of software packages that can perform the calculation, and it increases the computation time. But it provides a more accurate density calculation since the distance to the outer most pixel that counts for each density calculation is the same in a circle. If a moving square is used, the distance to the corner pixel of the square is 1.4 further away then the nearest outer-most pixel. I used a combination of PAMAP (PAMAP 1991) and ERDAS (ERDAS 1991) GIS software to perform the moving circle calculation. ARC/INFO (ESRI 1991) can also perform the calculation, but it uses a different algorithm for converting the vector road file into raster form which exaggerates the length of road by about 25%. Hart (1994) calculated a correction factor to use with ARC/INFO software.

Input data

The input data layer for the moving circle calculation was a vector road file containing all open roads, roads with some use restriction, and trails with motorized use. The road data for Flathead National Forest was acquired directly from Flathead National Forest, current as of 1994, while the data for Lolo National Forest was developed from cartographic feature files (Hart 1994), current as of 1992. The two sources were then combined to form one road file, slightly larger than the study area.

Using PAMAP software, the vector road file was converted to raster format at a 30 x 30 m pixel size. Each road pixel received a value of 1, representing a road length of 30 m. The raster file was converted to ERDAS format, where the SCAN routine was used to perform the actual moving circle calculation. I used a moving circle with a radius of 900 m (30 pixels) to count the number of road pixels within. This size of circle was chosen to yield a circular area as close as possible to 1 mi². Each moving circle contained 2828, 30 x 30 m pixels, yielding a 0.983 mi² circular area (a 31 pixel radius would yield a 1.04 mi² area). Non-metric units were used in these calculations because that has become standard. The output file from the SCAN routine was a raster file where the new pixel value represented the number of 30 m road segments in the surrounding 1 mi² circle. For example, a pixel value of 100 represented a total road length of 100 x 30 m = 3000 m (1.9 mi) leading to a 1.9 / 0.983 = 1.9 mi/mi² road density at that point. This way, each pixel in the area received value for road density specific for that point.
To evaluate potential linkage zones, I needed the road density values classified into 4 road density categories. To determine correct cutoff value (n) representing 1 mi/mi$^2$ road densities, I used the formula: $n = \frac{1609 \times 0.983}{30}$ and for the 2 mi/mi$^2$ cutoff, I used the formula $n = \frac{2 \times 1609 \times 0.983}{30}$. This yields cutoff values of 53 and 105. I then regrouped pixel values to represent road density categories: pixel values 1-53 represented 0.01 - 1.00 mi/mi$^2$, pixel values 54-105 represented 1.01 - 2.00 mi/mi$^2$, and pixel values > 105 represented road densities greater than 2 mi/mi$^2$. 
APPENDIX 3

Prediction of cover condition using LANDSAT satellite imagery
To develop a digital hiding cover map, I used multi-spectral LANDSAT Thematic Mapper data. First, I cut out the study area portion from the original image. Then I performed an unsupervised classification of bands 3 (red), 4 (near infrared), and 5 (mid infrared) using the VISUALIZATION/MAPPING algorithm (Ma 1994). This algorithm identifies spectral groups which visually simulates the enhanced color composite of the displayed Thematic Mapper bands. I used a color composite of band 3 as blue, band 4 as red, and band 5 as green. These 3 bands generally have the least spectral overlap among cover types (Ma and Olson 1989), so they are best for general cover discrimination (Horler and Ahern 1986). The VISUALIZATION/MAPPING algorithm placed pixels with similar color and brightness in the same spectral group (Hart 1994). The unsupervised classification yielded a single band file with 63 different pixel values or spectral groups. Using aerial photos and some knowledge about local conditions, pixel values representing hiding cover were distinguished from pixel values representing open areas. The single band file was then recoded into two classes, one representing areas with vegetation providing hiding cover, and another representing open areas. This way I created a preliminary map of cover conditions. After producing a preliminary cover map, I visited the areas that were difficult to classify. After the field visit, I made final adjustment and produced the final map depicting cover conditions. Further manipulation of this layer was then performed for input for linkage zone assessment and is described in the methods section.
APPENDIX 4

Predicting riparian area extent

A common approach to delineate of riparian areas over large areas has been to buffer all areas around rivers, streams, and lakes at a constant size (Fig 10A). However, by using standard GIS techniques in conjunction with digital data on hydrology and elevation, we can determine the extent of riparian areas more precisely (Fig. 10B). In a mountainous and topographically diverse region such as western Montana, the use of constant buffer-size around hydrological features is often an inaccurate method for determining the extent of riparian area. The topography of the area adjacent to the water course greatly influences the extent of the riparian area. Using a constant buffer-size would over-estimate the extent of riparian areas for water courses passing through narrow draws, and would under-estimate the extent of riparian areas where streams or rivers flow through flat areas.

Data sources

Digital information exists in the public domain at 1:24,000 scale for both elevation (USGS 1987a) and hydrography (USGS 1987b). From the hydrography information, I used perennial and intermittent streams, lakes, swamps, and marshes in the model. Elevation data were processed to produce a Digital Elevation Model (DEM) with a 30 m pixel size. The root-mean-square error for linear interpolated elevations is estimated to 7.5 m as compared to "true" elevations from published maps (USGS 1987b).

The model

I described the riparian extent prediction model by including ARC/INFO commands (ESRI 1991) to mark the procedural steps. The steps were developed with help from Z. Ma (pers. commen.). The general model could be run with many other GIS software packages.

The input file names were "water" for the vector line information depicting perennial and intermittent streams, lakes, swamps, and marshes; "dem" for the elevation file with a 30 m pixel size; and "lakegr" for lakes greater than 30 ha with a 30 m pixel size. In the model intermittent streams were treated the same as perennial streams based on recommendation by E. Ringelberg and P. Hansen (pers. commen.)

LINEGRID water 30 water raster
This command converts the "water" vector file into 30 m pixels, producing the file "water_raster" with pixel values of 1 for pixels representing water, and no data for non-water pixels. The LINEGRID command in ARC/INFO exaggerates the raster representation of vector by about 20 % as compared to other GIS software. It is therefore advisable to perform this step in a different software and then import the resulting raster to ARC/INFO for the rest of the model calculations.
Figure 10. Comparison of estimation of riparian extents for the southern end of the study area.
(a) Output from model using elevational information.
(b) Output from model using constant distance buffers.
water_dem = INT (water_raster * dem)
This command assigns the elevation value for each pixel in the
"water_raster" file and writes this value to the file "water_dem".

buffer_water1 = EXPAND (water_dem,10,table,water_dem.vat)
This command creates a 600 m (10 pixels x 30 m x 2 sides) buffer
around the water course and assigns the elevation value from the
adjacent "water_dem" pixel to each pixel. For example, if the elevation
of the "water_dem" pixel is 1500 m, all 10 adjacent pixels would also
receive that elevation value. Because the EXPAND command expands
the hydrology file only in perpendicular directions and not based on
radius distances, I choose to further refine this file. I created a vector
file based on a 210 m buffered radial distance to all water sources. I
converted this file to raster format and cut the file (buffer_water1)
developed using the EXPAND command to this file using the
SETMASK command. The resulting output file (buffer_water) was a
raster file limiting the maximum width of the riparian area to 7 pixels
(210 m) on either side of the water course. Schoen et al. (1994) used a
160 m constant width buffer around streams for development of a
habitat model for brown bears in Alaska. If the model was executed in
areas with broad valleys with large flood plains, a value larger than 7
should be used.

dem_buffer = dem - buffer_water
This command calculates the difference in elevation compared to the
elevation value from the 600 m wide "buffer_water" file and writes to the
difference to the file "dem_buffer". If the elevation value from the DEM
was 1506 m and the "buffer_water" value was 1500 m, the
"dem_buffer" value would be 6 m.

rip_zone = CON (dem_buffer < 8,dem,0)
This step represents a conditional statement for when the change in
elevation (dem_buffer, calculated above) between the water pixel itself
("water_dem") and the adjacent elevation ("dem") is less than 8 m. If
that was the case, the pixel was within the riparian area. The pixels
falling within the predicted riparian zone had the elevation value from
"dem" assigned to them. When the elevation change is 8 m or greater
for a pixel, that pixel was part of the adjacent non-riparian area, and
had the value 0 assigned. This information is written to the file
"rip_zone." The choice of using an 8 meter change in elevation as the
break between riparian and upland was done after discussion with
experts on riparian areas from the Montana Riparian Association
(Hansen pers. comm. and Ringelberg pers. comm.). No such
estimates existed in the literature. The choice of using 8 meter elevation change as the cut off was also supported by the approximate vertical accuracy (7.5 m) of the input DEM (USGS 1987). Using to a smaller elevational cutoff value would mean going beyond the resolution of the elevational input data. Hence, the model might be less useful in areas with little topographic variation.

\[
\text{rip\_zone\_1} = \text{CON (dem\_buffer < 10, 1, 0)}
\]

This describes the same conditional statement as above, but instead of assigning elevational values to the pixels within the riparian zone, a pixel value of 1 was assigned. Pixels outside riparian areas received the value of 0.

\[
\text{final\_rip} = \text{rip\_zone\_1} - \text{lakegr}
\]

This command excludes lakes that are larger than 30 ha (the file "lakegr") from the rest of the riparian areas. This creates the final delineation of riparian areas which was used in the model to evaluate potential linkage zones. This file could also be used as a cut-off for further classification of cover types within riparian areas using additional digital information on vegetation (Ma and Righter 1995). For example, if the vegetation classes coniferous and deciduous crossed through what we defined in this model as riparian areas, the additional vegetational categories coniferous riparian and deciduous riparian could be added.

To eliminate some of the noise associated with irregularities in the elevation data, a filtering step of the final output could also be added.

**Conclusion**

The importance of healthy riparian zones for many species of animals cannot be overemphasized. Many important conservation decisions concerning such subjects as water quality, spotted owls, and fisheries have been based on riparian areas which were estimated using a constant buffer-size without consideration for the topography of the landscape. This paper outlines alternative methods to delineate the extent of riparian areas over large landscapes by including consideration for topography. Using this model, the outcome (Fig 10B) differs substantially when compared with prediction of riparian areas using constant buffer-size (Fig 10A). This method will in no way replace site-specific field measurements. But with correctly chosen input values, this method can aid in delineating riparian area extent over areas which are too large to field sample.

The method described could be further improved by including additional vegetational information from remote sensing devices (Ma and Righter 1995). The final riparian output inevitably included some areas which did not contain riparian
characteristics due to incorrect elevation data or geological restrictions on vegetation. But, for assessing linkage zone potential, the most important aspect of the riparian layer was to identify the irregular but continuous, linear nature of the riparian network.