A Geographic Analysis of Historical Grizzly Bear Sightings in the North Cascades

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ABSTRACT: Historic grizzly bear sightings in the North Cascades area of Washington were analyzed using the GRASS geographic information system (GIS) software. A 22-class land-cover database that was determined to be 85 percent accurate was compared to 91 historic sightings of grizzly bears. The historic sightings were positively associated with the whitebark pine - subalpine larch and subalpine herb cover types. The sighting locations were found to have similar land-cover richness but land-cover interspersion different from the overall landscape within the study area. These data were used to develop new map layers for relative cover type and diversity selection which were then combined into a map of sighting potential for grizzly bears in the North Cascades.

INTRODUCTION

THE GRIZZLY BEAR (*Ursus arctos*) currently occupies less than half of its historic range in North America. Major population declines have occurred south of the Canadian border (Martinka and Kendall, 1986). Efforts to help grizzly bear populations recover were formally initiated in 1975, when the grizzly bear was classified as a "threatened" species under the Endangered Species Act. As part of the recovery effort, six areas have been designated as "grizzly bear ecosystems": four have specific plans for bear recovery and two, including the North Cascades area in Washington, are considered evaluation areas. The North Cascades Working Group, an interagency team, is evaluating the suitability of the North Cascades Grizzly Bear Evaluation Area (Figure 1) to support a viable grizzly bear population. The area contains over 3,000,000 ha of contiguous National Park and National Forest System lands, and is within the historic range of the grizzly bear, but the status of the current population is unknown. If a population is present, it is reclusive and probably small.

The evaluation effort will consider biological and social constraints and opportunities for grizzly bear management. If a recovery plan is approved, boundaries for the grizzly bear ecosystem will be delineated. The five-year evaluation period is complicated because of the apparent low numbers of grizzly bears in the area, making ecosystem-wide animal use studies difficult. The final decision will incorporate information from specific habitat studies (both radio-telemetry data on grizzlies, if available, and seasonal habitat and food identification) and apply them at a landscape (millions of hectares) level. A geographic information system (GIS) database is being built to assist the habitat analysis capability over this large area.

A digital database currently exists for a smaller area encompassing the North Cascades National Park Service Complex (Figure 1; Agee *et al.*, 1985). The objective of this research was to determine if the land-cover characteristics surrounding historic grizzly bear sightings were distributed differently from those in the existing database, and if so, to provide an analysis of areas where grizzly bears are most likely to be sighted.

To null hypotheses were tested for the grizzly bear sighting and land-cover data:

- Historical grizzly bear sightings by cover type have occurred in the same proportions as the availability of the cover types on the landscape.
- Historical grizzly bear sightings have occurred in areas proportional to the cover type diversity (measured by richness and interspersion) in the landscape within the GIS data base.

The objective of testing these hypotheses was to apply the results over the entire GIS database to determine the geographic locations of highest sighting potential. Analyses were based on the assumptions that grizzly bear sightings are a function of cover type and cover type diversity.

In other areas where grizzly habitat has been studied, a variety of vegetation units (habitat type, community type, habitat component, etc.) have been used to define habitat, on the basis that grizzly bears use the resources within these units preferentially (Craighead *et al.*, 1982; Mace, 1986); however, no system appears to be universally accepted. Characterizing diversity is even less standardized than the individual unit of habitat. It is known in the Yellowstone area that grizzly bears prefer forest-nonforest ecotones (Blanchard, 1983; Weaver *et al.*, 1986) but measurement of such diversity is difficult. Our objective differed from these studies in that we attempted to define sighting potential rather than habitat value. Although verification of model predictions are important (Lyon *et al.*, 1987), such verification is nearly impossible when dealing with animals in a part of their range where they are very rare.

METHODS

The existing North Cascades GIS data base includes 22 land-cover classes over a 850,000 ha area: eighteen vegetation classes and four inert classes (water, rock/bareground, snow/ice, and shadow). The raster database has a pixel size of 50 by 50 metres. The cover type classes were developed from 1978 and 1979 Landsat MSS data used in conjunction with Defense Mapping Agency (DMA) 1:250,000 topographic data (aspect, slope, elevation) and digitized precipitation isohyets. The cover type map was determined to be 85 percent accurate (Agee *et al.*, 1985).

In a separate study over a larger area, Sullivan (1983) mapped historic and recent reports of grizzly bear sightings. Such presence data are often used to verify species presence in certain areas or habitats (Jones, 1986). Sightings were identified by year, location, and reliability. Reliability was defined in one of four classes: Class 1, photograph or carcass; Class 2, multiple identification characteristics present: hump, claws, face, tracks, or scat; Class 3, a single characteristic; Class 4, size or color only, or lack of details (Sullivan, 1983). The percentage of observations in each class were Class 1, 5.2 percent; Class 2, 28.7 percent; Class 3, 43.8 percent; and Class 4, 22.3 percent. Within

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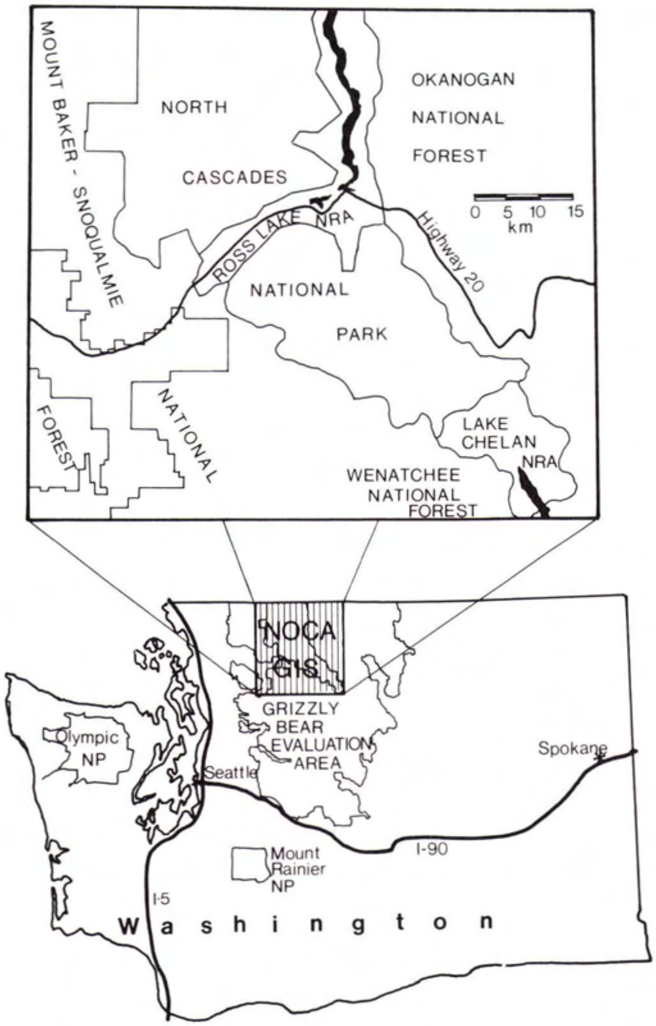

FIG. 1. The North Cascades area is in north-central Washington. The wavy line enclosing the larger area is the approximate boundary for the North Cascades Grizzly Bear Evaluation Area. The smaller box is the area covered by the existing North Cascades GIS, which is shown in more detail.

the area covered by the existing GIS database, the proportion of observations were similarly distributed (Chi-square = 3.51; critical value$_{0.05,3}$ = 7.81). The locations were mapped at 1:250,000, and 91 of the 233 sightings were in the area of the existing North Cascades GIS database.

There are three significant sources of potential error relevant to the association of cover types with the sighting data. First, large dots were used to identify locations; each dot covered an area > 1 square kilometre. Although the center of each dot can be precisely located, the dot in some cases represents only an approximate sighting location. Second, the sightings occurred over more than a century, introducing error associated with potential cover type change with time. About 10 percent of the sightings recorded occurred before 1920, 34 percent between 1920 and 1950, and 56 percent since 1950. None of the forests at the sighting locations appear to have been logged. Successional change in subalpine portions of the area, particularly after fire (Agee and Smith, 1984; Agee *et al.*, 1986) or climate change (Franklin *et al.*, 1971) have proceeded slowly, so that significant cover type change is unlikely. A third source of concern is the type of data which Sullivan collected. Visual observations are more probable in open landscapes where sight distances are longer. Such bias must be recognized when interpreting results.

Analyses were performed using the Geographic Resources Analysis Support System (GRASS) developed by the Army Corps of Engineers, Construction Engineering Research Laboratory. Through GRASS, various site descriptive analyses as well as separate map layers can be created and integrated.

A total of 91 grizzly bear sightings within the area of the USGS North Cascades National Park special map were remapped from Sullivan's (1983) 1:250,000 map to the park 1:100,000 map and the UTM coordinates were digitized. All classes of observations were used, as the mapped locations were not identified to a particular sighting reliability class. Another 91 random UTM coordinates were generated from random number tables within that same map area for comparison. These coordinates were entered into the GIS data base through a dBASE III file.

The first hypothesis was tested using the most commonly occurring cover type in variable sized windows around each historic grizzly bear sighting and random locations. Matrices were considered the most appropriate units to analyze, rather than points, due to the inexact locations of the grizzly sightings. The GRASS "*sites occurrence*" tool was used to compare the cover type distribution of historic sighting locations and randomly chosen locations to the expected number of locations in each cover type based on proportions of each cover type on the landscape.

The Chi-square analyses provided by the computer software have potential bias as some of the expected frequencies were less than five, so further analyses were conducted once an optimum matrix size was determined. A G-statistic based on the log-likelihood ratio (Zar, 1984), which is less sensitive to frequencies less than 5 and proportions less than 0.2, was applied to the same data. Individual cover types with high positive contributions to the G-statistic had critical lower confidence limits computed using the relationship between the F distribution and the binomial distribution (Zar, 1984). This allowed a more objective identification of those cover types where bears were sighted in higher than expected proportions.

The second hypothesis was tested by the GRASS "*neighbors-diversity*," "*interspersion*," and "*sites-occurrence*" tools, which generated two land-cover diversity analyses. Diversity was defined as a combination of cover type richness (number of cover types represented) and interspersion, which can be considered a form of beta diversity (between community or stand). Diversity as characterized by richness was measured as the number of cover types within the 11 by 11 matrices, with the richness being assigned to the center cell for mapping purposes. Richness was calculated for matrices around each historic grizzly bear sighting and for the randomly located points. The mean cover type richness of the two analyses was tested for significant differences by a t-test (Zar 1984). Diversity as characterized by interspersion was calculated by first running a 3 by 3 window through the land-cover file, and assigning the percent difference in cover types between the center and immediate surrounding cells, as a measure of interspersion, to the center cell. Then the distribution of interspersion values within each 11 by 11 matrix around historic grizzly sightings were summarized through "*sites-occurrence*" and compared to the distribution of interspersion for the landcover file as a whole.

Three final layers in the GIS database were generated from the analyses above, using the GRASS "*reclass*" tool. For the first layer (cover type preference), each pixel was assigned a value of 0, 2, or 4 based on the lower, average, or higher than expected proportions of historic grizzly bear sightings for the cover type represented in that pixel.

For the second layer (cover type diversity), a similar 0 to 4 value was produced from the combination of cover type richness (0 to 2) and interspersion (0 to 2). The cover type richness around historic grizzly bear sightings was compared to the random locations to determine if grizzly sighting locations had a significantly different distribution. If the distributions differed, a value of 2 would be assigned to each pixel with most preferred cover type richness, 1 to those pixels with possibly preferred richness, and 0 for richness levels not well represented in the grizzly sighting matrices. The distribution of cover type interspersion was compared to the distribution of interspersion for the entire landcover file using a G-test (Zar, 1984), and the two groups showing the largest differences between observed and expected (based on p levels) were assigned 2 and 1, respectively, with other groups being assigned a 0.

The third layer was developed under the assumption that cover type and diversity are equally important in grizzly bear sighting potential. The values in the first two layers were added together using GRASS tool *"Gmapcalc,"* to form a possible range of values from 0 to 8, representing low to high potential for the sighting of grizzly bears.

RESULTS

Sightings by Cover Type

Cover type analyses around grizzly bear sightings were made for pixel windows 1 by 1, 3 by 3, 5 by 5, 7 by 7, 9 by 9, 11 by 11, 13 by 13, 15 by 15, and 17 by 17. For the 1 by 1 matrix, subalpine herb was the most common cover type in which grizzly bears were sighted, but the whitebark pine/subalpine larch cover type had the largest proportional difference between actual sightings and the number expected if sightings were proportional to cover type distribution on the landscape. As matrix size increased, subalpine herb remained the most common cover type in which obervations were made; the largest differences between expected and actual cover type distribution of sightings were for the whitebark pine/subalpine larch types (both open and closed canopy), subalpine herb, and open canopy subalpine fir (Table 1).

The Chi-square analyses indicate that cover types on which grizzlies have been sighted differ significantly from that expected based on availability on the landscape. All of the matrix sizes had Chi-square values above the critical level (alpha 0.05,21 = 32.7; Figure 2). Matrices around the randomly chosen points do not significantly differ in cover type distribution from the overall map expected distribution. As matrix size increases, the grizzly sighting Chi-square values peak at the 9 by 9 matrix size and 11 by 11 matrix size, while the random point Chi-square values slowly decline as matrix size increases. The 11 by 11 pixel matrix (30.25 ha) was selected as the optimum size for further analysis.

Because the frequency of many of the expected cover types is less than 5, the Chi-square analysis (Table 1, Figure 2) could be statistically biased. For the 11 by 11 matrix, the calculated G-statistic ($G = 39.07$; $G_{0.01,21} = 38.9$) confirmed the results of the Chi-square test. Confidence limits (e.g., Neu *et al.* (1974)) were calculated for the proportion of total landscape in cover types which had high positive contributions to the G-statistic (Zar, 1984). Critical levels of significance were computed using these limits and expected proportions (Table 2), indicating that the whitebark pine/subalpine larch cover type (open and closed canopy) had the highest sighting potential, followed by the subalpine herb cover type. Characteristics of the whitebark pine/subalpine larch cover type and the subalpine herb cover type are summarized in Table 3, adapted from Agee *et al.* (1985). Dominant plant species characteristic of these cover types (huckleberries [*Vaccinium* spp.], whitebark pine, and a wide variety of herbaceous species) are similar to species preferred by grizzly bears in the Rocky Mountains (Serveen, 1983; Eggers, 1986; Almack, 1986).

The first null hypothesis was rejected. The grizzly sightings exist in significantly higher than expected proportions in certain cover types.

Table 1. Distribution of Grizzly Bear Sightings by Cover Type for the 11 by 11 Matrix. Table generated by the grass Site Occurrence Report.

Cover Type*	Percent Cover in GIS**	Expected Sites**	Actual Sites
Douglas-fir (C)	10.1	9.2	7
Subalpine fir (C)	10.2	9.3	10
Whitebark pine/subalpine larch (C)	2.2	2.0	5
Mountain hemlock (C)	3.8	3.5	5
Pacific silver fir (C)	8.4	7.7	4
Western hemlock (C)	10.1	9.2	7
Hardwood forest	1.2	1.1	0
Tall shrub	4.9	4.5	4
Lowland herb	1.6	1.5	1
Subalpine herb	8.5	7.7	12
Heather meadow	0.6	0.5	0
Ponderosa pine (O)	0.2	0.2	0
Douglas-fir (O)	4.5	4.1	3
Subalpine fir (O)	4.5	4.1	7
Whitebark pine/subalpine larch (O)	1.7	1.5	8
Mountain hemlock (O)	2.0	1.8	2
Pacific silver fir (O)	2.5	2.2	2
Western hemlock (O)	5.2	4.7	4
Water	1.1	1.0	0
Snow	3.9	3.5	0
Rock, Inert	12.3	11.2	10
Shadow	0.8	0.7	0
Total	100.0	91.0	91

*(C) and (O) refer to closed canopy and open canopy portions of a forested cover type, defined by Landsat spectral signature. Open canopy denotes significant herbaceous, deciduous, or inert (rock/soil) cover within the type.
**sum of individual values may vary from total due to rounding off.

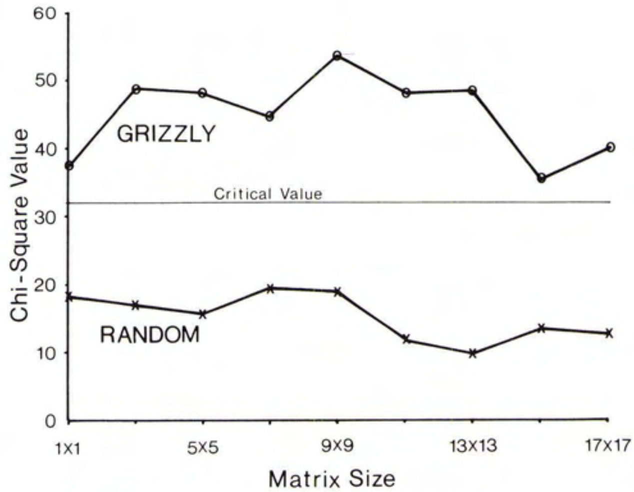

Fig. 2. Differences in cover type distribution for grizzly bear sightings and randomly located points compared to availability of cover types over the North Cascades GIS data base. Separate analyses were done for various sized matrices around each sighting or random point. The straight horizontal line represents the critical Chi-square value for $p = 0.05$, d.f. = 21. The elements of each matrix are 50 by 50 *m* pixels.

TABLE 2. CIRTICAL VALUES FOR THE PROPORTION OF A SAMPLE IN A SINGLE COVER TYPE COMPARED TO ITS AVAILABILITY ON THE LANDSCAPE. COVER TYPES SHOWN ARE THE SIX LARGEST CONTRIBUTORS TO THE G-STATISTIC, AND MOST LIKELY TO HAVE PROPORTIONS OF TOTAL GRIZZLY BEAR SIGHTINGS SIGNIFICANTLY HIGHER THAN EXPECTED.

Cover Type	p-value*
Whitebark pine/subalpine larch open canopy	<0.001
Whitebark pine/subalpine larch closed canopy	<0.10
Subalpine herb	<0.16
Subalpine fir - open canopy	<0.25
Mountain hemlock - closed canopy	<0.50
Subalpine fir- closed canopy	<0.50

*This is the probability of a cover type proportion exceeding the expected proportion based on availability on the landscape if in fact no real differences occur between the two proportions. A probability >0.50, for example, means that there is more than a 50 percent chance that a proportion for that cover type as large as shown in Table 1 will occur from a similar; sized random sample from the North Cascades GIS data base.

TABLE 3. CHARACTERISTICS OF THE THREE COVER TYPES WITH PREFERENTIAL HISTORIC SIGHTINGS OF GRIZZLY BEARS.

Characteristic	Whitebark pine-subalpine larch open canopy	Subalpine herb	Subalpine fir open canopy
Average elevation (m)	1912	1670	1652
Average slope (percent)	52	42	53
Tree Basal Area (sq. m/ha)			
Subalpine fir	9	0	9
Whitebark pine	4	0	1
Subalpine larch	4	0	0
Other	3	0	11
Tree Cover (percent)	30	T	22
Common Shrub Constancy (percent)			
White heather	25	8	52
Mountain juniper	19	–	–
Partridgefoot	–	20	40
Oregon boxwood	33	–	35
Red heather	71	24	55
Mountain-ash	–	20	40
Blue huckleberry	24	24	45
Big huckleberry	–	–	40
Common Herb Constancy (percent)			
Arnica	–	16	25
Sedge	38	64	25
Daisy	38	36	25
Lupine	38	28	30
Bluegrass	52	32	–
Valerian	19	44	25
False hellebore	–	32	25

COVER TYPE DIVERSITY

The richness of cover types for 11 by 11 matrices around grizzly bear sightings showed higher (5.42) but statistically non-significant (at alpha = 0.05) diversity compared to matrices around randomly chosen locations (5.07). Grizzly bears are not usually sighted in the most fragmented landscapes or the most homogeneous (there was a range of from 1 to 12 different cover types in the surrounding 11 by 11 matrix), but were sighted in essentially the same proportions of cover type richness as contained in the entire database. The first part of the second null hypothesis was therefore accepted: grizzly bears are being seen in landscapes of similar diversity as the landscape in the GIS database.

The second part of the diversity hypothesis was tested by comparing the distribution of land-cover interspersion around grizzly sightings to the entire land-cover file (Figure 3). The distributions were significantly different ($G = 19.84$, $G_{0.001,4} = 18.5$). Therefore, the second part of the cover type diversity null hypothesis was rejected. Bears were sighted in areas with different land-cover interspersion than that available for the entire database. Confidence limits for the interspersion levels indicated bears were being sighted preferentially in the 31 to 45 percent interspersion class ($p < 0.005$) and the 46 to 60 percent class ($0.025 < p < 0.05$).

AREAS OF HIGH SIGHTING POTENTIAL

The previously described analysis provided input to develop a map identifying areas of high, medium, and low sighting potential based on the characteristics of the historic grizzly bear sightings. Two new files were created using the GRASS "*reclass*" procedure. The first file was based on the cover type analysis. For the entire GIS data base, those cover types with highest sighting potential (Table 2; $p < 0.2$) – whitebark pine/subalpine larch (open and closed canopy) and subalpine herb – were assigned a 4, those with $0.25 < p < 0.20$ (subalpine fir-open canopy) were assigned a 2, and those with $p > 0.25$ were assigned a 0.

For the cover type diversity file, land-cover richness of the matrices around grizzly bear sightings did not differ from that available for the landscape as whole. Therefore, no new file was created for land-cover richness as all pixels would have been assigned a 0. For land-cover interspersion, which did show significant differences between grizzly sightings and the overall landscape, a 2 was assigned to each pixel with 31 to 45 percent interspersion, a 1 was assigned to each pixel with 46 to 60 percent interspersion, and a 0 was assigned to pixels with higher or lower interspersion.

The two files were then added together using the GRASS tool "*Gmapcalc*," producing a file with sighting potential values ranging from 0 to 6. This procedure weights cover type selection more heavily than land-cover diversity, because of the lack of association between grizzly sightings and land-cover richness.

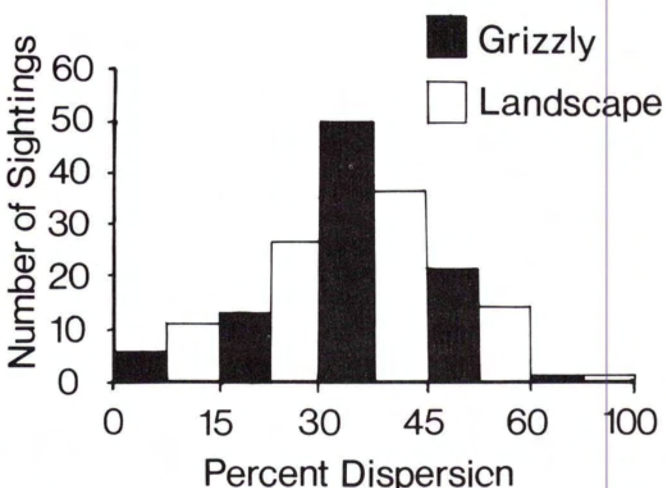

FIG. 3. The distribution of grizzly bear sightings in five interspersion classes, compared to the interspersion distribution for the landscape as a whole. Grizzly bear sightings are skewed to the moderate to high interspersion of 30 to 60 percent, representing relative differences between the land-cover assignment of a pixel and its eight immediately surrounding pixels.

This file was then mapped, and a subset of the entire file is shown in Plate 1 for the western and eastern portion of the study area.

DISCUSSION

The analysis of historical grizzly bear sightings shows generally higher potential for such sightings in the eastern part of the North Cascades GIS (Plate 1). This is where the highest concentration of the whitebark pine/subalpine larch cover type is found. The subalpine herb cover type is also more widespread there, although it is also found in the more maritime western portion of the North Cascades.

The higher potential for sightings in the eastern portion of the study area may reflect areas with both higher potential occurrence and a more open landscape. For example, Agee and Kertis (1987) showed that the North Cascades cover types with an interior climatic influence (ponderosa pine, Douglas-fir, and subalpine fir) have slightly higher proportions of cover in "open canopy" than the corresponding maritime climate forest cover types (western hemlock, Pacific silver fir, and mountain hemlock) and presumably would have longer sight distances. Herbaceous types might also have a higher probability of sightings due to the open nature of the landscape.

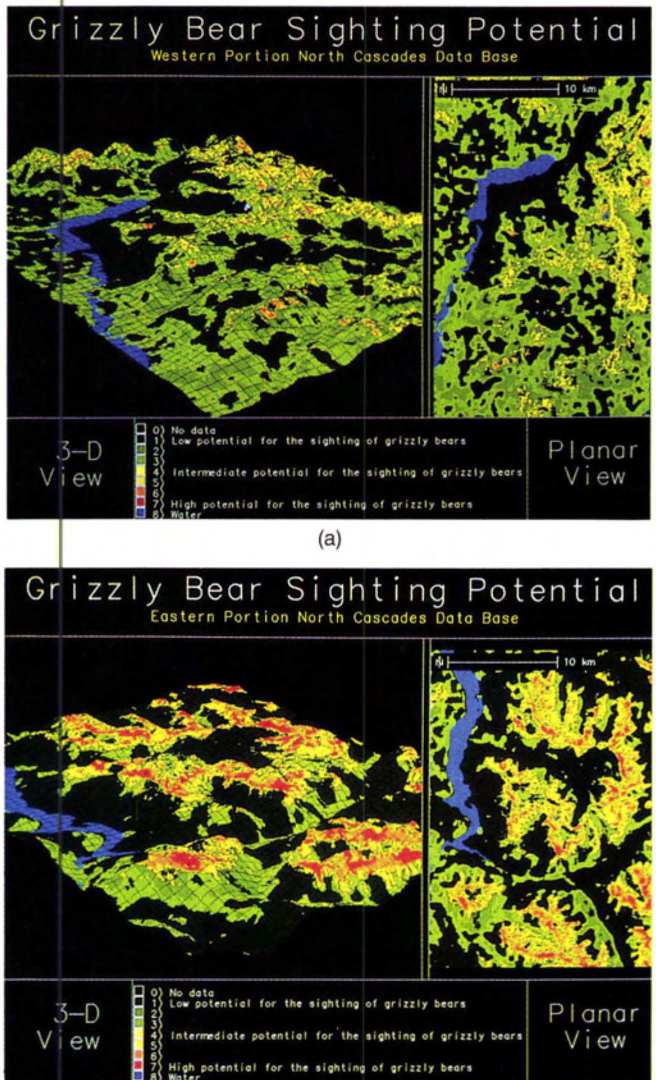

PLATE 1. Grizzly bear sighting potential in the western (a) and eastern (b) portions of the North Cascades GIS. The hues of green-yellow-orange-red represent increasing potential for sighting grizzly bears. The eastern portion of the data base has higher sighting potential than the western portion, based on historical grizzly bear observations.

Access has historically been easier in the eastern portion of the North Cascades, due to continental instead of alpine glaciation (Franklin and Dyrness, 1973), which produced more moderate topography. The eastern Cascades also have better weather for camping, hiking, fishing, and hunting, so more people have been present to make sightings. However, the data from Table 1 do not support such a hypothesis of observability bias. The sum of expected observations based on availability for closed forest cover types is 40.9, and the actual observations totaled 38. The expected sum for all forest cover types (open plus closed canopy) is 60.6, with actual observations totaling 64. Non-forested sites had expected and actual observations of 30.6 and 27. Had observability bias been evident actual observations should have been much higher in the non-forested cover types and much lower in the forested ones, particularly the closed canopy forest cover types.

Despite the identified biases, including the reliability of the observations and their locations, the analysis does have utility in the evaluation of the North Cascades area for defining suitability of the area to support grizzly bears. First, it indicates, at a landscape level, areas having characteristics similar to those where grizzly bears have historically been sighted. This reduces some of the access bias, but it may still omit other areas where grizzly bears have moderate to high potential of occurring.

For example, closed forest types have often been shown to be used by grizzly bears less than expected based on availability (Servheen, 1983), yet a bear may have chosen a home range because of the presence of forest (McLellan, 1986). Timber adjacent to areas of high sighting potential may be an important element of grizzly bear habitat even if its grizzly bear sighting potential is low. Second, the analysis serves as a model for expanded analysis of the 230+ historic and continuing observations of grizzly bears over a larger geographic area than the current 850,000 ha study area. Third, it serves as a comparative data set for potential analyses of radio telemetry data. The telemetry data, if available, will likely be of limited geographic scope, however, and can suffer from similar difficulties in terms of precise location of observations, particularly in the rough terrain of the North Cascades (Springer, 1979).

It is most probable that several additional types of information, including telemetry and food analyses on actual grizzly bears, will be useful in the definition of suitable habitat for grizzly bears, when coupled with GIS analysis techniques. Such techniques will supplement and strengthen the eventual database that will be used to support critical management decisions relative to grizzly bears in the North Cascades area.

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