USE OF LANDSAT MULTISPECTRAL SCANNER IMAGERY AND GEOGRAPHIC INFORMATION SYSTEMS TO MAP VEGETATION IN THE NORTH CASCADES GRIZZLY BEAR ECOSYSTEM

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Abstract: Landsat multispectral scanner (MSS) imagery and a ground-based vegetative inventory were used to develop a map of vegetation for the North Cascades Grizzly Bear Ecosystem (NCGBE). An assessment of the interpreted data showed a 95% accuracy level for the general vegetation types and 92% for detailed vegetation types. Additional data layers were developed in a geographic information system (GIS) to evaluate the availability and distribution of vegetation types on a seasonal basis, assess the impacts of human activities on the habitat, assess ungulate food sources, and estimate the abundance of bear foods in various vegetation types. These technologies proved useful in evaluating the suitability of the ecosystem to support grizzly bears (*Ursus arctos horribilis*).

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The Grizzly Bear Recovery Plan (U.S. Fish and Wildlife Service 1982) identified the NCGBE as 1 of 6 possible recovery areas south of Canada. Implementation of the recovery plan led to the establishment of the Interagency Grizzly Bear Committee (IGBC) in 1983. The IGBC coordinates federal, state, and private research and management programs that are designed to promote grizzly bear recovery.

The IGBC in 1985 provided the impetus for grizzly bear investigations in the North Cascades by directing a 5-year evaluation to determine the suitability of the NCGBE to support a viable grizzly bear population. Landsat MSS imagery and a GIS were valuable tools used in completing the evaluation. These technologies were selected to accomplish the following objectives: (1) produce a map of vegetation and cover types for the NCGBE; (2) assess the accuracy of the mapping process; (3) provide a baseline list of probable grizzly bear foods identified in the NCGBE; and (4) collect information concerning the location of human population centers, recreation sites, livestock grazing allotments, and roads. In this paper we will discuss the methods used to meet these objectives, provide examples of the results that can be expected such as mapping products and accuracy levels, and discuss the advantages and disadvantages of using these technologies.

STUDY AREA

Our study area included all of the NCGBE, which encompasses 2,620,755 ha (Table 1), including all of the North Cascades National Park Complex (NCNP), and most of the Mount Baker-Snoqualmie (MBSNF), Wenatchee (WNF), and Okanogan (ONF) national forests (Fig. 1). The area was bounded on the north by the United States-British Columbia border, on the west by the western edge of the MBSNF, on the south by Interstate Highway 90, and on the east by the ONF and state lands west of the Okanogan and Columbia rivers. The NCGBE is composed of 82% federal lands, 8% state lands, and 10% private lands.

Elevations vary from about 150 m near the Puget Sound Trough on the west slope of the North Cascades to 3,285 m on Mount Baker. Most ridge systems on the west slope are near 1,525 m. The Cascade crest varies from about 2,100 to 3,213 m on Glacier Peak.

Table 1. Area and percent of the North Cascades Grizzly Bear Ecosystem within each administrative unit or ownership.

Administrative class	Area (ha)	Portion of ecosystem (%)
Private land (TOTAL)	263,394	10
State land (TOTAL)	217,206	8
Bureau Land Management	2,201	<1
Okanogan National Forest	599,617	23
Wenatchee National Forest	642,048	24
Mount Baker-Snoqualmie National Forest	620,847	24
North Cascades National Park and Recreation Area	275,443	11
Federal land (TOTAL)	2,121,732	82

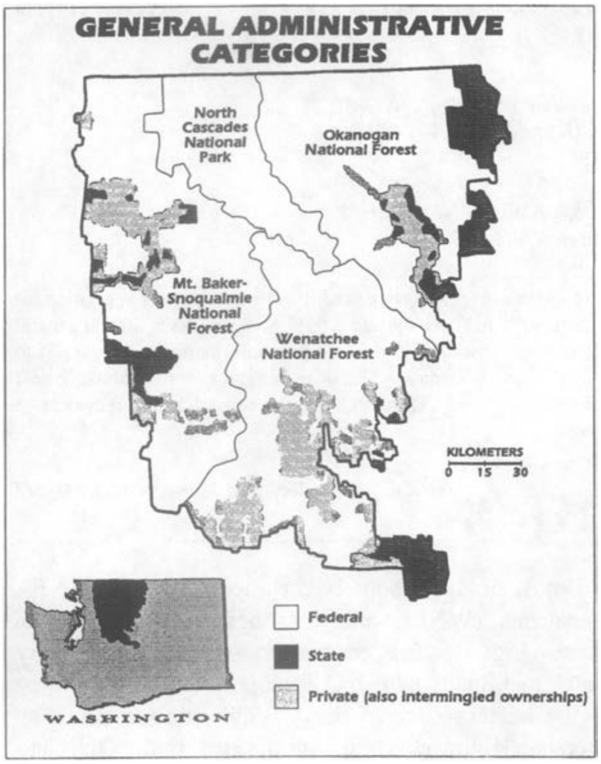

Fig. 1. The North Cascades Grizzly Bear Ecosystem and study area.

East slope elevations generally vary from 762 to 2,712 m.

The weather on the west side of the NCGBE includes mild temperatures, lengthy periods of cloud cover, and abundant annual precipitation (170-300 cm), falling mostly as rain. The Cascade crest blocks much of the westerly maritime flow, shrouding the east slope in a comparably dry rain shadow. Continental airmasses on the east slope interact moderately with Pacific flows, producing more severe temperature extremes and much less annual precipitation (25-50 cm), falling mostly as snow.

The volcanic, uplifting, and glacial histories of the Cascades influence local vegetation patterns (McKee 1972, Staatz et al. 1972, Rowe 1974, Harris and Tuttle 1977). Franklin and Dyrness (1973) identified 12 major vegetation zones in the North Cascades. On the west side these include the western hemlock (*Tsuga heterophylla*), Pacific silver fir (*Abies amabilis*), and mountain hemlock (*T. mertensiana*) zones. Subalpine and alpine zones occur throughout the mountainous areas. On the east side, major vegetation zones include ponderosa pine (*Pinus ponderosa*), grand fir (*A. grandis*), Douglas-fir (*Pseudotsuga menziesii*), western hemlock, lodgepole pine (*P. contorta*), subalpine fir (*A. lasiocarpa*), and shrub steppe areas.

Access into the North Cascades is provided by 5 major highways, numerous secondary roads, and a minor trail system. British Columbia Highway 3 penetrates the North Cascades through Manning Provincial Park and allows access by secondary road to the Hozomeen area of NCNP. The North Cascades Highway, State Highway 20, crosses the ecosystem from Sedro Woolley on the west slope to Winthrop on the east slope. State Highway 2 crosses the Cascades from Everett on the west to Wenatchee on the east. Interstate Highway 90 is the southern limit if the NCGBE, crossing from Seattle to Ellensburg. State Highway 97 runs north-south, providing access points by secondary roads along the east slope. Although many secondary and light-duty roads access the periphery of the ecosystem, few of these penetrate the core area.

METHODS

Vegetation and Cover Type Mapping

A map of vegetation types was developed from Landsat MSS satellite data to display vegetation distribution. A detailed and extensive field plot database was constructed to (1) support the Landsat vegetation mapping process, and (2) to identify and quantify the occurrence of plant species within each vegetation type.

Several methods have been described to map vegetation and evaluate grizzly bear habitat (Christensen and Madel 1982, Butterfield and Key 1986, Leach 1986, Mattson and Knight 1989). The most common, but very time-consuming, method involves interpretation of aerial photographs combined with various intensities of ground truthing to identify vegetation types used by grizzly bears. Recent studies have demonstrated the use of Landsat MSS data to map grizzly bear habitat (Craighead et al. 1982, Craighead et al. 1985, Butterfield and Key 1986, Butterfield et al. 1989). Because Landsat technology provides an efficient inventory of vegetation over a large area, we selected this method to map vegetation in the NCGBE.

Landsat MSS data from July and August of 1986 were used with 4 Landsat scenes purchased to cover the entire study area. Landsat MSS data uses 4 separate spectral bands: green, red, and 2 bands of reflected infrared. The data were in the form of a digital image that imposed a grid over the entire study area. This grid was divided into subunits referred to as pixels. The digital value of each pixel is related to the intensity of light reflected from vegetation or other surface cover for that spectral band. Using specialized computer software, the raw spectral bands are processed into a single map image where unique spectral classes are identified.

Repetitive clustering of data from many parts of the study area identified the widest possible range of spectral signatures. Each spectral signature was represented as a spectral class by its statistical description in a computer file. The spectral classes were evaluated statistically for overlap and tested in small areas on the ground. A final set of spectral classes was used to classify the entire Landsat data set and produce a map layer of spectral classes where each pixel was assigned to the spectral class of highest statistical probability. The spectral class layer was georeferenced to the Universal Transverse Mercator (UTM) map projection, zone 10, with a pixel size of 57×57 m. The Landsat spectral class data were transferred in digital form to a GIS.

We conducted a comprehensive field sampling effort to identify the vegetation types correlated with each spectral class. A wide geographic distribution of field plots was needed to identify the variation in vegetation conditions and types that any spectral class could represent over the entire study area. Data were collected from field plots during 1986, 1988, 1989, and 1990 field seasons. Plots were located by overlaying 1:24,000 scale orthophotos with spectral class displays and selecting large, contiguous areas of identical spectral classes. We selected polygons with a minimum size of 9×9 pixels where possible because it could be accurately located on the ground and easily identified on the orthophotos. Although forested vegetation types dominate the ecosystem, nonforested areas were sampled in greater proportion than their occurrence. This sampling strategy was used because plot data available from other studies (Williams and Lillybridge 1983, Henderson and Peter 1985, Agee and Kertis 1986, Williams and Smith 1990) provided information on forested areas, but little data existed for nonforested plant communities. Some plots were located in smaller polygons if they could be easily identified on the ground.

Vegetation data from field plots, slope, elevation, aspect, geographic location, and spectral class number were recorded on a standard form. The percent cover was recorded for all understory plants, shrubs, and trees within the plot. Trees were sampled in 0-1, 1-3, and >3 m height classes, and by stem percentages in several diameter classes. Densiometer readings of the canopy were taken in all 4 cardinal directions at 5 randomly chosen sites within the plot. Also noted were the frequency and magnitude of any disturbances, the presence of surface water, patchiness, and the size of the forested stand. A representative photograph of the area was taken.

We identified plants in the field using the nomenclature of Hitchcock and Cronquist (1987) and Hitchcock et al. (1955, 1969). Alphanumeric code names for plants followed Garrison and Skovlin (1976).

We established 1,726 plots during this study and the data were entered into a database. These data were supplemented with plot data collected on the 3 national forests within the ecosystem. These additional plots included 2,158 from the MBSNF (Henderson and Peter 1985), 445 plots from the ONF (Williams and Lillybridge 1983), and 679 plots from the WNF (Williams and Smith 1990). Data from 469 plots located in the NCNP (Agee and Kertis 1986) were also used. Plot data from all sources were integrated into a single computer database which was then used for vegetation mapping and to determine the composition of plant species within each vegetation type. This database contained all of the field plot information and the Landsat spectral class number for each field plot.

The analysis of the Landsat spectral classes alone could not produce the level of vegetation map detail required for our study. Therefore, additional GIS map layers were needed to refine the Landsat spectral class map into a vegetation type map. We developed additional layers that included elevation, slope, aspect (U.S. Geological Service [USGS] digital terrain data), precipitation, sun incident angle, riparian zones, and land ownership. The riparian zone GIS layer was created by digitizing a map of major riparian areas interpreted from high-altitude aerial photographs. A vegetation map of the MBSNF obtained from The Wilderness Society (Morrison et al. 1990) was also integrated into our GIS for further refinement. All GIS layers were geographically coregistered with the map projection and coordinates of the spectral class layer. In addition, the field plot locations were digitized so that any GIS layer attribute could be extracted and added to the field plot database. In this way, data on precipitation, geographic location, and map coordinates were added to the field plot database.

We grouped the plots into clusters of similar vegetation to determine the vegetation types that corresponded to specific Landsat spectral classes (Wheeler 1987). Data from the field plots were used to identify variables (slope, elevation, aspect, distance from water, etc.) that distinguished each vegetation type. This information was then used to develop predictive modeling rules. A 2-step GIS modeling process was used to produce the vegetation map. A general ecological zone GIS layer was developed as the first step. Ecological zone boundaries were determined from an analysis of the vegetation types and their association to elevation, aspect, slope, precipitation, land ownership, and general geographic location. In the second step, we developed a more refined vegetation model for each ecological zone using spectral class data, elevation, aspect, and proximity to riparian areas. These ecological models were implemented in the GIS to produce 2 vegetation maps.

The first map, Level 1, differentiated vegetation types mainly on the basis of structure (i.e., herbs/forbs, shrubs, forest). The second map, Level 2, provided detail on the basis of major plant communities. The term vegetation type was used to describe the portions of the Level 1 and Level 2 maps that represent existing vegetative conditions, and the term cover type refers to areas mapped such as rock, snow, ice, etc., that generally lack vegetation.

Spring Snowline Analysis

We conducted a snowline analysis to determine the portion of the ecosystem free of snow and available to grizzly bears during the early spring. The snowline analysis was completed by purchasing a hard copy black and white print of a Landsat scene taken during an average snowfall year and selecting data points along the snowline from the photo. We used data from U.S. Weather Service records to choose a year that represented an average amount of snowfall. Our selection of Landsat photos was limited because of the difficulty in obtaining an image that was cloud free. We selected a scene taken on the first of April in 1975. A total of 80 data points were selected from the east side of the ecosystem and 50 points from the west side of the ecosystem. At each point the slope, elevation, aspect, and precipitation zone were determined. This information was used to develop a predictive model to determine the location of the snowline across the ecosystem.

Accuracy Assessment

We assessed the accuracy of the vegetation and cover type maps by conducting a polygon analysis (Dicks and Lo 1990). Twenty-one USGS 7.5 min quads were randomly selected for the accuracy assessment. On each quad, 50 to 100 polygons (each 1.6 ha in size) were randomly selected for a total of 1,099. These polygons were assigned an identification number and classified into one of the vegetation types by aerial photo-interpretation, or by making ground or helicopter observations. The classification made during the accuracy assessment was then compared to the mapped classification for both Level 1 and 2 maps. Matrices showing the relationship between correct and incorrect classifications were constructed and percent accuracy of the Landsat MSS classification determined (Lillesand and Kiefer 1979).

Identification of Probable Grizzly Bear Foods

We developed a list of probable grizzly bear foods in the NCGBE by extracting information from sighting reports, analysis of bear scats, and by making a thorough review of food habitat studies conducted on grizzly bears south of Alaska. Through this effort we identified 124 plant species known to be grizzly bear foods.

We determined the plant species present in each Level 2 vegetation type by developing 2 computer programs. The first program sorted all field plots into categories corresponding to the Level 2 vegetation types. The second program summarized the mean percent cover and constancy of plant species within each vegetation type. Probable grizzly bear foods were identified through a comparison with our 124 known plant species of grizzly bear foods. This analysis provided an assessment of the diversity and abundance of vegetal foods within each Level 2 vegetation type and across the ecosystem.

The abundance and diversity of grizzly bear foods is commonly assessed on a temporal scale (Mace 1984). This study was not designed to assess the availability of vegetative food sources over time. This would require more detailed sampling and a study of the phenology of specific plant species.

We also gathered data on other food sources that are available to grizzly bears in the NCGBE. We mapped winter ranges for bighorn sheep (*Ovis canadensis*), mountain goats (*Oreamos americanus*), deer (*Odocoileus hemionus*), and elk (*Cervus elaphus*), and summarized population data for each species. Winter ranges were mapped based upon survey data (Edwards 1936, Edwards 1937, Edwards 1938, Zeigler 1978, U.S. Department of Agriculture 1989, Musser and Bracken 1990, U.S. Department of Agriculture 1990). We also mapped the location of anadromous fish-bearing streams and summarized population data for the fisheries within these streams.

Human Activities

We identified human activities present within and adjacent to the NCGBE and included them in our GIS.

The GIS layer developed for human activity sites included campgrounds (except backcountry camps in the NCNP), population centers, ski areas, and airstrips. Additional layers were developed for roads, trails, and grazing allotments on national forest lands.

We conducted a road density analysis on a pixel by pixel basis by using a system of grids 15 × 15 pixels in size. The level of road density in the grid around each pixel was determined from the roads information in our GIS. We then assigned each pixel to one of the following road density zones based upon the density of roads in the grid: Zone 1 = 0 km/km^2, Zone 2 ≥0 to 1 km/km^2, Zone 3 ≥ 1 to 3 km/km^2, and Zone 4 >3 km/km^2. The hectares and percentage of the NCGBE area within each of the road density zones were then calculated as an index to assess the effects of roads.

RESULTS AND DISCUSSION

Vegetation and Cover Type Mapping

Our analysis of the field plot database and the GIS data layers produced 50 vegetation and cover types for the Level 2 map of the NCGBE (Tables 2 and 3). Sixteen of the Level 2 vegetation types were subdivided into east and west variants along the Cascade Crest, allowing a more detailed analysis of the plant species present. Figures 2 and 3 illustrate the relative abundance of the major Level 2 types.

Vegetation types dominated by coniferous trees covered 62.41% (1,630,467 ha) of the study area. Five conifer vegetation types occurred on 46.86% of the study area. The vegetation type dominated by subalpine fir, Engelmann spruce (*Picea engelmannii*), and lodgepole pine located on the east side of the ecosystem, was the most abundant type (14.28%). Pacific silver fir forests on the west occurred on 9.27% of the study area. Mountain hemlock forests located on the west covered 9.25% of the study area. An east-side vegetation type, dominated by Douglas-fir and mixed with other conifer tree species, comprised 8.00% of the area. The vegetation type dominated by ponderosa pine and Douglas-fir covered 6.06% of the study area. The remaining conifer vegetation types covered 15.55% of the study area and no single type covered more than 5%.

Vegetation types composed of deciduous forests covered 3.07% (80,312 ha) of the ecosystem. These areas included both riparian and nonriparian habitats.

Nonforested vegetation types covered 37.59% (982,531 ha) of the study area. These vegetation types included areas dominated by shrubs, herbs, and mosaics of shrubs and herbs. The most abundant shrub vegetation type was the montane shrub type, located west of the Cascade crest; it composed 2.51% of the study area. Vegetation types dominated by subalpine heather (*Phyllodoce* and *Cassiope* spp.) and huckleberry (*Vaccinium deliciosum*) composed 2.20% of the study area. Subalpine meadows on the east side of the Cascade Crest and dominated by huckleberry (*V. scoparium* and *V. caespitosum*) composed 1.51% of the ecosystem.

The most abundant herb vegetation types occurred in shrub-steppe areas that were dominated by herbs; these types covered 2.89% of the ecosystem. West-side subalpine lush meadows composed 2.43% of the ecosystem, and the east-side montane-herbaceous vegetation type covered 2.27% of the study area.

Spring Snowline Analysis

Snowline analyses showed those areas snowfree during the early spring (Fig. 4) were also where the highest degree of human use occurred. Additionally, only 9% of the snowfree area lies within wilderness, national park, or other protected areas. The distribution of the snowfree areas were mainly located along the western and eastern boundaries of the ecosystem where elevations are lower.

The snowline analysis should not be interpreted as an analysis of spring range for grizzly bears. R. Knight (Interagency Grizzly Bear Study Team, pers. commun., 1991) commented that grizzly bears will use microsites that are snow free at elevations above the snowline. Our analysis does not take these areas into account, thus under-representing the amount of habitat available. Also, further study of radio-collared grizzly bears is needed to determine spring habitat. Until such studies are completed, the results of our snowline analysis provide the best information on the location, amount, and distribution of the snowfree areas available for grizzly bears during the early spring.

Accuracy Assessment

The accuracy of the mapping process was assessed for the general vegetation type map, referred to as the Level 1 map, and for the more detailed final, or Level 2 map. Of the 1,099 polygons used in the accuracy assessment, 703 (64%) were field verified and 396 (36%) were verified by interpretation of aerial photographs. The overall accuracy of the Level 1 map was 94.8% (Table 4).

The overall accuracy of the Level 2 map was 93.2% (Table 4). Because the location of the sample polygons

Table 2. Hectares and percent of Level 2 vegetation and other cover types on private, state, and federal lands within the North Cascades Grizzly Bear Ecosystem.

	Private		State		Federal	
Vegetation/cover type	ha	%	ha	%	ha	%
Water	2,523	0.96	301	0.14	26,410	1.23
PIPO	15,026	5.71	6,680	3.19	34,746	1.62
PIPO-PSME	21,007	7.98	20,589	9.84	116,835	5.46
PSME-mixed conifer-east	19,400	7.37	21,216	10.14	168,440	7.87
PSME-mixed conifer-west	2,503	0.95	1,961	0.94	1,641	0.08
ABLA2-PIEN-PICO-east	16,097	6.12	34,024	16.27	322,913	15.08
ABLA2-PIEN-PICO-west	9	0.00	0	0.00	2,046	0.10
PIEN riparian	447	0.17	635	0.30	11,879	0.55
Young PSME-managed (MBS only)	279	0.11	98	0.05	28,264	1.32
TSHE-east	1,216	0.46	0	0.00	7,71	0.36
TSHE-west	33,835	12.86	22,852	10.92	73,07	13.41
ABAM-east	7,213	2.74	0	0.00	75,574	3.53
2ABAM-west	14,832	5.64	12,205	5.83	215,294	10.06
TSME-east	921	0.35	0	0.00	45,773	2.14
TSME-west	2,842	1.08	3,514	1.68	235,307	10.99
PIAL	129	0.05	396	0.19	11,147	0.52
LALY	210	0.08	370	0.18	19,317	0.90
Shrub steppe -herbaceous	24,770	9.41	20,911	10.00	29,949	1.40
Shrub steppe-PUTR	9,246	3.51	8,057	3.85	8,422	0.39
Shrub steppe-ARTR	3,527	1.34	2,763	1.32	2,350	0.11
Southeast shrub steppe	1,99	4.76	13,370	6.39	1,872	0.09
Alpine meadow-east	219	0.06	122	0.05	11,369	0.53
Alpine meadow-west	19	0.01	0	0.00	9,913	0.46
Subalpine lush meadow-east	624	0.24	93	0.04	25,816	1.21
Subalpine lush meadow-west	2,013	0.76	601	0.29	60,890	2.84
Subalpine meadow (mesic/dry)-east	990	0.38	1,300	0.62	35,695	1.67
Subalpine meadow (mesic/dry)-west	551	0.21	138	0.07	17,919	0.84
Subalpine heather-VADE meadow	1,459	0.55	1,150	0.555	4,948	2.57
Subalpine-alpine VASC-VACA meadow	134	0.05	903	0.43	38,398	1.79
Subalpine mosaic-east	557	0.21	833	0.40	6,251	0.29
Subalpine mosaic-west	74	0.03	79	0.04	3,150	0.15
Montane mosaic-east	825	0.31	3,779	1.81	12,441	0.58

	Private		State		Federal	
Vegetation/cover type	ha	%	ha	%	ha	%
Montane mosaic-west	53	0.02	8	0.00	3,282	0.15
Montane herbaceous-east	6,043	2.30	5,985	2.86	47,239	2.21
Montane herbaceous-west	7,073	2.69	3,155	1.51	27,197	1.27
Montane shrub-east	5,635	2.14	235	0.11	31,027	1.45
Montane shrub-west	12,275	4.66	4,188	2.00	49,223	2.30
Lush shrub (ALSI, etc)-east	771	0.29	21	0.0	15,553	0.26
Lush shrub (ALSI, etc)-west	748	0.28	336	0.16	7,785	0.36
Lush low elevation herbaceous-east	397	0.15	125	0.06	291	0.01
Lush low elevation herbaceous-west	3,166	1.20	694	0.33	250	0.01
Lush low elevation shrub-east	130	0.05	58	0.03	5	0.00
Riparian deciduous forest-east	1,467	0.56	192	0.09	2,880	0.13
Riparian deciduous forest-west	4,176	1.59	661	0.32	2,105	0.10
Nonriparian deciduous forest-east	4,960	1.88	795	0.38	26,146	1.22
Nonriparian deciduous forest-west	15,516	5.90	7,954	3.80	13,459	0.63
Barren, snow, unclassified	7,656	2.91	5,272	2.52	205,553	9.60
Agriculture-fallow and dry pasture	1,999	0.76	434	0.21	28	0.00
Agriculture-orchard and crops	5,465	2.08	115	0.06	0	0.00

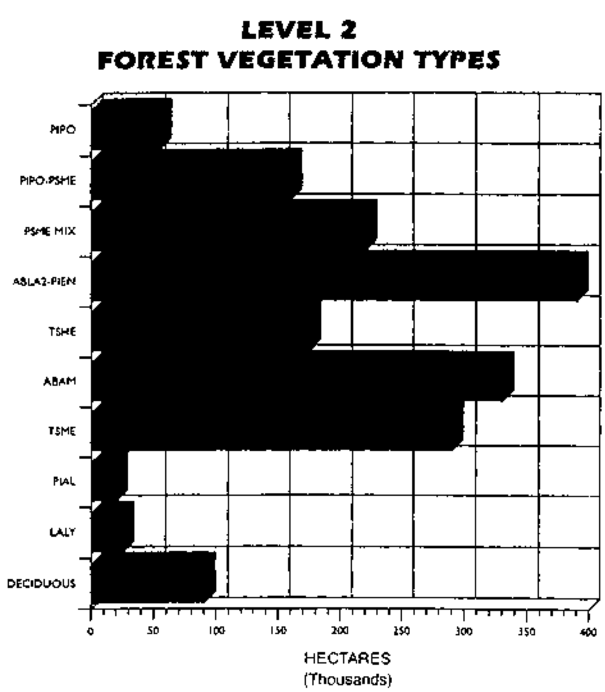

Fig. 2. The relative abundance of Level 2 forested vegetation types within the North Cascades Grizzly Bear Ecosystem.

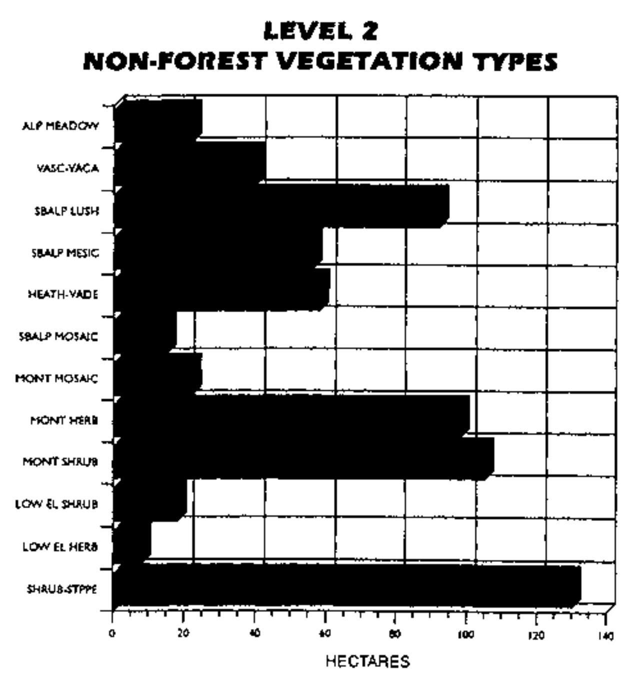

Fig. 3. The relative abundance of Level 2 nonforested vegetation types within the North Cascades Grizzly Bear Ecosystem.

Table 3. Hectares and percent of Level 2 vegetation and other cover types in wilderness areas, national parks, and national recreation areas in the North Cascades Grizzly Bear Ecosystem.

Vegetation/cover type	Hectare	%	Cum. %
Water	10,891	1.05	1.30
PIPO	4,597	0.44	1.74
PIPO-PSME	6,252	0.60	2.35
PSME-mixed conifer-east	24,577	2.36	4.71
PSME-mixed conifer-west	1,618	0.16	4.87
ABLA2-PIEN-PICO-east	136,404	13.12	17.99
ABLA2-PIEN-PICO-west	984	0.09	18.08
PIEN riparian	5,917	0.57	18.65
Young PSME-managed (MBS only)	529	0.05	18.71
TSHE-east	2,972	0.29	18.99
TSHE-west	26,482	2.55	21.54
ABAM-east	50,426	4.85	26.39
ABAM-west	103,837	9.99	36.38
TSME-east	38,999	3.75	40.13
TSME-west	159,925	15.39	55.52
PIAL	7,857	0.76	56.28
LALY	14,451	1.39	57.67
Shrub steppe-herbaceous	4,336	0.42	58.08
Shrub steppe-PUTR	587	0.06	58.14
Shrub steppe-ARTR	116	0.01	58.15
Southeast shrubby shrub steppe	10	0.00	58.15
Alpine meadow-east	8,949	0.86	59.01
Alpine meadow-west	7,335	0.71	59.72
Subalpine lush meadow-east	23,292	2.24	61.96
Subalpine lush meadow-west	44,513	4.28	66.24
Subalpine meadow(mesic/dry)-east	24,687	2.38	68.62
Subalpine meadow(mesic/dry)-west	14,755	1.42	70.04
Subalpine heather-VADE meadow	42,479	4.09	74.12
Subalpine mosaic-east	2,955	0.28	74.41
Subalpine mosaic-west	2,269	0.22	74.63
Montane mosaic-east	1,775	0.17	74.80
Montane mosaic-west	102	0.01	74.81
Montane herbaceous-east	7,278	0.70	75.51
Montane herbaceous-west	7,269	0.70	76.21
Montane shrub-east	16,343	1.57	77.78
Montane shrub-west	14,375	1.38	79.16
Lush shrub (ALSI,etc)-east	3,989	0.38	79.55
Lush shrub (ALSI,etc)-west	5,103	0.49	80.04
Lush low elevation herbaceous-east	16	0.00	80.04
Low elevation herbaceous-west	178	0.02	80.06
Lush low elevation shrub-east	2	0.00	80.06
Riparian deciduous forest-east	1,127	0.11	80.17
Riparian deciduous forest-west	766	0.07	80.24
Nonriparian deciduous forest-east	8,638	0.83	81.07
Nonriparian deciduous forest-west	2,814	0.27	81.34
Barren, snow, unclassified	169,433	16.30	97.64
Subalpine-alpine VASC-VACA	24,473	2.35	100.00

for the accuracy assessment were randomly selected and the sample polygon was 1.6 ha, some of the vegetation types for Level 2 that covered only a small portion of the study area were not adequately sampled. Time or resources were not available to do additional sampling of the Level 2 map. However, the calculation of the overall accuracy of Level 2 is based on an adequate overall sample size and is comparable, or higher than, accuracy levels reported in other studies using satellite imagery (Miller and Conroy 1990).

Identification of Probable Grizzly Bear Foods

We identified 124 plant species as grizzly bear foods from other studies. It is important to note that additional plants that are located within, and in some cases are unique to the NCGBE, may also provide foods for grizzly bears. However, since we have no food-habits data specific to this ecosystem and these plants were not identified in other studies, these potential foods were not accounted for in our analysis.

All of the vegetation types contained some plant species on our list of probable grizzly bear foods. One hundred of the 124 plant species that are known to be grizzly bear foods from other studies were identified in our ecology plots. The mean number of known grizzly bear foods that occurred within a vegetation type was 37 species (range = 3 to 90) (Table 5) indicating that

Table 4. Results of the accuracy assessment for the Level 1 and Level 2 vegetation and other cover types mapped within the North Cascade Grizzly Bear Ecosystem.

Vegetation/cover type	Number of plots	Accuracy level (% mapped correctly)
LEVEL 1		
Water	80	100.0
Conifer 70%+	575	95.0
Conifer 50-70%	211	93.8
Conifer 30-50%	84	90.5
Herbaceous	186	91.9
Shrub	66	98.5
Clearcut	63	100.0
Deciduous forest	37	91.9
Shrub-steppe	98	93.9
Barren	64	92.2
Agricultural	15	100.0
Snow	53	100.0
Overall Accuracy of Level 1	1532	94.8
LEVEL 2		
PIPO	18	81.8
PIPO-PSME	79	89.9
PSME-mixed conifer	63	90.6
ABLA2-PIEN-PICO	172	95.9
Young PSME-managed	19	100.0
TSHE	35	88.6
ABAM	147	98.6
TSME	57	91.2
PIAL	3	33.3
LALY	6	100.0
Shrub steppe-herbaceous	64	94.4
Shrub steppe-shrub	34	91.2
Alpine meadow	4	100.0
Subalpine lush meadow	6	83.3
Subalpine meadow (mesic/dry)	11	100.0
Subalpine heather-VADE meadow	29	86.2
Subalpine mosaic	2	0.0
Montane mosaic	20	90.0
Montane herbaceous	50	96.0
Montane shrub	45	91.1
Lush shrub (ALSI,etc)	6	100.0
Lush low elevation herb-shrub	5	100.0
Overall Accuracy of Level 2	871	93.2

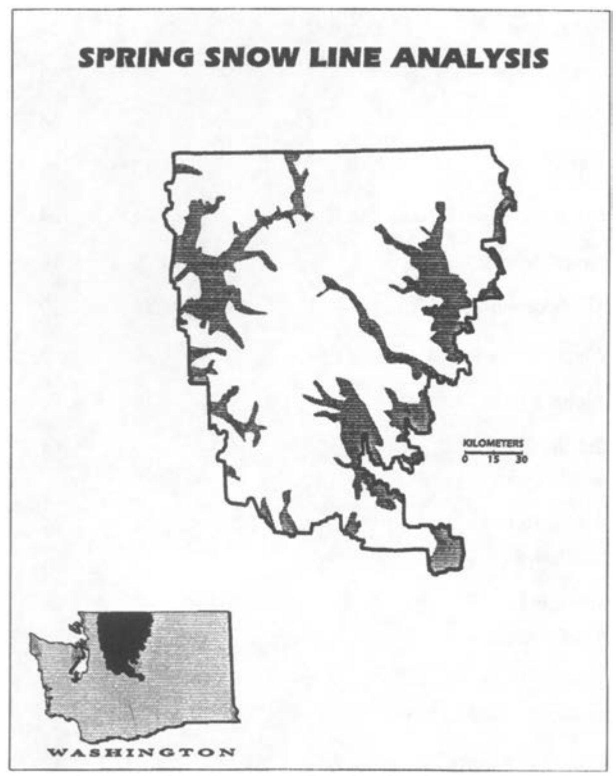

Fig. 4. Map showing the distribution of the snowfree areas within the North Cascades Grizzly Bear Ecosystem during the early spring (based on data from 1 April 1975).

Table 5. The number of plant species that are probable grizzly bear foods within each Level 2 vegetation type in the North Cascades Grizzly Bear Ecosystem.

	Number of species of probable grizzly bear foods			
Vegetation/cover type	Trees	Shrubs	Herbs	Total
PIPO	0	6	16	22
PIPO-PSME	1	16	15	32
PSME-mixed conifer-east	1	32	33	67
PSME-mixed conifer-west	2	19	14	35
ABLA2-PIEN-PICO-east	2	32	56	90
ABLA2-PIEN-PICO-west	2	19	43	64
PIEN riparian	1	21	33	55
TSHE-east	1	6	8	15
TSHE-west	2	29	24	55
ABAM-east	2	21	26	49
ABAM-west	1	25	40	66
TSME-east	2	18	33	53
TSME-west	2	18	43	63
PIAL	2	4	8	14
LALY	1	3	12	16
Shrub steppe-herbaceous		9	25	34
Shrub steppe-PUTR		5	9	14
Shrub steppe-ARTR	1	3	15	19
Alpine meadow-east	1	8	19	28
Alpine meadow-west		5	16	21
Subalpine lush meadow-east	1	17	46	64
Subalpine lush meadow-west	1	20	44	65
Subalpine meadow(mesic/dry)-east	2	17	47	66
Subalpine meadow(mesic/dry)-west	2	7	27	36
Subalpine heather-VADE meadow	2	12	31	45
Subalpine mosaic-east	1	10	13	24
Subalpine mosaic-west		2	9	11
Montane mosaic-east		3	2	5
Montane mosaic-west	1	2		3
Montane herbaceous-east		9	23	32
Montane herbaceous-west		2	6	8
Montane shrub-east	2	36	48	86
Montane shrub-west	2	31	34	67
Lush shrub (ALSI,etc)-east	1	18	22	41
Lush shrub (ALSI,etc)-west		17	24	41
Lush low elevation herb-east		6	22	28
Low elevation herb-west		2	1	3
Lush low elevation shrub		19	24	43
Rip deciduous forest-east		6	11	17
Rip deciduous forest-west	1	11	9	21
Nonriparian deciduous forest-east		13	16	29
Nonriparian deciduous forest-west		9	9	18
Subalpine-alpine VASC-VACA	1	7	19	27

vegetative foods are readily available in the study area. These species would provide a diversity of foods and were well distributed throughout the NCGBE.

Population estimates for 5 salmonid species, chinook (*Oncorhynchus tshawystcha*) chum, (*O. keta*), coho (*O. kisutch*), pink (*O. gorbuscha*), and sockeye (*O. nerka*) salmon in 8 major streams are provided in Table 6. In general, major fisheries occur on the west slopes of the NCGBE. The salmonid fisheries on the east side of the NCGBE have been greatly reduced since the construction of dams along the Columbia River. Population estimates of 4 ungulate species are provided in Table 7.

Table 6. Population estimates of salmon species in 8 major streams within the North Cascades Grizzly Bear Ecosystem (USDA 1990*a*, W. Somes, U.S. For. Serv., pers. commun., USDA 1990*b*).

	Salmon species				
River system	Chinook	Pink	Chum	Sockeye	Coho
Nooksack	3,460	15,192	18,800	0	650
Skagit	6,170	132,210	17,100	0	8,100
NF Stillaguamish	430	18,000	2,140	0	3,930
SF Stillaguamish	500	26,460	2,440	0	4,475
Skykomish	550	28,440	790	0	8,560
Wenatchee	6,220	0	0	31,785	0
Entiat	860	0	0	0	0
Methow	1,875	0	0	0	0
Total	20,065	220,302	40,470	31,925	25,715

Table 7. Population estimates and hectares of winter range for ungulates on National Forest lands within the North Cascades Grizzly Bear Ecosystem (W. Myers, Wash. Dep. of Wildl. pers. commun., C. Vandemoer, U.S. For. Serv., pers. commun.)

Species	Estimated population	Winter range
Deer	38,090	548,710
Elk	5,750	36,397
Mountain goat	780	
Bighorn sheep	200	

Human Activities

We mapped a total of 69 population centers, 258 campgrounds (excluding the backcountry camps in the NCNP), and 34 other sites (e.g., airstrips, ski areas) within the NCGBE. Assuming a zone of influence of 1,500 m around population centers and 500 m around each of the other sites, 43,800 ha (1.7% of the ecosystem) of habitat are affected. If the zone of influence is 2,000 and 1,000 m for population centers and other sites, respectively, then 110,765 ha (4.2% of the ecosystem) of habitat are affected.

We identified 14,594 km of roads in the ecosystem (Table 8). Our analysis showed that 68% of the NCGBE has no open roads. Road densities up to 1 km/km^2 occurred on 10% (243,927 ha) of the study area. Road densities from 1-3 km/km^2 occurred on 18% (469,855 ha) of the ecosystem, and densities >3 km/km^2 occurred on 4% (110,376 ha) of the area.

Livestock grazing is permitted on the ONF, WNF, Bureau of Land Management (BLM), state land managed by Washington Department of Natural Resources (WDNR) and Washington Department of Wildlife (WDW), and private land. The allotments on national forests occur on approximately 477,749 ha, portions of which are in wilderness (Table 9). Three sheep allotments are permitted on the ONF. All of these are operated by the same permittee and 2 of the allotments are used in alternate seasons. Portions of all of the sheep allotments on the ONF are in wilderness.

Table 8. Kilometers of roads in each administrative unit within the North Cascades Grizzly Bear Ecosystem.

		State		Other federal		National Forest		
Road type	Private	WDW[a]	WDNR	BLM	NCNP	ONF	WNF	MBSNF
Primary highway	285	1	27		45	70	94	71
Secondary paved	556	6	48	2	5	159	174	151
Improved gravel	296	43	105		24	936	347	847
Improved dirt	893	148	514	17	44	733	849	650
Unimproved	1,227	133	642	14	44	853	1,871	370
TOTAL	3,257	331	1,336	33	162	2,751	3,335	3,089
Total Paved	841	7	75	2	50	229	268	222
Total Unpaved	2,416	324	1,261	31	112	2,522	3,067	2,867
Gated Road[b]	94	11	21			605	217	19
Blocked Road[b]	67	2	19			573	255	225

[a] Washington Department of Wildlife (WDW), Washington Department of Natural Resources (WDNR), Bureau of Land Management (BLM), North Cascades National Park Service Complex (NCNP), Okanogan National Forest (ONF), Wenatchee National Forest (WNF), Mount Baker-Snoqualmie National Forest (MBSNF).

[b] Gated Roads and Blocked Roads are subsets of the Total roads.

Table 9. Hectares and percent of the North Cascades Grizzly Bear Ecosystem within range allotments.

Administrative unit[a]	Allotment type	Hectares	% of ecosystem	% federal and state
ONF	Cattle	275,248	11	12
ONF	Sheep	70,000	3	3
WNF	Cattle	46,376	2	2
WNF	Sheep	86,125	3	4

[a] Okanogan National Forest (ONF), Wenatchee National Forest (WNF).

CONCLUSIONS

The use of Landsat MSS and GIS proved to be an efficient and accurate way of mapping general vegetation types in the NCGBE. We feel that these technologies are very appropriate for mapping such a large area. However, for the mapping information to be useful for project-specific analyses of the effects on grizzly bears, a microsite analysis must be completed. The resolution of our vegetation map was too large to accurately map some very important small habitat types. For example, small avalanche chutes and small wet areas were not mapped and provide important habitat values for grizzly bears. These areas need to be identified in project-specific analyses.

The GIS allowed a tremendous amount of data to be stored, accessed, and analyzed. In addition to vegetation data, we collected data about the level of human activities within the ecosystem. This information was very important in determining the suitability and capability of the ecosystem to support a viable population of grizzly bears (Servheen et al. 1991). These data will be very valuable as we proceed with recovery efforts in the NCGBE.

APPENDIX

List and description of Level 2 vegetation and cover types mapped in the North Cascades Grizzly Bear Ecosystem.

WATER
This is self explanatory.

PIPO
Conifers over 10 feet tall cover ≥30% of the total tree cover. Ponderosa pine and Douglas-fir are ≥1/2 the total tree cover, and ponderosa pine covers > area than Douglas-fir.

PIPO-PSME
Same as above except ponderosa pine cover ≤ to the Douglas-fir cover, and the ponderosa pine composes ≥ to 5% of the total tree cover.

PSME-mixed conifer-east
Same as above except that the amount of ponderosa pine cover is <5% of the total tree cover, and it is located on the east side of the ecosystem.

PSME-mixed conifer-west
Same as above except that it is located on the west side of the ecosystem.

ABLA2-PIEN-PICO-east
The total cover of ponderosa pine and Douglas-fir are ≤ to half of the total tree cover. Whitebark pine is not dominant and Engelmann spruce cover is <10%. These areas do not occur within 142 m of a stream, river, or wetland.

ABLA2-PIEN-PICO-west
Same as above except it is located on the wet side of the ecosystem.

PIEN riparian
Ponderosa pine and Douglas-fir cover is ≤ half of the total tree cover. Whitebark pine is not dominant and Engelmann spruce cover is ≥ to 10% of the total cover. These areas are located within 142 m of a stream, river, or wetland.

Young PSME-managed (MBS only)
This is self explanatory.

TSHE-east
Hemlock composes >10% of the total tree cover. Ponderosa pine and Douglas-fir make up ≤1/2 of the total tree cover. These areas are located on the east side of the ecosystem.

TSHE-west
Same as above except that it is located on the west side of the ecosystem.

ABAM-east
Pacific silver fir cover is ≥10% of the total tree cover. Ponderosa pine and Douglas-fir cover is ≤1/2 the total tree cover. Whitebark pine or western larch are not dominant. These areas are located on the east side of the ecosystem.

ABAM-west
Same as above except located on the west side of the ecosystem.

TSME-east
The amount of hemlock tree cover is ≥10% of the total tree cover. Ponderosa pine and Douglas-fir compose ≤1/2 of the total tree cover. Whitebark pine or western larch are not dominant. These areas are located on the east side of the ecosystem.

TSME-west
Same as above except that it is located on the west side of the ecosystem.

PIAL
White bark pine is the dominant tree cover.
LALY
Western larch is the dominant tree cover.
Shrub steppe-herbaceous
These areas are composed of bitterbrush, sagebrush, balsam root, bunchgrasses, phlox, etc. In this class the herbaceous plants are dominant.
Shrub steppe-PUTR
Same as above except that bitterbrush is dominant.
Shrub steppe-ARTR
Same as above except that sagebrush is dominant.
Southeast shrub steppe
Composed of bitterbrush, sagebrush, balsam root, bunchgrasses, phlox, etc. Shrubs are dominant and these areas are located in the lower Wenatchee Valley.
Alpine meadow-east
Herbaceous vegetation is dominant. Composed of alpine meadows usually above 7000 feet. Located on the east side of the ecosystem.
Alpine meadow-west
Same as above except located on the west side of the ecosystem.
Subalpine lust meadow-east
These are located in the subalpine zone and are composed of lush subalpine meadow vegetation on the east side of the ecosystem.
Subalpine lush meadow-west
Same as above except located on the west side of the ecosystem.
Subalpine meadow (mesic/dry)-east
These areas are located in the subalpine zone. They are composed of mesic to dry meadows on the east side of the ecosystem.
Subalpine meadow (mesic/dry)-west
Same as above except located on the west side of the ecosystem.
Subalpine heather-VADE meadow
Subalpine shrubs and meadow with huckleberry (*Vaccinium deliciosum*).
Subalpine-alpine VASC-VACA meadow
Subalpine shrubs and meadows with huckleberry (*V. caespitosum*, *V. scoparium*) present.
Subalpine mosaic-east
A mixture of shrubs, trees, herbs, and bare ground with no clear dominant. Located in the subalpine zone on the east side of the ecosystem.
Subalpine mosaic-west
Same as above except located on the west side of the ecosystem.
Montane mosaic-east
A mixture of shrubs, trees, herbs, and bare ground with no clear dominant. Composed of montane vegetation in the montane zone on the east side of the ecosystem.
Montane mosaic-west
Same as above except located on the west side of the ecosystem.
Montane herbaceous-east
Dominated by herbaceous vegetation. Located in the montane zone on the east side of the ecosystem.
Montane herbaceous-west
Same as above except located on the west side of the ecosystem.
Montane shrub-east
A variety of montane and subalpine shrubfields. Located on the east side of the ecosystem.
Montane shrub west
Same as above except located on the west side of the ecosystem.
Lush shrub (ALSI, etc.)-east
Shrub cover is >74%. Composed of lush alder and vine maple fields on the east side of the ecosystem.
Lush shrub (ALSI, etc.)-west
Same as above except located on the west side of the ecosystem.
Lush low elevation herbaceous-east
Composed of lush low elevation herbaceous plants that are below the subalpine zone on the east side of the ecosystem.
Lush low elevation herbaceous-west
Same as above except it is located on the west side of the ecosystem.
Lush low elevation shrub-east
Composed of lush low elevation shrubs below the montane zone on the east side of the ecosystem only.
Riparian deciduous forest-east
The deciduous forest cover is ≥50% cover, or is > other forest types. These areas are located within 142 m of a stream, river, or wetland, and are on the east side of the ecosystem.
Riparian deciduous forest-west
Same as above except located on the west side of the ecosystem.
Nonriparian deciduous forest-east
Same as above except these areas are greater than 142 m from a stream, river or wetland. Located on the east side of the ecosystem.
Nonriparian deciduous forest-west
Same as above except it is located on the west side of the ecosystem.
Barren, snow, unclassified
This is self explanatory.

Agriculture-fallow and dry pasture
These are composed of dry pasture, fallow fields, and dryland crops.

Agriculture-orchard, crops
These are composed of orchards, lush pastures, and lush crop fields.

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