Utilization of Landsat TM and Digital Elevation Data for the Delineation of Avalanche Slopes in Yoho National Park (Canada)

K. Wayne Forsythe and Roger D. Wheate

***Abstract*—There is an ongoing need for a long-term Grizzly Bear Management Plan in Yoho National Park as a result of human–bear conflicts and periodic human mortality. Avalanche slopes offer preferred feeding sites to the grizzly bear population, and hence a more detailed knowledge of their location and extent is needed as a management tool. Landsat Thematic Mapper (TM) satellite image bands, a normalized difference vegetation index (NDVI), and the principal component associated with "greenness" (derived from the TM image data), along with digital elevation model variables provided the best classification with an avalanche slope accuracy of 82%. The classified data were imported into a geographic information system (GIS) and the area of the avalanche slopes determined to be 66 km^2 or approximately 5% of the total park area. The resulting GIS database is being used by the park for management purposes.**

***Index Terms*—Avalanche slope classification, geographic information system (GIS), grizzly bears, management plan, normalized difference vegetation index (NDVI), principal component analysis (PCA), Thematic Mapper (TM) satellite imagery.**

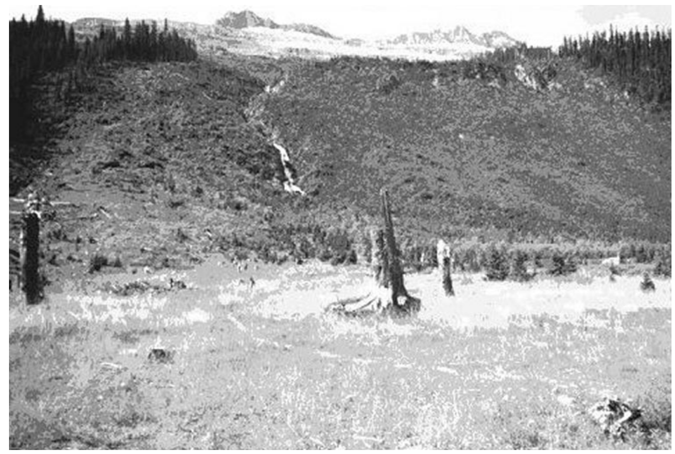

Fig. 1. Avalanche slope at Takakkaw Falls, Yoho National Park. Looking west, the slope is approximately 500 m wide.

I. Introduction

REMOTELY sensed satellite data and geographic information systems (GIS) are routinely used for the management of natural areas, especially with regard to the mapping and assessment of vegetation types and habitats [1]–[4]. Although fatal encounters with grizzly bears (*Ursus arctos*) are not common in mountain parks—less than one per year in total [5]—they earn exaggerated publicity and often result in extermination or relocation of the bears involved. Minimizing grizzly bear encounters with visitors is, therefore, a necessity. The Yoho National Park (YNP) Conservation Plan states that "bears will be given a high priority for protection and the interest of the species will take precedence over visitor use" [6]. This requires, as indicated in the Conservation Plan [7], a more detailed knowledge of vegetation and habitats and the significance of avalanche slopes, which offer preferred feeding sites to the grizzly bear population. The bears are attracted here to a rich variety of herbaceous plants for food supply (in comparison with coniferous forests) including blueberries (*Vaccinium spp.*), Canadian buffalo-berries (*Shepherdia canadensis*), the roots of sweetvetch (*Hedysarum boreale*) and cow parsnip (*Heracleum lanatum*) [8], [9]. The intent of this letter is to use satellite imagery and digital elevation model (DEM) data as management tools for locating and mapping the vegetated portions of avalanche slopes in Yoho National Park.

In forested regions such as the subalpine forest of the Canadian Rockies, avalanche tracks can be identified as swaths of herbaceous, shrubby deciduous, and stunted coniferous vegetation that cut distinctive linear tracks through the surrounding coniferous forest (Fig. 1). Avalanche slopes have been studied and mapped in the past for a number of reasons including land use planning, hazard evaluation, avalanche frequency, geomorphic activity, association with geologic features, and vegetation patterns [10], [11].

Classification procedures using remote sensing data in mountainous environments are more complicated than in less rugged and gently rolling terrain, since anisotropic reflectance due to topography and landcover can affect the signal received at the sensor [12], [13]. However, Cohen *et al.* [14] did not correct for these effects, as the forest clearcuts they were classifying (much like avalanche slopes) had such a different spectral signature compared to the surrounding vegetation. This would indicate that the option to perform a topographic normalization depends on the needs of the researcher(s) and the goal(s) of the research. Topographic effects can be taken into consideration either by incorporating DEM data and/or derived image layers. Vegetation indices are ratios that serve to suppress possible data processing issues due to topography. Principal components

Manuscript received April 2, 2003; revised July 3, 2003. This work was supported by Yoho National Park.

K. W. Forsythe is with the Department of Geography, Ryerson University, Toronto, ON M5B 2K3, Canada (e-mail: forsythe@geography.ryerson.ca).

R. D. Wheate is with the Faculty of Natural Resources and Environmental Studies, University of Northern British Columbia, Prince George, BC V2N 4Z9, Canada (e-mail: wheate@unbc.ca).

Digital Object Identifier 10.1109/TGRS.2003.817183

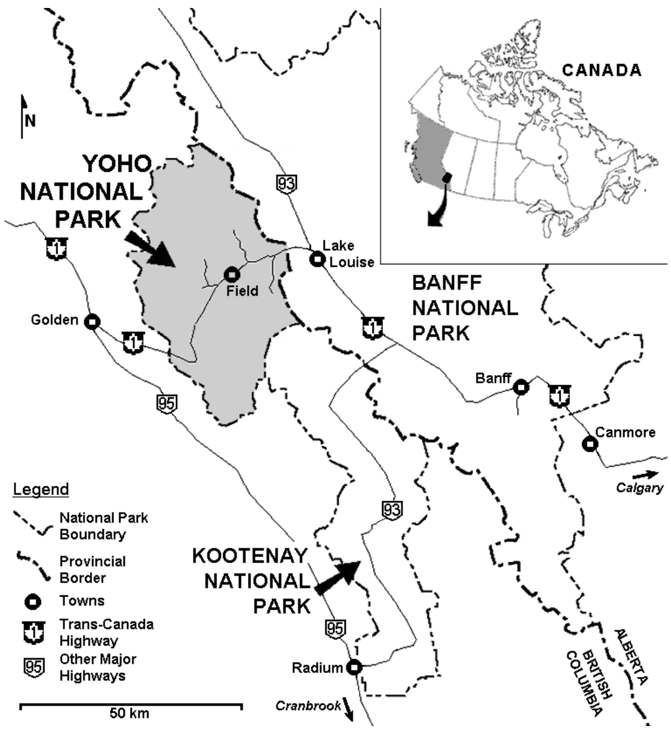

Fig. 2. Location of Yoho National Park. Source: modified after [7] and [16].

can also be useful, as they provide a linear transformation, which rotates the axes of image space along lines of maximum variance.[1]

II. Study Area

Yoho National Park (Fig. 2) is one of four contiguous national mountain parks in the Canadian Rocky Mountains (Yoho, Kootenay, Jasper, and Banff) that were collectively designated by the United Nations in 1985 as a UNESCO World Heritage Site. Yoho in the Cree language means "astonishment or wonder" [15]. The park is located to the west of the British Columbia–Alberta border, and covers an area of approximately 1300 km^2.

The park includes the Burgess Shale fossil deposits, separately designated a UNESCO world heritage site in 1981. The Kicking Horse River corridor bisects the park and also contains the main transportation routes in the Trans-Canada highway and the main east–west Canadian Pacific Railway line. The road, rail, and hiking trail network in the park can, however, cause habitat fragmentation especially among some of the wide-ranging carnivores in the park such as grizzlies and wolves [7]. The town of Field (population $\sim$ 300) is the main service and population center in the park.

Three distinct vegetation zones are found in the park, consisting of montane, subalpine, and alpine zones. The climate can be characterized as having long winters and short cool summers with occasional hot spells [16]. Elevation ranges from 1035 m at the western entrance to the park to 3562 m at the top of Mount Goodsir. The combination of steep glaciated valley sides and high winter precipitation in the form of snow with elevated moisture content in locations on the west side of the continental divide results in a high frequency of snow avalanches and severe impacts [17].

[1]See http://www.pcigeomatics.com.

TABLE I
Parks Canada Attendance for 1995–1996 to 1999–2000 Seasons. Number of Person-Visits for Mountain National Parks, Percent Change From 1998–99 to 1999–00 in Brackets. Source: Modified After [24] and [25]

National Park	1995-96	1996-97	1997-98	1998-99	1999-00
Banff (7)	4,858,161	4,453,021	4,269,105	4,361,330	4,677,572
Jasper (0)	1,647,417	1,820,506	1,816,677	1,899,705	1,904,240
Waterton Lakes (-1)	357,575	349,741	369,089	425,436	422,376
Mt. Revelstoke and Glacier (-5)	568,774	532,153	558,343	559,198	530,638
Kootenay (-6)	1,288,495	1,260,310	1,558,576	1,690,882	1,590,596
Yoho (28)	761,871	814,801	1,040,185	1,068,730	1,371,105
All Canadian National Parks (4)	15,385,828	14,684,145	14,904,140	15,696,158	16,260,557

The park has experienced increased visitation in recent years especially when compared to other Canadian National Parks: latest available data (from 1995 to 1996 to 1999 to 2000) indicate an average yearly increase of almost 17%. From 1998 to 1999 and 1999 to 2000, the increase was 28%, with an estimated total of almost 1.4 million visitors (Table I). In contrast, the total increase in visitation in the entire national park system was approximately 4%. In the adjacent and better known Banff National Park the increase was only 7% for the 1998–1999 and 1999–2000 periods, and overall visitation is down from a high during the 1995–1996 season. This may suggest that Banff has reached its capacity, and tourists who are seeking a less stressful experience are continuing west on the Trans-Canada Highway to Yoho National Park. While this increase in visitation may be good for service-related activities in the park, it most certainly will cause increased stress on facilities in the park such as hiking trails.

III. Methodology

A. Data Acquisition and Preprocessing

A Landsat-5 Thematic Mapper (TM) satellite image from September 2, 1988 and a 100-m resolution DEM (generated by digitizing 1 : 250 000 contours) were made available by Yoho National Park (from their data holdings) for this analysis. A subset of 2000 columns by 2800 lines covering the park was extracted from the satellite image. TM band 1 was not useable due to considerable striping. TM band 6 (thermal infrared) was not considered for this study, as the spatial resolution of 120 m only allows for the identification of the largest avalanche slopes. The DEM data had previously been registered to the Universal Transverse Mercator (UTM) system, which forms the basis for Canadian topographic mapping. The satellite data were geocorrected to register with the DEM. A root-mean-square (RMS) accuracy of under 0.4 pixels (X: 0.378, Y:0.303) for 50 ground control points was obtained, which corresponds to a maximum error of approximately 10–12 m in any compass direction.

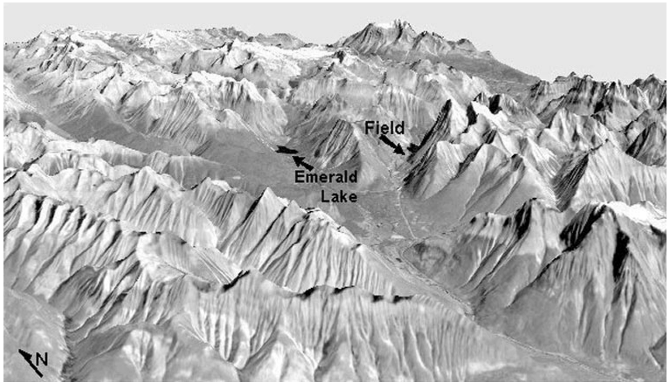

Fig. 3. TM Band 4 draped over the DEM Data (view from the southwest).

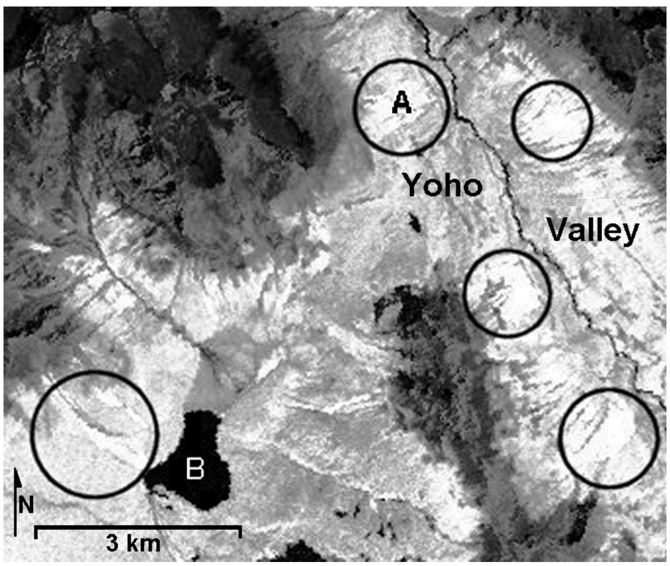

Fig. 4. NDVI image of central YNP. A indicates the avalanche slope from Fig. 1. B identifies Emerald Lake from Fig. 3.

Data layers for slope and incidence were created from the DEM data. The digital elevation model, though of medium resolution, nevertheless played an important role. Glaciated mountain regions tend to contain continuous valley sides with relatively constant slope and aspect. For this reason, less information is lost with larger pixel sizes than in many other types of environments, where the surfaces are defined by more subtle differences. The model was also quite adequate for generating perspective views (Fig. 3) that have been found to be highly effective both for resource planning by park managers and for landscape visualization by park visitors [18].

B. Generation of Additional Image Layers

In addition to using the TM bands and DEM-derived layers (elevation, slope, and incidence), two further layers were derived from the TM data to maximize vegetation information. The use of satellite images for vegetation study is mostly based on different vegetation reflectances in the near-infrared and visible bands [19]. The normalized difference vegetation index (NDVI) has been shown to be least affected by topographic factors [20], because it is based on a ratio of bands. For Landsat TM data, the formula is $(\text{Band4} - \text{Band3})/(\text{Band4} + \text{Band3})$. In the NDVI image (Fig. 4), the avalanche slopes (major areas circled) appear brighter than the surrounding coniferous forest in the image. Other forms of linear data transformations have been developed for vegetation monitoring, with sensors and vegetation conditions dictating the transformations.

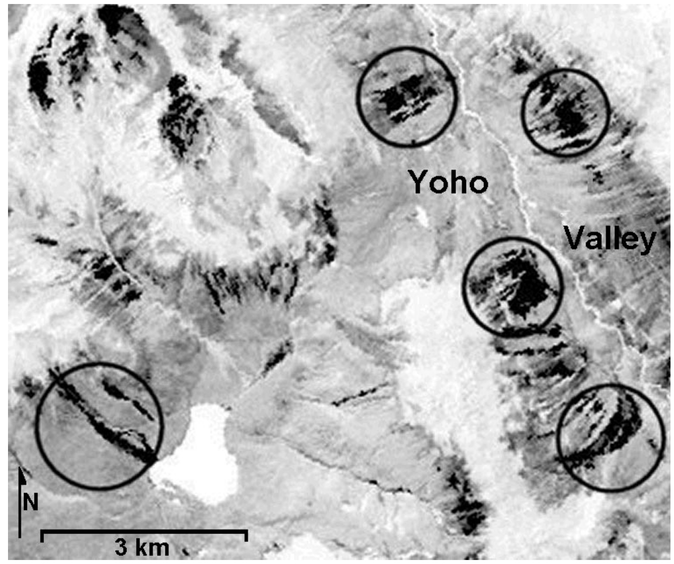

Fig. 5. Third principal component image: central YNP.

TABLE II
LANDSAT TM PCA: EIGENVECTOR MATRIX AND PERCENT EXPLAINED VARIANCE

Principal Component	TM Band 2	TM Band 3	TM Band 4	TM Band 5	TM Band 7	Percent Explained Variance
1	0.405	0.577	0.389	0.509	0.305	68.53
2	0.383	0.451	0.141	-0.700	-0.375	27.19
3	0.131	0.359	-0.864	-0.046	0.326	4.04
4	-0.802	0.505	0.172	-0.183	0.195	0.12
5	0.170	-0.282	0.231	-0.465	0.789	0.11

Principal component analysis (PCA) was also performed on the TM data, since the principal component associated with "greenness"—in this case, PC3 (Fig. 5)—has been shown to identify vegetation types and avalanche tracks (which appear black) more effectively than any individual TM band [21], [22].

Although PC3 explains only 4% of the total scene variance, the major effects due to topography have been removed through the higher components (PC1 and PC2) , and PC3 corresponds to the difference between near-infrared (band 4) and the visible bands as indicated by the opposing signs of the eigenvectors (Table II).

C. Classification of TM and DEM Data

Four classes were used to map the avalanche tracks in the park. These were as follows:

1) avalanche (vegetated tracks);
2) forest (deciduous and coniferous);
3) meadow (including tundra);
4) mixed (scrub vegetation of various types including burn areas).

The classification scheme was based on reference data (provided by the park) in the form of aerial photographs and an ecological land classification (ELC). In addition, field studies were

TABLE III
CLASSIFICATION ACCURACY RESULTS (PERCENT)

Classification	Avalanche	Forest	Meadow	Mixed	Overall
a. bands 3,4,5,7	79.0	99.0	69.8	78.0	79.75
b. a + elev	78.9	98.3	100.0	88.2	84.50
c. b + slope	76.8	99.0	99.5	94.1	91.75
d. c + incidence	80.6	100.0	99.4	88.2	92.25
e. d + NDVI, PC3	81.7	95.4	99.0	94.4	90.00

undertaken by the authors along the major transportation corridors through the park and in one of the major side valleys (the Yoho Valley). Training sites were created for these classes in all regions of the park, which established a spectral and geomorphic signature for each class. The signatures were then used in classification procedures incorporating both the satellite and DEM data. Meadow and mixed sites are also used by grizzly bears due to the presence of herbaceous foods. The remaining areas were unvegetated (such as bare rock, glaciers, water, and gravel bars) and left as unclassified.

Band 2 was discarded as a raw input for classification purposes as previous studies have shown it to be the least effective in vegetation discrimination [10]. Classifications were performed using a full maximum-likelihood classification (MLC) technique with the remaining TM bands and derived layers comprising the following datasets:

a) TM bands 3, 4, 5, and 7 alone;
b) TM bands 3, 4, 5, and 7 plus elevation;
c) TM bands 3, 4, 5, and 7 plus elevation and slope;
d) TM bands 3, 4, 5, and 7 plus elevation, slope, and incidence;
e) TM bands 3, 4, 5, and 7 plus elevation, slope, incidence, NDVI, and PC3.

D. Accuracy Assessment

Random samples of approximately 200 points per class were extracted (using in-house software) from the database. Points that were located directly on boundaries between two or more classes were removed. Discriminant analysis was then used to determine the accuracy of the various classifications that were performed. This statistical technique uses a linear combination of variables to distinguish between two or more categories of cases. The variables "discriminate" between groups of cases and predict into which category or group a case falls, based on the values of these variables [23].

IV. RESULTS AND DISCUSSION

The class and overall classification accuracies for the images from the discriminant analyses are outlined in Table III. Classification "e" incorporating the NDVI and PC3 layers resulted in the best delineation of avalanche slopes (81.7%), although classification "d" had a slightly higher overall accuracy. Since the prime objective was to delineate avalanche slopes (and to a lesser extent, meadows), classification "e" was selected and a 3×3 median filter applied to smooth the classification and improve avalanche path mapping characteristics (Fig. 6). These results were then ported to a raster GIS (SPANS) for class area determination, mapping, and reporting, and clipped to the outline of the Yoho National Park. The area analysis function reported the area of the avalanche slopes in the entire park for this filtered classification as being 66.09 km^2. As a percentage of the entire park area, this is approximately 5.08% of Yoho National Park.

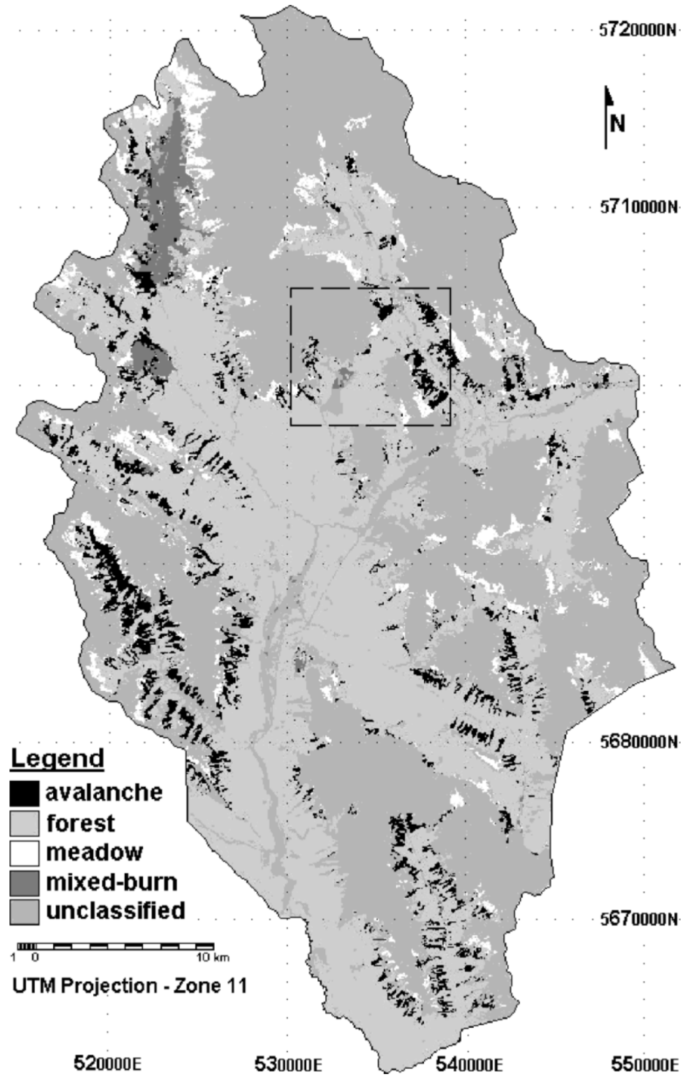

Fig. 6. Classification results after the 3×3 filter. Dashed box indicates the area featured in Figs. 4 and 5.

In addition, the results were visually compared with air photo and ELC information provided by the park. The larger avalanche slopes (greater than 50 m wide) were very well represented. Smaller slopes between 15 and 50 m wide were not always clearly delineated. However, the intrusion of smaller avalanches deep into forested areas does not often occur, and therefore the classification result represents the location of the slopes quite well.

V. CONCLUSION

Remotely sensed satellite data and DEM data can be used for determining the extent and location of avalanche paths and alpine meadows in mountainous areas. The results are improved with the inclusion of principal component analysis and the calculation of NDVI. Classification accuracy might be further enhanced with the availability of higher resolution data, which might better resolve situations such as edge pixels and narrow avalanche chutes. Landsat-7 satellite image data should prove useful in updating and upgrading avalanche slope mapping databases. These are available at US $600 per scene, and the spatial resolution can be "improved" through image fusion techniques using the simultaneously acquired panchromatic band (15-m resolution).

The new park management plan has already resulted in some changes. Some trails have been closed during seasonal grizzly foraging activity and others have been permanently closed (Parks Canada, 2002). The challenge for park managers will be in using tools such as GIS and remote sensing to help them make informed decisions.

Acknowledgment

The authors would like to thank PCI Geomatics for image processing and GIS software. Four anonymous reviewers are also thanked for their comments and suggestions that helped to improve the final manuscript.

References

[1] S. P. S. Kushwaha, "Forest type mapping and change detection from satellite imagery," *ISPRS J. Photogramm. Remote Sens.*, vol. 45, pp. 175–181, 1990.

[2] V. A. Johnson and S. H. Paine, "Visualization and analysis of resource conflicts using a geographic information system: A case study," in *Proc. 14th Can. Symp. on Remote Sensing*, Calgary, AB, Canada, May 6–10, 1991.

[3] T. Blaschke, "GIS techniques and hybrid parametric/nonparametric image classification: A case study showing the potential for signature training and accuracy assessment," in *Proc. XVIII ISPRS Congress*, vol. XXXI, International Archives of Photogrammetry and Remote Sensing, Vienna, Austria, July 9–19, 1996, pp. 15–19.

[4] J. Franklin, "Integrating GIS and remote sensing to produce regional vegetation databases: Attributes related to environmental modeling," in *Proc. 3rd Int. Conf. and Workshop on Integrating GIS and Environmental Modeling*, Santa Fe, NM, Jan, 21–26, 1996.

[5] S. Herrero, *Bear Attacks: Their Causes and Avoidance*. New York: Winchester Press, 1985.

[6] Parks Canada–Heritage Resource Conservation (PC-HRC), "Park Conservation Plan, Yoho National Park," Parks Canada—Heritage Resource Conservation (PC-HRC), 1992.

[7] Parks Canada. (2000) Yoho National Park of Canada Management Plan. Parks Canada, Hull, QC, Canada

[8] B. Gadd, *Handbook of the Canadian Rockies*, 2nd ed. Jasper, AB, Canada: Corax, 1995, p. 725.

[9] Parks Canada. (2002) Yoho National Park of Canada Implementation Report. Parks Canada, Hull, QC, Canada. [Online]. Available: http://www.pc.gc.ca/pn-np/bc/yoho/

[10] D. R. Connery, "Avalanche vegetation classification using Landsat imagery and a digital elevation model in southwestern Alberta," M.S. thesis, Dept. of Geography, Univ. Calgary, Calgary, AB, Canada, 1992.

[11] Y. Leclerc, "The design of FM: Data integration software for the zoning of natural hazards in developing countries," M.E. Des. Project, Faculty of Environ. Design, Univ. Calgary, Calgary, AB, Canada, 1994.

[12] J. D. Colby, "Topographic normalization in rugged terrain," *Photogramm. Eng. Remote Sens.*, vol. 57, no. 5, pp. 531–537, 1991.

[13] J. D. Colby and P. L. Keating, "Land cover classification using Landsat TM imagery in the tropical highlands: The influence of anisotropic reflectance," *Int. J. Remote Sens.*, vol. 19, no. 8, pp. 1479–1500, 1998.

[14] W. B. Cohen, M. Fiorella, J. Gray, E. Helmer, and K. Anderson, "An efficient and accurate method for mapping forest clearcuts in the pacific northwest using Landsat imagery," *Photogramm. Eng. Remote Sens.*, vol. 64, no. 4, pp. 293–300, 1998.

[15] D. Beers, *The Wonder of Yoho*. Calgary, AB, Canada: Rocky Mountain Books, 1989.

[16] Parks Canada, "Yoho National Park of Canada (Fact Sheet)," Parks Canada, Hull, QC, Canada, 2001.

[17] S. J. Walsh, D. R. Butler, D. G. Brown, and L. Bian, "Form and pattern in the alpine environment: An integrated approach to spatial analysis and modeling in Glacier National Park, USA," in *Mountain Environments and Geographic Information Systems*, M. F. Price and D. I. Heywood, Eds. London, U.K.: Taylor and Francis, 1994, pp. 189–217.

[18] R. D. Wheate, "Re-examining the cartographic depiction of topography," in *Cartographic Design, Theoretical and Practical Perspectives*, C. H. Wood and C. P. Keller, Eds. New York: Wiley, 1996.

[19] Z. Yin and T. H. L. Williams, "Obtaining spatial and temporal vegetation data from Landsat MSS and AVHRR/NOAA satellite images for a hydrologic model," *Photogramm. Eng. Remote Sens.*, vol. 63, no. 1, pp. 69–77, 1997.

[20] J. G. Lyon, D. Yuan, R. S. Lunetta, and C. D. Elvidge, "A change experiment using vegetation indices," *Photogramm. Eng. Remote Sens.*, vol. 64, no. 2, pp. 143–150, 1998.

[21] S. J. Walsh, J. W. Cooper, I. E. Von Essen, and K. R. Gallager, "Image enhancement of Landsat Thematic Mapper data and GIS data integration for evaluation of resource characteristics," *Photogramm. Eng. Remote Sens.*, vol. 56, no. 8, pp. 1135–1141, 1990.

[22] R. D. Wheate and S. E. Franklin, "Principal component transformation of satellite imagery in mountain areas," in *Proc. 14th Can. Symp. Remote Sensing*, Calgary, AB, Canada, May 6–10, 1991.

[23] J. C. Davis, *Statistics and Data Analysis in Geology*, 2nd ed. New York: Wiley, 1986.

[24] Parks Canada. (2002) Parks Canada—Parks Canada attendance 1998–99 to 2002–03. Parks Canada, Hull, QC, Canada. [Online]. Available: http://www.pc.gc.ca/docs/pc/rpts/visit/table1_e.asp.

[25] Parks Canada. (2002) Parks Canada—State of the Parks 1997 Report—Appendix 7: Parks Canada Attendance 1993–94 to 1996–97. Parks Canada, Hull, QC, Canada. [Online]. Available: http://www.pc.gc.ca/docs/pc/rpts/etat-state/state-etat194_e.asp.