Spatial Information and Environmental Decision Making
The Windermere Valley, British Columbia

Gregory George Yetman

Department of Geography, McGill University, Montreal

August 1999

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements of the degree of Master of Arts

0-612-64207-0

Abstract

Local participation in environmental decision making processes is a recognized need if the goals of sustainable development are to be met. Spatial information is an important part of environmental decision making, but so far, technical barriers have prevented effective public participation in spatial data management and analysis. These barriers need to be overcome if participants are to take part in a decision making process in a manner that is both fair and competent. The study was undertaken to quantify land cover change in a particular region and, through this exercise, to determine what the practical barriers to public participation in decision making might be. The work was conducted in the Windermere Valley, British Columbia. Community questions about local environmental change were determined from a local newspaper and discussions with Environmental Non-Governmental Organizations (ENGO's). Using satellite imagery and other geospatial data, community questions about local environmental change were answered through the detection of land cover change for the period 1974 – 1991. The processes of acquiring the data and completing the analysis were evaluated with the criteria of fairness and competence. The products of the change detection analysis were evaluated based on how well they answered community questions. Suggestions are presented on what tools and resources ENGO's would require to complete a similar study to answer questions about the environment.

Résumé

La participation locale est nécessaire dans les processus de prise de décision environnementale afin de rencontrer les objectifs de développement durable. L'information géographique est une part importante de la prise de décision environnementale, mais jusqu'à maintenant des obstacles techniques ont empêché une participation efficace du public à la gestion et à l'analyse de données géographiques. Ces obstacles doivent être surmontés pour que des participants prennent part au processus de prise de décision de façon équitable et compétente. La présente étude a été réalisée dans le but de quantifier le changement dans le couvert terrestre d'une région et par cet exercice déterminer quels pouvaient être les obstacles pratiques à la participation du public au processus de prise de décision. Le travail a été effectué dans la vallée Windermere, en Colombie-Britannique. Les questions de la communauté concernant les changements environnementaux ont été déterminées par l'étude d'un journal local et des discussions avec des organisations non gouvernementales. En utilisant des images satellites et autres données géospatiales, les réponses aux questions de la communauté concernant le changement environnemental local ont été trouvées par la détection du changement dans le couvert terrestre pour une période s'échelonnant de l'année 1974 à l'année 1991. Les processus de cueillette de données et d'analyse de ces données ont été évalués par des critères d'équité et de compétence. Les résultats de l'analyse de la détection de changement ont été évalués sur leur aptitude à répondre aux questions de la communauté. Des suggestions sont présentées à savoir quels outils et quelles ressources les organisations non gouvernementales exigeraient pour compléter une étude semblable et répondre aux questions relatives à l'environnement.

Table of Contents

List of Tables

List of Figures

Acknowledgements

As with any undertaking of this nature, there are many people deserving of thanks for their help and support. The author would like to thank Thom Meredith and John Lewis for all of their support and advice as committee members, and for their assistance in editing. Many thanks to Lilian Lee for providing technical support in the GIS lab. Thanks also to Michelle Douville, for providing the solution to the translation problem with the data from British Columbia. The author would like to offer grateful acknowledgement for support received in the form of data provided for the study from Kootenay National Park, the Invermere Office of the British Columbia Ministry of Forests, The Windermere Valley Echo, and Bighorns in Our Backyard. While doing fieldwork in British Columbia, advice and assistance were generously provided by Alan Dibb and Larry Halverson of Kootenay National Park. At the Windermere Valley Echo, Ian Cobb and Linda Harrison were kind enough to provide assistance in accessing the newspaper archives. Thanks also to Darrell Smith at the Ministry of Forests for his help in locating the forestry and rangeland data. To Bob and Lorraine Campsall, who were kind enough to invite the author in their home, many thanks.

Special thanks to my parents, without their encouragement this undertaking would not have been possible. Thanks to Catherine Bolduc for her help in editing and for her support which was, as always, invaluable.

Chapter 1: Public Participation and Environmental Decision Making

1.1 Introduction

From the local to the international scale, the need for public participation in the environmental decision making process has been voiced and recognized:

> "One key theme heard during the Round Table's public consultations was the need for local participation in planning and decision making... In every one of the communities visited by the Round Table, people expressed a desire for some mechanism by which local residents could undertake locally-led sustainability initiatives and resolve local sustainability conflicts" (British Columbia Round Table on the Environment and the Economy, 1993, p. 19);

> "The law alone cannot enforce the common interest. It principally needs community knowledge and support, which entails greater public participation in the decisions that affect the environment" (World Commission on Environment and Development, 1987, p. 6).

The call for public participation in environmental decision making is clear — what remains is to implement processes that allow this participation to occur.

This study uses the criteria of fairness and competence in public participation as described by Webler (1995) to evaluate the products of land cover change detection for a portion of the Windermere Valley in British Columbia (Figure 1.1). Fairness requires that the public have an opportunity to participate in a decision making process, while competence requires that participants have the opportunity to participate at a level of complexity appropriate for the issue being dealt with. The case study identifies specific barriers to accessing spatial information at the community level. The detection of land

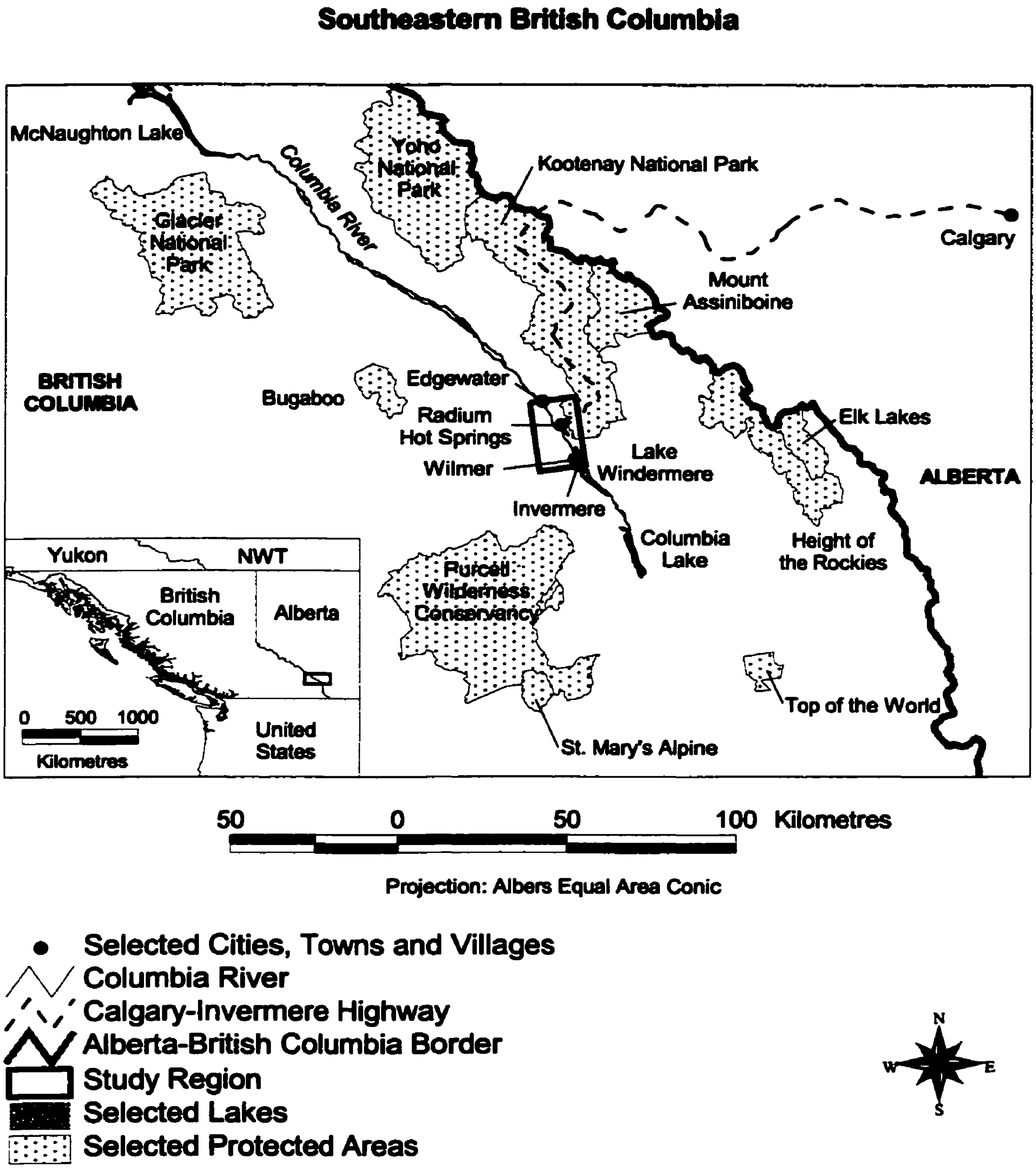

Figure 1.1 Southeastern British Columbia. Sources: Digital Atlas of the World (1994); British Columbia Land Use Coordination Office (1998).

cover change was undertaken in an effort to answer community questions about the local environment identified through sampling a local newspaper. The products of the change detection analysis are presented, discussed, and evaluated according to Webler's criteria.

This study is part of an effort to improve decision making through providing more factual information to aid in resolving factual disagreements between stakeholder groups (Meredith, 1998). The effort to improve the information flow to the community includes the provision of spatial information — the production of land cover change maps described in this study.

1.2 Public Participation in Environmental Decision Making

Humans are inextricably linked to the process of environmental change (Figure 1.2): humans initiate change, have the capacities to 'buffer' the effects of change, and experience the change and respond to it. Human driving forces in the process of environmental change are not constant, instead they change with the circumstances of the actors. One factor that may alter the driving forces is the perception of the consequences of environmental change. Sustainable development requires that this perception should result in decisions or actions that maximize social and economic benefits while minimizing environmental costs. Environmental decisions are made based on the information at hand at the time.

Meredith (1997a) explains that environmental decisions are made using scientific information (the explained world) and people's own interpretations (the perceived world) to arrive at a decision that will impact on the real world. There are, in effect, three overlapping yet distinct 'worlds' that need to be considered in decision making. Brookfield (1982) notes that decision makers' perception of ecosystems may differ

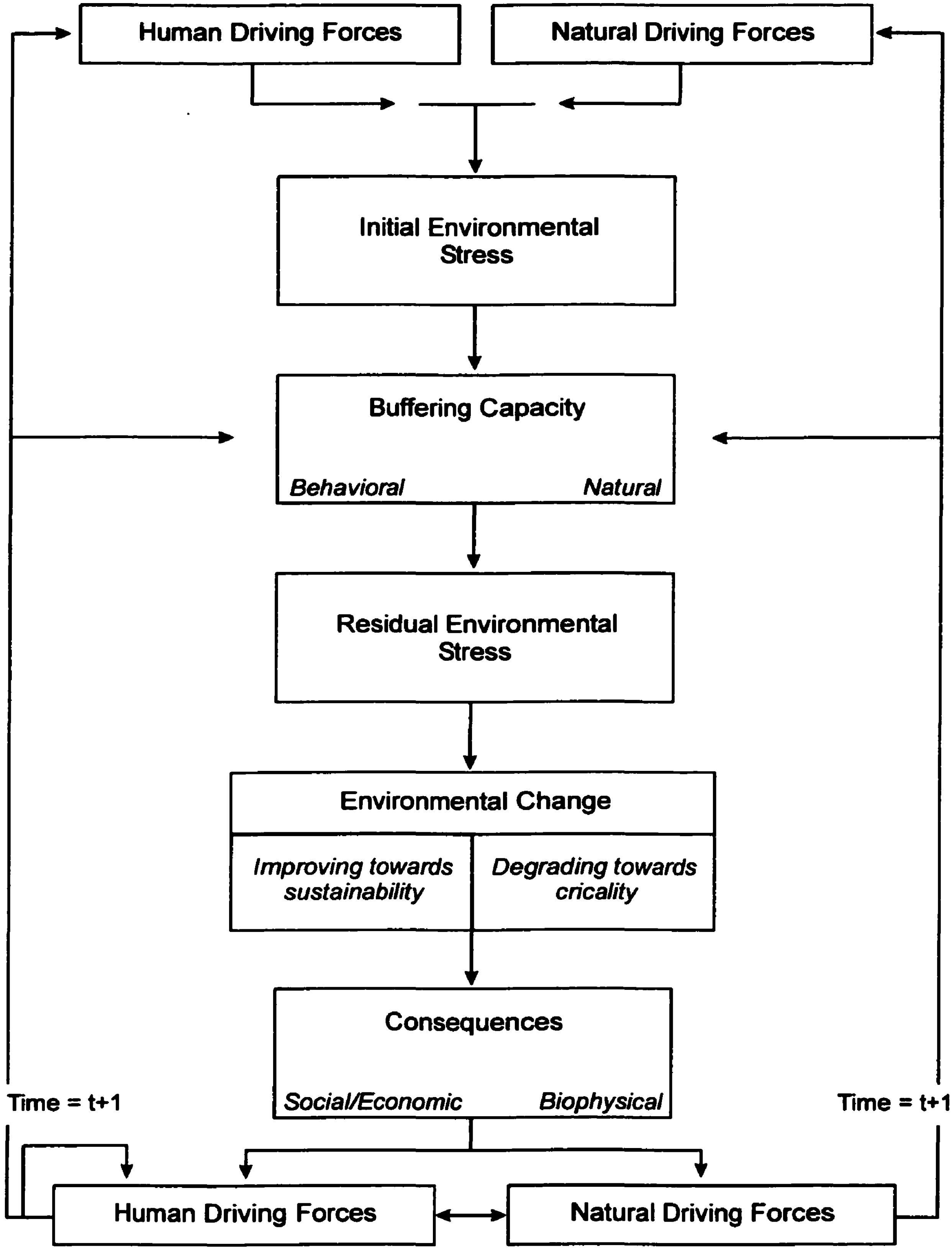

Figure 1.2 Process of Environmental Change. Redrawn from Meredith et al, 1994, p. 4.

substantially from the real system and its environment. Neither the world as explained by science nor the world as perceived by decision makers, or the public, perfectly reflects the real world. When the process of environmental change (Figure 1.2) is examined in the context of these 'three worlds', one reason for continued environmental degradation can be recognized — imperfect decisions may result from flaws in the explained or perceived understanding of natural systems. Actions or decisions based on explained and perceived worlds that are imperfect will not always provide a remedy to the causes of negative environmental change in the real world. The goal of scientific research and education are to bring these three worlds together; that is to make the explained and perceived worlds agree with the real world.

The addition of new knowledge and information to the explained world through scientific research and a better understanding by people of how they relate to the environment in which they live can improve the knowledge base available to decision makers. The combination of accurate scientific information and a good comprehension of that by decision makers *and* the public can increase the probability of solving environmental problems. A combination of information from the explained world and the perceived world is the best basis on which to make a decision regarding environmental problems. Most often, in a decision making process, public input or participation is used to expand decision makers' knowledge of the perceived world. This knowledge is combined with knowledge from the explained world, such as expert advice and reports, to arrive at a decision. Dietz and Stern (1998) argue that the best method for biodiversity policy making is a combination of scientific analysis and deliberation that includes input from scientists, decision makers and stakeholders. In this more iterative approach to policy making: "Analysis and deliberation interact to ensure that science is directed toward decision-relevant questions and that deliberation is grounded in knowledge as well as in values" (Dietz and Stern, 1998, p. 443). Ideally, this would result in the convergence of the perceived and real worlds as science becomes more responsive to social needs.

Public perception of environmental problems is comprised of the public's direct experience of the world (derived from their interaction with the environment) and their exposure to and comprehension of the explained world. Environmental decisions are influenced to varying degrees by public input in the decision making process. Efforts to include public input in decision making processes vary from efforts designed to co-opt or pacify the public to those that attempt to include the public as legitimate participants who can influence the outcome of the process (Renn et al., 1995). Public participation in environmental decision making occurs in many forums — environmental assessments, land use planning, and facility siting decisions are several examples. These forums use various models for receiving public input, including public hearings, public meetings, focus groups, surveys, citizen advisory committees, referendums and initiatives, public inquiries and negotiation (Renn et al., 1995; Webler and Renn, 1995).

Renn et al. (1995) conclude that traditional decision making strategies are insufficient for solving environmental problems. They note two critiques of these strategies. First, the strategies de-emphasize the impact of decisions on affected parties, which prevents the popular acceptance of the decisions. Not accounting for the impacts of decisions, such as the cost of implementation or any impedance that it may place on a party's economic activity can brand the decision as unfair. Second, the strategies rely on systematic observations and general theories which fail to include local knowledge of the public, therefore risking "...outcomes that are incompetent, irrelevant, or simply unworkable" (Renn et al., 1995, p. 1). A partial solution is proposed by Renn et al. (1995) and Webler (1995): a normative theory on citizen participation in environmental decision making that includes fairness and competence as 'metacriteria' and a set of specific criteria with which to evaluate methods of public participation.

Modifying Habermas' (1973) requirements for the ideal speech situation, Webler describes the requirements that must be met to fulfill the metacriteria of fairness. For fairness to occur in public participation,

> "...not only are people provided equal opportunities to determine the agenda, the rules for discourse, and to speak and raise questions, but also equal access to knowledge and interpretations" (Webler, 1995, p. 38).

Equal access to knowledge and interpretations includes academic research relating to environmental issues that the public is attempting to solve. The argument that people must have access to knowledge and interpretations is one of the premises upon which the study described here is built.

Webler's prerequisites for competence include two basic needs: access to information and its interpretations, and the use of best available procedures for selecting knowledge (Webler, 1995). These are necessary to construct "...the most valid understandings and agreements possible given what is reasonably knowable at the time" (Webler, 1995, p. 58). Fairness and competence are linked, in that both require equal access to information and its interpretations. To put this in Meredith's terms, for participation in a decision making forum to be both fair and competent, participants need access to relevant information and interpretations from the explained world to integrate with knowledge from the perceived world.

Public participation in decision making is not a panacea for solving environmental problems. Webler and Renn (1995, p. 28) describe five complications of participation:

i. decision making bodies can be blamed for the negative impacts of an activity whether or not the public was involved in the decision making process;
ii. if the emotion of the moment carries the decision in spite of scientific evidence or professional judgement, public participation could result in a damaging outcome;
iii. early public involvement may cause inefficiencies as citizens concerned with impacts could downplay cost considerations;
iv. consensus could be difficult to achieve; and
v. public involvement may expand the scope of the debate if participants push to achieve broader objectives.

Evident in these complications is the difficulty in deciding when a decision making process requires public input. While this is a difficult issue to resolve, it does not justify ignoring the need for public participation because it is not appropriate in every situation. Environmental decisions that have an impact on various parties require the involvement of those parties to be acceptable to the public (Renn et al, 1995). The complications of choosing how to best provide for public input in the process do not diminish the need for input.

1.3 Role of Spatial Information in Environmental Decisions

Environmental decisions typically use spatial information — these decisions are in fact often spatial in nature as they answer questions of land resource allocation. Spatial information, which includes spatial data and the interpretations drawn from the data, must be accessible to the public. Only when accessible can spatial information contribute to fairness and competence in environmental decision making. Determining how to make spatial information and the tools for its analysis available to the public is necessary if the goals of fairness and competence in environmental decision making are to be met.

Numerous barriers can block public access to spatial information relevant for environmental decisions. Meredith describes seven categories of barriers to accessing information:

i. lack of awareness of information sources;
ii. legal barriers to data access;
iii. financial barriers to data access;
iv. technical limits on data management;
v. lack of paradigms for data interpretation;
vi. lack of means of managing non-conventional data and information;
vii. barriers in data presentation.

(Meredith, 1997b, p. 135; see also Meredith, 1998).

As spatial information is a subset of general information, these types of barriers are equally applicable when spatial information is needed in a decision making process.

Sources of spatial data are numerous, but a lack of awareness of these sources is a definite barrier to data access for public participation. Due to the specialized nature of spatial data, awareness of sources for this type of information are lower than that of less specialized forms of information (Goodchild, 1998). As a simple example, public libraries are well-known and easily accessible sources of general information almost anywhere in developed countries, while map libraries and collections are typically found in university libraries and government offices, sources that are less known to the public.

Legal barriers to accessing spatial information include the restrictions to access placed on data and information because of issues related to copyright, intellectual property rights, confidentiality and privacy (Onsrud and Rushton, 1995). Data collected by private organizations are not only little known by the public, but often inaccessible because releasing the information would result in the loss of a competitive advantage for the company that had collected the data. Legal barriers overlap considerably with financial barriers to accessing data (Meredith, 1997b). One of the competitive advantages that could be lost if a proprietary database were to become public arises from a competitor's ability to obtain the data at little or no cost, despite the often high investment required to build the database. Spatial databases cost more to develop due to the fact that they are more complex than typical non-spatial databases (Adam and Gangopadhyay, 1997).

The larger and more complex the spatial phenomenon, or the higher the spatial resolution of the data, the more expensive the data acquisition. Base topographic data for GIS studies can be expensive, for example Britain's Ordnance Survey charges over £365,000 for base mapping digital data of Britain (Skyes, 1994). In contrast, much of the United State's digital base mapping data are available at no charge via the Internet. Canada's National Topographic System (NTS) sells digital versions of its topographic maps not at a fixed price per map sheet, but at a rate per kilometre of linear features and by number of point objects contained in the map sheet. These increasing cost-detail and cost-extent relationships hold true for the 'infrastructure' necessary to store, manage and analyze spatial data, especially if this is done with digital data. Hardware and software that deal with large, complex spatial data sets can be prohibitively expensive (Goodchild, 1998).

The complexity of spatial data not only increases costs, but also imposes technical limits on data management. Spatial data are more complex than most types of data and their analysis is more complex (Adam and Gangopadhyay, 1997). Increases in computing power through better hardware and the improvement of Geographic Information Systems (GIS) software have made the analysis of digital spatial data easier to accomplish (Goodchild, 1998). The use of GIS has not developed to the point where data are transferred between systems without problems. It has been estimated by industry experts that between 60 and 85% of the cost in a GIS project can be attributed to data conversion (Clément, et al., 1996), including the assembly of data from multiple sources, converting data to a digital format, translating existing digital data to a common format, and putting all of the data into the same projection.

Once the data are in the GIS, there is a need to decide how to analyze it so that the question at hand can be answered. With the relatively recent development of GIS, analysis methodologies are not fully established. New methods must be developed to solve complex environmental problems using both spatial and non-spatial data (Rindfuss and Stern, 1998).

Most commercial GIS software packages have been developed as a product for government bodies or private companies. As a result, these packages are not well-suited to handling non-conventional data and information. Much of the data and information that comes from communities is in non-conventional format and much of this is important to environmental decisions (Meredith, 1997b). The inability of GIS software to deal with this important information can act as a barrier to fairness.

Spatial information is presented most often in the form of a map. The ability to produce a map of professional quality requires training and resources beyond that necessary for data that are best represented as a table or graph (Monmonier, 1991). Maps can be misused or used as propaganda, rather than as an objective presentation of information (Muehrcke, 1986; Monmonier, 1991). Barriers to producing maps by local communities result in the spatial arguments of communities being absent from decision making processes. Proponents of projects, or even government officials can take advantage of the ability to produce deceptive maps. For truly fair and competent participation in environmental decision making, communities must be able to produce (or have produced for them) maps that answer questions about their environment and display community knowledge.

All of the barriers described above were encountered in this study. The problems experienced here (and the methods used to overcome them) are discussed in the final chapter.

1.4 Role of Technology in Accessing Spatial Data

Many discussions of both the potential benefits and dangers arising from improvements in information technology have stemmed from the onset of technical change. The policy implications of technological change and its role in the exchange of information for decision making have been noted and discussed since the onset of the information revolution (see, for example, Ward, 1966). The common theme that arises from these discussions is that technological innovations have both provided benefits to society and been used as instruments of domination (Miller, 1996). Whether societal benefits outweigh the negative impacts of technological change is widely debated and is a question that will remain as information technology develops.

Advances in information technology that can act as a means of information dissemination have been described as a way of allowing access to traditionally marginalized groups (Pickles, 1995b). However, as Pickles notes, this view is not unproblematic:

> "But, like all highways, the information highway requires points of access, capital investment, navigation skills, and spatial and cultural proximity for effective use. Like the automobile highway, the information highway fosters new rounds of creative destruction and differentiates among users and between users and nonusers" (Pickles, 1995a, p ix).

The issues surrounding access to the information highway (the Internet) are important to consider in the context of the dissemination of information for environmental decision making as many organizations are turning to this technology as their primary tool for distributing information. The Center for International Earth Science Information Network (CIESIN) acts to provide socioeconomic data related to the causes and impacts of global change (Miller, 1996). Combining its efforts with other institutions, CIESIN provides information to researchers and the public through information sharing technologies — mainly the Internet (Coullahan, 1996; Miller, 1996). Other organizations use the Internet as their primary method of describing and disseminating (or selling) spatial data and information, such as the United States Geological Survey's Earth Resources Observations Systems (EROS) data center, the Canadian Centre for Remote Sensing (CCRS), and the United Nations Environment Programme Global Resource Information Database (UNEP/GRID). Despite the problems noted above, the Internet is a valuable tool for the dissemination of information. Ensuring that community organizations working towards sustainability have access to the Internet is perhaps one of the best ways to improve local access to spatial data and information, though access does not ensure the ability to effectively analyze the data made available.

1.5 Role of Geographic Information Systems in Data Analysis

GIS can be simply defined as "...computer tools for manipulating maps, digital images and tables of geocoded (geographically located) data items..." (Bonham-Carter, 1994, p. 1). Software and hardware elements vary, but all GIS have the ability to store, manage, query and output spatial data. Many different analysis capabilities are included in different GIS software packages. These capabilities allow for the transformation of spatial data into information through its analysis. GIS are used as a tool in many different contexts: resource management, facilities and infrastructure management, siting decisions, archaeological studies, medical geography, and commercial marketing of goods, plus others not listed here. Clearly, GIS are used as a tool for the management and use of spatial information for problem solving.

Examining GIS from a functional viewpoint ignores the social context in which this tool operates. GIS can also be situated as:

> "...a tool to protect disciplinary power and access to funding; as a way of organizing more efficient systems of production; and as a reworking (and rewriting) of cultural codes — the creation of new visual imaginaries, new conceptions of earth, new modalities of commodity and consumer, and new visions of what constitutes market, territory and empire" (Pickles, 1995a, p. viii).

The dichotomy between GIS as a useful tool and GIS as an instrument for maintaining existing power relations in society is similar to the debate over the neutrality of science. Casting aside the tool because it can be used to reinforce negative social relations will not solve the problem. Others would only pick up the tool for use towards their own ends. Instead, users of GIS technology must recognize the social implications of their actions. Users must put their everyday use of the technology in a broader context to move beyond the particular of technical challenges (Curry, 1998). Pickles (1995a) puts forward the view that GIS should be seen as both a technique (or tool) and as a social relation. As noted in the previous section, the debate over the benefits and drawbacks of technological change is difficult to resolve:

> "Such processes of territorial colonization, globalization, and production of new scales of action contrast sharply with a technocultural ideology of enhanced autonomy and self-actualization, and severely complicates the assessment of the relationship between technological innovation and social change" (Pickles, 1995a, p. ix).

GIS is used in this study as a tool to answer questions that residents of the study region have asked about their environment. The spatial data collected and analyzed in this study are put forward as an aid to public participation in environmental decision making processes. The use of GIS here to aid in fair and competent public participation is an example of the use of GIS with the awareness of the social context. By working through this example, this study identifies limits to the better use of GIS as a tool for the transfer of spatial information to communities and discusses potential methods to overcome these limits.

1.6 Role of Environmental Non-Governmental Organizations

At the community level, Environmental Non-Governmental Organizations (ENGO's) often play an important role in raising environmental awareness and making environmental decisions by acting as advocates, through hands-on environmental management, and acting to transform government and society (Gardner, 1993). ENGO's encourage public participation in making environmental decisions and often act as representatives of the public interest in decision making processes. When undertaking to participate in environmental decision making processes, ENGO's need a solid information base (Gardner, 1993). ENGO's also act as disseminators and analysts of information, including spatial information (Tulloch, 1998). Given the important role of ENGO's as participants in environmental decisions and the difficulty in assessing how useful spatial information can be to individuals in a community, this study will concentrate on how spatial information can be accessed, analyzed and placed in a form suitable for use by ENGO's.

1.7 Objectives of the Research

This research involved exploring the issues outlined above by working in a community setting where there was a real concern about local environmental change. The study encountered problems that are specific to the case study and study region chosen. However, many of these problems are indicative of the types of problems encountered by local groups attempting to solve environmental and sustainability issues. The study undertaken was designed as an effort that could be undertaken by a local group concerned about environmental issues. While the objectives of this study are specific, it is hoped that the problems identified and the solutions attempted are useful examples for others working in these areas. The objectives of the research described in this thesis are to:

i. identify community questions about the local environment that relate to land cover change;
ii. answer these questions using satellite imagery and ancillary data of the study region;
iii. evaluate the usefulness of the product of the image analysis for answering the community questions; and
iv. produce results from the analysis that can aid in answering the community questions.

The ability of this study to achieve these objectives and the implications of the results are presented and discussed in the final chapter.

1.8 Methods

The research methods involved three steps. Community questions relevant to land cover change were identified from a local newspaper. Sources of spatial information were identified, and the data acquired were used to detect land cover change in the study region. The results of the change detection were queried to identify and quantify trends in land cover change that could answer community questions identified in the local newspaper. These three methods are described in detail in the following chapters.

Chapter 2: The Study Region and Issue Selection

2.1 Study Region

A portion of the Windermere Valley in southeastern British Columbia was chosen as the study region (see Figure 1.1). This area was chosen for several reasons. There was a demonstrated public concern over environmental issues related to land cover change. Several community groups were active in the region, including the East Kootenay Environmental Society, the Jumbo Creek Conservation Society, Bighorn in our Backyard, and a coalition to preserve public lands. Finally, during the process of choosing a study region, sources of spatial data were identified that were useful for a study such as the one described here.

2.1.1 Biophysical Characteristics

Within the Rocky Mountain Trench lies the scenic Windermere Valley, a portion of which comprises the study region (Figure 1.1). The study region is bordered to the west by the Purcell Mountains (part of the Columbia Mountains) and to the east by the Kootenay Ranges of the Rocky Mountains. The Columbia River flows from southeast to northwest through the study region. Elevations within the study region range from 785 to 2512 m.

The study region is influenced by a continental climate with warm, dry summers and cool winters (Weestra, 1995). The north-south orientation of the mountain chains creates a rainshadow, removing moisture from the air masses that move over the region from the Pacific Ocean and giving the region a dry climate (Weestra, 1995). With an annual average precipitation at Invermere of 302 mm, moisture deficits occur periodically throughout the year (Kelly and Holland, 1961). Typically, more precipitation falls as snow than rain; March and April are the driest months in the Valley (McLean and Holland, 1958).

The study region is comprised of four biogeoclimatic zones: the Interior Douglas-fir zone (IDF), the Montane Spruce zone (MS), the Engelmann Spruce-subalpine Fir (ESSF) zone, and the Alpine Tundra zone (AT) (Pojar and Meidinger, 1991). The valley bottom is comprised of the Columbia Wetlands, part of the longest continuous body of wetlands in North America (Wings Over the Rockies, 1997). A generalized cross-section of the valley in the study region progresses from wetlands at the lowest elevations, followed by the IDF zone at middle elevations, the ESSF zone at upper elevations, and the AT zone at the highest elevations.

Within the study region wetlands occur in the valley bottom but not exclusively so, as they also occur in upland areas that have poor drainage. Wetlands can include shallow open waters, marsh, fen, swamp and bog types (National Wetlands Working Group, 1988). The vegetation present in the wetlands is variable, including submerged and floating aquatic macrophytes, emergent vegetation, grasses, shrubs, mosses, trees and sphagnum (Pojar, 1991). The extensive wetlands in the Columbia Valley are important habitat for many different species of migratory birds.

The IDF zone dominates the low to middle elevations in the south-central interior of B.C., typically occurring at elevations ranging from 600 to 900 m but it can occur as high as 1450 m (Hope et al., 1991a). Open to closed stands of Douglas-fir are common, often mixed with Ponderosa pine on drier sites and hybrid white spruce on sites which have more moisture (Hope et al., 1991a). Grassland communities, typically dominated by bluebunch wheatgrass, occur in the study region. The distribution of these grasslands is controlled by the fire history, edaphic and topographic conditions, and the grazing of domestic livestock (Hope et al., 1991a). The IDF zone provides important winter habitat for ungulates (Parish et al., 1996).

The MS zone occurs above the IDF zone in the study region at elevations of 1250 to 1700 m (Hope et al., 1991b). The MS zone is classed as transitional between the lower IDF zone and the higher ESSF zone with some vegetation in common with both zones, including Douglas-fir, spruce, and subalpine fir (Hope et al., 1991b). In wet areas in the MS zone a mixture of lodgepole pine, hybrid white spruce and subalpine fir are found, while drier areas may have Douglas-fir present. Areas that have been exposed to fire typically have lodgepole pine present (Hope et al., 1991b). The MS zone provides habitat for many ungulates during the spring, summer and fall; all ungulates except caribou (which are not present in the study region) and occasionally moose migrate to lower elevations during the winter to avoid deep snow (Hope et al., 1991b).

Ranging from 1500 to 2300 m in elevation (Coupé et al., 1991), the ESSF zone is the highest forested zone in the study region. The ESSF zone varies from continuous forest cover at lower and middle elevations, typically Englemann spruce and subalpine fir, to mixed clumps of trees with areas of heath, meadow and grassland at higher elevations (Coupé et al., 1991). Lodgepole pine is common as a seral species after fire and snow avalanche tracks are common in mountainous areas (Coupé et al., 1991). The

ESSF zone is productive for grizzly bears, and often contains ungulates during the spring, summer and fall (Coupé et al., 1991).

Occurring in only the highest parts of the study region (above 2250 m elevation), much of the AT zone is "...the domain of rock, ice, and snow" (Pojar and Stewart, 1991, p. 264). Some trees are present in stunted (Krumholz) form, including subalpine fir, Engelmann spruce, white spruce, mountain hemlock, and whitebark pine (Pojar and Stewart, 1991). Dwarf scrub woody plants are common vegetation in the AT zone, with alpine grass vegetation being dominant in dry areas (Pojar and Stewart, 1991). The habitat value of the AT zone is generally poor, though Rocky Mountain Bighorn Sheep utilize this zone, and other ungulates and grizzly bears can be found in the lower-elevation meadows during the summer and fall (Pojar and Stewart, 1991).

2.1.2 Socioeconomic Characteristics

Settlements in the study region include Invermere on the northwest shore of Lake Windermere (est. 1996 population: 2,687), the Village of Radium Hot Springs just outside of the southwestern gate to Kootenay National Park (est. 1996 population: 530), the community of Edgewater at the northern edge of the study region, and the community of Wilmer to the north of Invermere (population estimates from BC Stats, 1998). The communities of Edgewater and Wilmer are not incorporated, and thus no population estimates are available for these communities.

The Regional District of East Kootenay, which encompasses the study region, stretches from the border with the United States in the south and the British Columbia-Alberta border in the east to the McNaughton reservoir in the north, extending west to the Purcell Mountains (the dividing line between the East and West Kootenays). The most important economic activities in the Regional District of East Kootenay are mining, forestry, and tourism (BC Stats, 1996a). Agriculture, primarily ranching, is also an important activity in the Regional District of East Kootenay (CORE, 1994). Efforts to develop an irrigation scheme and fruit growing industry to attract settlers to Invermere in the early 1900's were unsuccessful (Meredith, 1988). Within the study region, mining is less important than for the whole of the Regional District. Forestry is an important and long standing industry for all of British Columbia; the only major industrial employers in Radium Hot Springs are the Radium Forest Products saw mill and Kirk Forest Products.

Part of a region recognized for its natural beauty and wildlife resources, the study region contains a portion of Kootenay National Park, all of the Columbia National Wildlife Area and Dry Gulch Provincial Park (a provincial class 'A' park). Other protected areas near the study region include the Height of the Rockies, the Bugaboos and the Purcell Wilderness Conservancy (see Figure 1.1). The many parks of the study region and the scenic beauty of the area are strong tourist attractions — established in 1920, Kootenay National Park now draws over 1 million visitors a year (Parks Canada, 1998). The study region contains hotels, campgrounds, and summer homes along with golf and equestrian activities. The retirement sector has also grown due to high population growth in Vancouver, Calgary, Lethbridge and Edmonton (CORE, 1994). In terms of employment, the tourism related accommodation and food and beverage services industries are the most important in both Invermere and Radium Hot Springs (BC Stats 1996b).

2.2 Newspaper Analysis

Issues in the study region were identified through the local weekly newspaper (The Windermere Valley Echo) and contacts with ENGO's working on environmental issues in the region. The Windermere Valley Echo serves all of the communities inside the study region, as well as several outside of it. The Echo was sampled at a five year interval starting in 1974 and continuing until 1991 (1974, 1979, 1984, 1989 and 1991 were the years sampled). The start and end dates were chosen to match the dates of the images used in the change detection (the change detection methodology is described in the next chapter). Many expressions of concern arose in response to particular events that are well chronicled in the newspaper, such as development proposals. Items from the weekly newspaper that described environmental issues of concern to local residents were read and summarized in a database. Particular attention was paid to letters to the editor, as these described residents' and organizations' concerns over local environmental issues. The databases from the sampling of the newspaper along with unstructured interviews with the members of community organizations form the basis of the description of environmental issues that follows.

2.3 Environmental Issues in the Study Region

Evidence of land use conflicts in the study region are evident in the newspaper record. In 1974, the provincial departments of lands, forests, water resources, recreation and conservation, mines and petroleum resources, industrial development, trade and commerce, agriculture and highways, and the hydro authority developed a draft integrated resource management study for the Purcells (Anon., 1974). When the report was released, the province created the position of a resource manager for the Kootenays and a new park in the Purcells (Anon., 1974b). In 1979, a proposed ski resort development to the southwest of the study region along with a boom in residential development sparked a new debate about the impact of resort and subdivision developments, leading to a ban on all development in unzoned lands until a planning study could be completed. The settlement plan that resulted from this effort was still in effect in 1984, in spite of 'stalled' growth (Ede, 1984). Issue specific plans were developed in 1989: a study of snow recreation opportunities in southeastern British Columbia was undertaken so as to avoid conflicts (Anon., 1989a), changes to forest tree farm licences and forestry practices were debated (Anon., 1989b), and the Director of planning for the Regional District announced that the east side of Lake Windermere required a plan for orderly development (Anon., 1989c).

In 1989, it was noted that there had been 9 different provincial inquiries into land use in the region over the period of "... the last 20 years" (Demarchi, as quoted in Jefferson, 1989, p. 2). In 1991 British Columbia proceeded with consultations for its proposed parks plan in the region. Response to the plan, combined with concerns related to a shortage of lots in Invermere due to a boom in construction, prompted the Regional District to request funds from the province to develop a comprehensive land use strategy for the Kootenay-Boundary Region (Anon., 1991). This request led in part to the Consultation on Resources and the Environment undertaken by the British Columbia government starting in 1994. As the above planning efforts indicate, the study region is part of a larger region that has an established history of land use conflict that continues beyond the time frame of this study.

Many of the issues identified in the newspapers centered on conflicting values over different land uses among groups and individuals in the region. Although conflicting land uses can be associated with land cover in the study region, the debate over differing values cannot be resolved through additional information on land cover. The issues focused on in the remainder of this section are the factual debates related to land cover — questions that this study can aid in answering.

Several issues that are related to land cover change but that cannot be directly measured with satellite images were also identified, including the degradation of water quality from poor sewage systems and the loss of access to recreational resources due to the privatization of land. There were articles in every year sampled that dealt with concerns of water quality, often related to the plans to treat sewage from new housing or resort developments. These concerns were expressed by such varying stakeholders as local residents, landowners adjacent to proposed development sites, Invermere Town Council, the board of the Regional District of East Kootenay, and the East Kootenay Environmental Society. Concerns over access to recreational resources focused on two types of access: beach access around Lake Windermere and access to back country areas for hunting, prospecting, hiking and other 'wilderness' activities.

In all 5 years in which the newspapers were sampled, articles and editorials which expressed a need for more comprehensive land use planning and integrated decision making within the study region were identified. Specific issues of concern that are related to land cover change that appeared in all 5 years were: forestry practices, forest ingrowth on grazing lands, the loss of prime agricultural land and concerns about the impacts of increased housing. Later years in the sample of newspapers included articles and editorials on the issues of wetland drainage and the proliferation of golf courses. Providing a record of environmental change can aid in resolving the factual debate over issues of how much change has occurred. This is a good way to set the context for the ongoing debates over land use planning, a debate that often takes place with the aid of maps that portray only the present pattern of land use and cover. Each of these issues is discussed below.

2.3.1 Forestry Practices

Most concerns about forest practices that were expressed related to the impacts of forestry activities and the rate of deforestation. One article describes a study undertaken to assess logging on the slopes of the Kootenays to answer the questions:

> "Where had the old methods gone wrong, how badly had the forest lands been degraded, what had happened to these lands since logging, was regeneration satisfactory and what was the effect of slash burning on site recovery?" (Anon., 1979, p. 12).

The public concerns over forestry led to the involvement of a public advisory council to aid in setting the sustained yield that would be extracted from the forest. Another recurring concern was the impact of loss of habitat for wildlife due to forestry, especially species important to hunters.

2.3.2 Forest Ingrowth

Ranchers, wildlife biologists and hunters identified the loss of important grazing habitat for both cattle and wildlife as a concern. The fact that the grasslands of the valley bottom and slopes in the study region are important habitat for wildlife and prime ranching areas led to numerous conflicts between ranchers and the wildlife that competed with cattle for forage. The newspaper recorded efforts to supplement the diet of wildlife through feeding animals in the winter, as well as attempts to improve winter habitat through prescribed burns and efforts to clear brush. In 1991, an area hunter was reported to be feeding approximately 80 elk on a daily basis on his land in an effort to keep the stock healthy (Maloney, 1991).

2.3.3 Urban Expansion

Population growth in the study region, mostly through seasonal and permanent immigration, led to land speculation in the study region. The subdivision and sale of land plots for residential development caused many residents to ask if the people moving to the valley would ruin the features that initially attracted them to the area. Concerns over impacts on water quality (due to inadequate sewage treatment), the restriction of public access to formerly open lands, and the impact on wildlife that is dependant on the areas being settled were the primary concerns expressed in the newspaper record.

2.3.4 Recreational Expansion (Golf Courses)

The construction of resort type golf courses relates to urban expansion as described above, as these courses typically have adjacent residential developments that contribute to urban expansion. In addition to these concerns, residents expressed concerns that golf courses were permanently removing agricultural land from use. Since 1988, golf courses had been permitted on agricultural land as a 'compatible use' (Bond, 1991), in part because it was possible that the land could revert to agriculture in the future. Given the high costs of development, residents expressed the opinion that this was highly unlikely. In 1991, the newly elected New Democratic government revoked the provincial Order In Council that allowed golf courses to be developed on Agricultural Land Reserve (ALR) property and placed a freeze on golf course development (Cobb, 1991). At the time, there were 17 golf courses proposed for the East Kootenays, at least 7 of which were on ALR land (Bond, 1991). The impacts of the use of pesticides, fertilizers and irrigation associated with golf courses were also of concern to some residents.

2.3.5 Loss of Agricultural Land

Related to the issues of golf course development and urban expansion described above, the loss of agricultural land was viewed as potentially dangerous to the maintenance of agriculture as a viable activity in the long term. As residential and resort development outside of urban centres encroached on agricultural lands, this traditional activity was perceived as threatened by these competing uses which garnered a higher price for the land. The ALR was designed to solve this problem after a development freeze on all agricultural land in 1972 (Anon., 1974c). The effectiveness of the ALR in protecting agriculture was questioned in 1979, when it was noted that subdivision of lands into smaller parcels was still permitted and that it could be later argued that these smaller parcels were too small to be viable for agriculture, thus providing a loophole in the ALR. As noted in the preceding section, golf courses were permitted developments on ALR land from 1988 to 1991.

2.3.6 Wetland Loss

Despite the designation of the Columbia National Wetlands, Thompson (1991) expressed concerns that many residents did not appreciate the importance of the wetlands as habitat for many bird species and an important draw for tourism. Many letters and articles were also written about residents' strong opposition to the proposal to divert the Kootenay River into the Columbia River at Columbia lake to increase the flow for hydroelectric generation downstream. The proposal was debated throughout the interval that the newspapers were sampled and was eventually placed 'on the back burner', but it has never been completely removed from BC Hydro's list of projects (Reed, 1989). The lack of a policy for industrial and suburban developments that required the draining of wetlands or the filling in of waterways was also a concern expressed by residents.

Chapter 3: Image Analysis Methodology

3.1 Land Cover Change Detection

Following from the identification of the need for information on environmental change in the study region, land cover change analysis was chosen as a test to determine what useful spatial information could be produced. The ability to complete the analysis performed here was in part dictated by the availability of the satellite images (the data used are described in the following section). The availability of the satellite images and ancillary data allowed only certain avenues of analysis to be explored. This is analogous to real world problem solving — efforts are often limited by time constraints and data availability.

Change detection using remotely sensed imagery has been identified as useful in managing natural resources and adding to the understanding of environmental change (Avery and Berlin, 1992). Many different approaches to change detection have been used, including image arithmetic (band differencing), the comparison of Normalized Differentiated Vegetation Indexes (NDVI), the on screen digitizing of change polygons, multiple date Principle Component Analysis (PCA), and post-classification comparison (Jensen et al, 1997). Post-classification comparison was the chosen method for this study because the differences in spectral and spatial resolutions between the two satellite images used make the use of other methods problematic. The process of classifying the satellite images for use in the change detection analysis is shown in Figure 3.1. The steps are shown in Figure 3.1 and described in detail in later sections of this chapter.

The two images (from 1974 and 1991) were classified into eight land cover categories: open forest, closed forest, grassland, wetland, water, irrigated land, rock/soil, and urban. These eight categories were chosen as they related well to the land cover in the region and to problems of environmental change identified in the review of the Windermere Valley Echo. Once classified into these categories, the two images were compared in an effort to quantify change in land cover so that questions of environmental change could be answered.

3.2 Data

Multiple sources and types of data were identified and acquired for the study region. Two satellite images were the primary source of information for the change detection analysis. Satellite images require much preprocessing before a classification algorithm can be meaningfully applied or a useful product can be obtained. The satellite images, other ancillary data used, and preprocessing of the data are described below.

3.2.1 Satellite Images

Satellite sensor distortion can cause errors in the images including band-to-band offsets (where different image bands do not align), and line length errors (due to dropped pixel values) (Ehlers, 1997). The earth's rotation during the acquisition of imagery results in image skew — where the rectangular satellite image actually corresponds to a rhomboidal area of the earth's surface (Drury, 1990). These errors have been corrected for by the preprocessing described below.

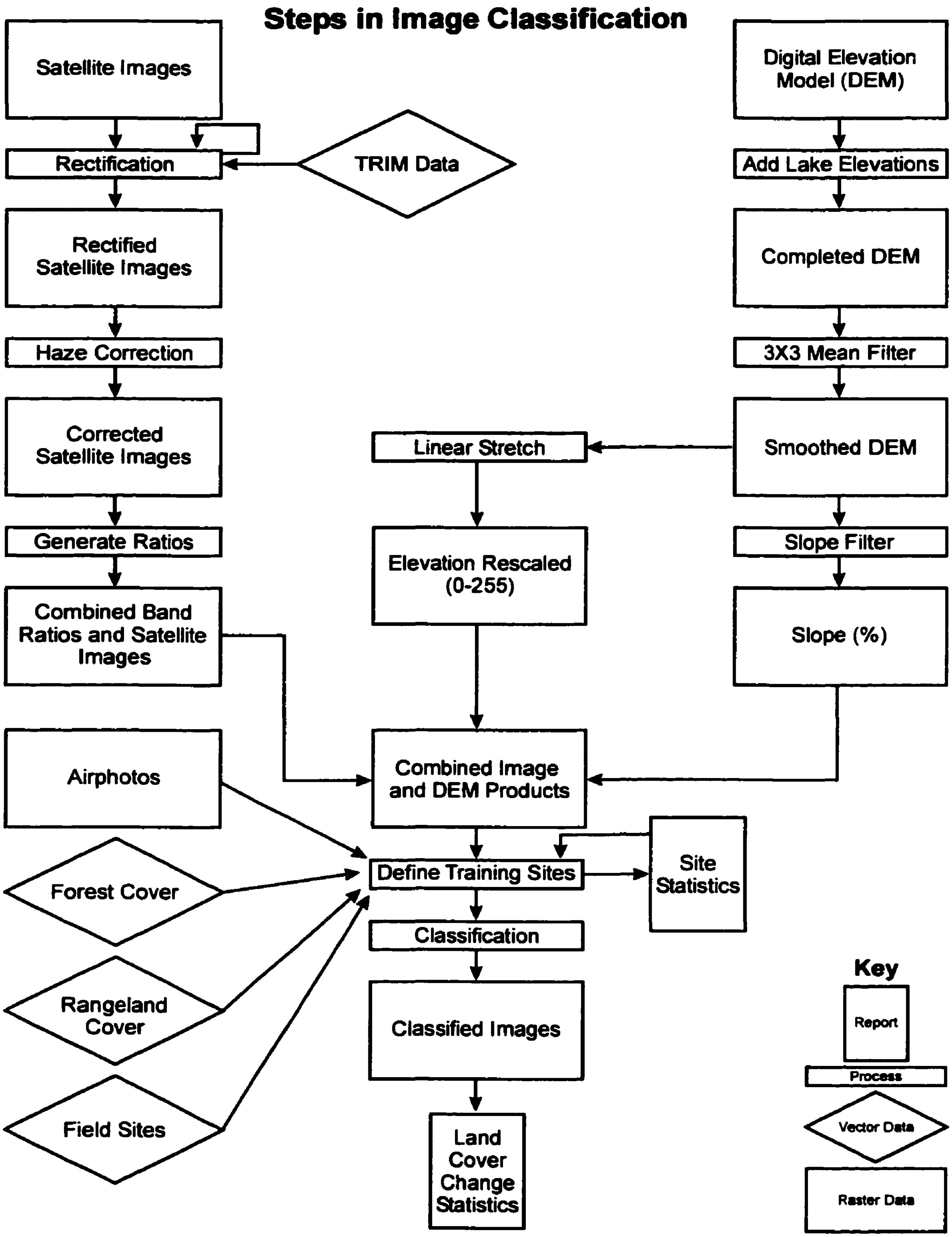

Figure 3.1 Generalized steps taken in the classification of both the 1974 and 1991 images. Loops represent iterative processes.

Two Landsat satellite subscenes were provided by Kootenay National Park to complete the land cover change assessment. The first is a Landsat 1 Multi-Spectral Scanner (MSS) image recorded on the morning of August 3, 1974 (Figure 3.2). The band and spectral ranges of Landsat 1 are given in Table 3.1. Although the MSS sensor of the Landsat 1 satellite collected data at a ground resolution of 79 X 79 metres (Avery and Berlin, 1992), the subscene acquired was previously resampled to a ground resolution of 50 X 50 metres. The morning overflight (sun elevation of 51°, azimuth of 139°) produced topographic shadows in the study region, which can be seen in Figure 3.2. Before acquisition by Kootenay National Park, the image was corrected to the *precision* level, which includes radiometric and geometric correction using the satellite model and platform/ephemeris information (NASA, 1998). *Precision* correction also includes rotating and aligning the image to the Universal Transverse Mercator (UTM) projection using ground control points to improve the satellite model (NASA, 1998).

Table 3.1 Band names and spectral ranges of the MSS sensor from Landsat 1 and the TM sensor from Landsat 5 (source: Avery and Berlin, 1992, pp. 137;141). A * denotes bands not included with the TM image as provided.

Band Number	Name	Wavelength (m)	Satellite
MSS Band 4	Green	0.5-0.6	Landsat 1
MSS Band 5	Red	0.6-0.7	Landsat 1
MSS Band 6	Near Infrared	0.7-0.8	Landsat 1
MSS Band 7	Near Infrared	0.8-1.1	Landsat 1
TM Band 1*	Blue-green	0.42-0.52	Landsat 5
TM Band 2	Green	0.52-0.60	Landsat 5
TM Band 3	Red	0.63-0.69	Landsat 5
TM Band 4	Near Infrared	0.76-0.90	Landsat 5
TM Band 5*	Mid Infrared	1.55-1.75	Landsat 5
TM Band 6*	Thermal Infrared	10.40-12.50	Landsat 5
TM Band 7*	Mid Infrared	2.08-2.35	Landsat 5

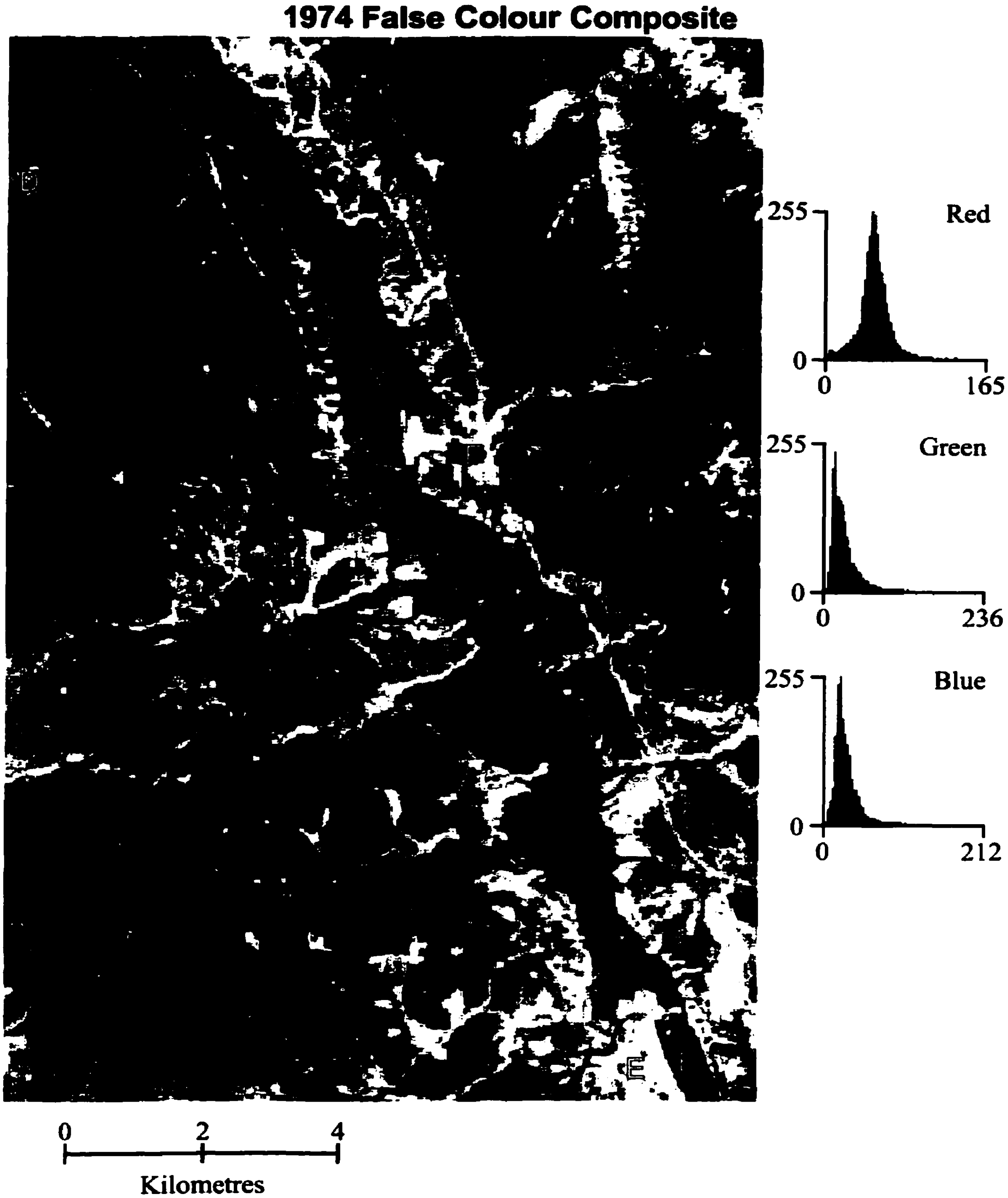

Figure 3.2 False colour composite and band histograms of the 1974 MSS image. In this composite, shown here in greyscale, band 7 is red, band 5 is green and band 4 is blue. A=topographic shadow, B=Lake Windermere, C=golf course, D=clearcut forest, E=Invermere, F=Radium Hot Springs. Histograms show dequantized digital numbers. The outlines of Kootenay National Park and Dry Gulch Provincial Park are shown in grey.

The second image is a Landsat 5 Thematic Mapper (TM) image recorded on the morning of September 4, 1991 (Figure 3.3). The band and spectral ranges of Landsat 5 are given in Table 3.1. Although the TM sensor of the Landsat 5 satellite collected data at a ground resolution of 30 X 30 metres (Avery and Berlin, 1992), the subscene acquired was previously resampled to a ground resolution of 25 X 25 metres. Presumably the two images (MSS and TM) were ordered at these resolutions by Kootenay National Park so that comparison would be facilitated. Similar to the MSS data, the morning overflight of Landsat 5 (sun elevation of 42°, azimuth of 146°) produced topographic shadows in the study region which can be seen in Figure 3.3. Before acquisition by Kootenay National Park, the image was corrected to the *systematic* level, which includes radiometric and geometric corrections using the satellite model and platform/ephemeris information (NASA, 1998). *Systematic* correction also includes rotating and aligning the image to the UTM projection (NASA, 1998). Unlike *precision* correction, ground control points are not used in *systematic* correction to improve the satellite model.

3.2.2 Topographic Data

British Columbia's Terrain Resource Information Management program (TRIM) produces 1:20,000 scale map sheets in digital form which include digital elevation data, natural features, human features and toponymy data (Geographic Data BC, 1998a). Kootenay National Park provided two adjacent sheets (numbers 082K060 and 082K070) in digital format. The area covered by these two sheets was chosen as the study region for the image analysis. The availability of these two map sheets in digital format allowed a more comprehensive analysis of the satellite images and their boundaries were thus

1991 False Colour Composite

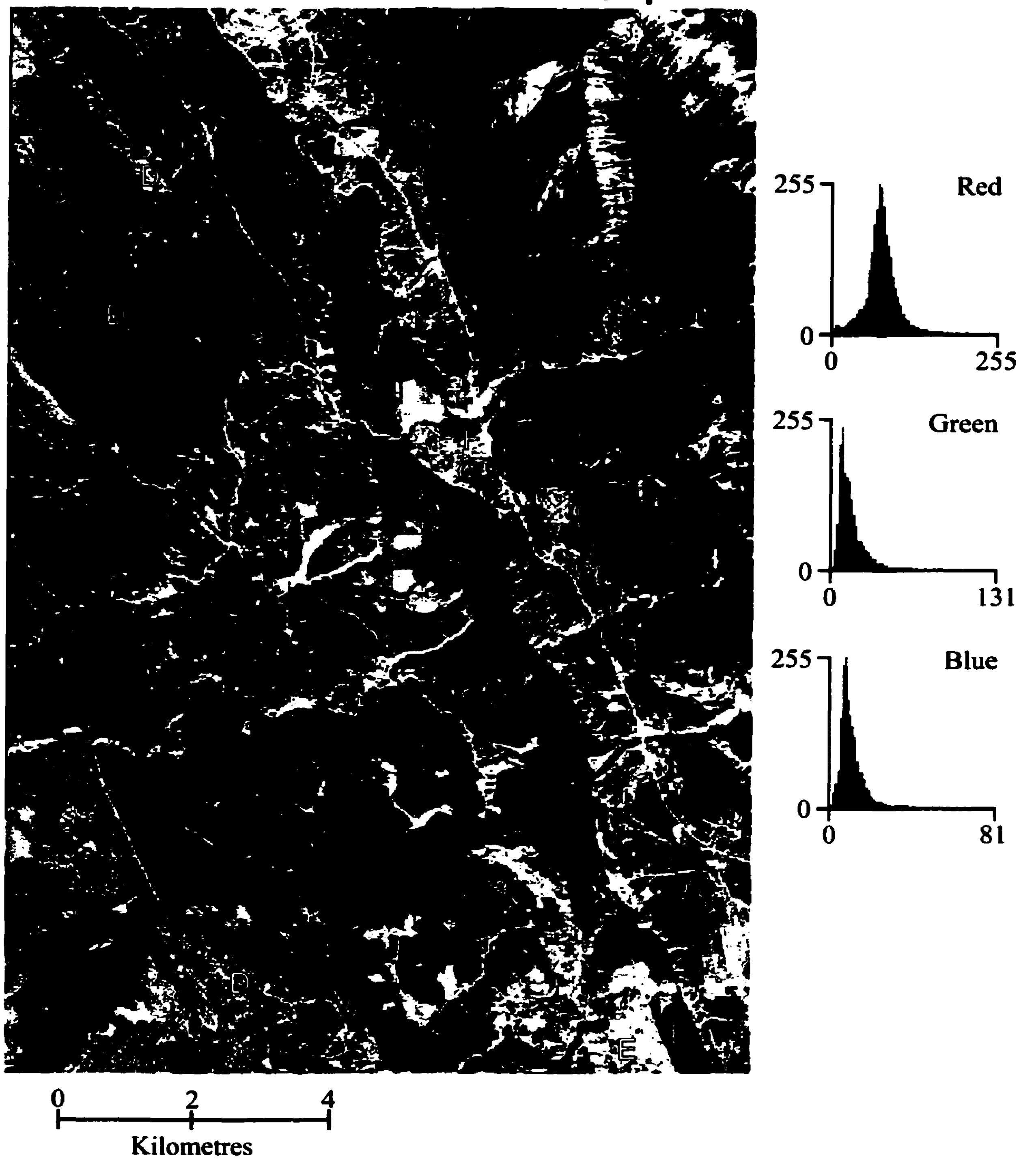

Figure 3.3 False colour composite and band histograms of the 1991 TM image. In this composite, shown here in grey, band 4 is red, band 3 is green and band 2 is blue. A=topographic shadow, B=Lake Windermere, C=golf course, D=clearcut forest, E=Invermere, F=Radium Hot Springs. Histograms show dequantized digital numbers. The outlines of Kootenay National Park and Dry Gulch Provincial Park are shown in grey.

chosen as the limits of the area selected for the image analysis. The details of the analysis are described in the methodology section below.

The TRIM digital map sheets include a Digital Elevation Model (DEM) at a horizontal resolution of 25 X 25 metres (Figure 3.4). The data for this grid were derived from stereo airphotos and GPS data. The data points have an error range of plus or minus 10 metres in horizontal location and are within 5 metres of the vertical 90% of the time (Geographic Data BC, 1998b). Elevation data for lakes were not included with the DEM as provided. To prevent the no-data (lake) areas from being enlarged during the application of filters to the DEM, the lowest elevations of the lakeshores were determined and used to flood-fill the no data areas that corresponded to lakes. This provided an approximation of the elevation of the lake surface. Preprocessing of the DEM before its use in analysis included the estimation of lake surface elevations described above and the application of a mean filter using a 3 X 3 matrix to smooth the DEM and remove artifacts in the data.

3.2.3 Forest Cover

The Invermere District office of the British Columbia Ministry of supplied the forest cover data Forests in digital and paper format. Based on interpretation from a photogrammetric base and surveys, the maps delineate polygons of forest cover and other land cover types at a scale of 1:20,000. The information stored with these forest cover polygons includes species composition, stand age, height index, density and historic disturbances (Resource Inventory Branch, 1998). British Columbia's forest cover map series take their digital base maps from TRIM data. Two map sheets (082K060 and 082K070) were obtained in digital and paper formats to match the study region. The

Digital Elevation Model

Figure 3.4 Shaded Digital Elevation Model of the study region. The DEM is illuminated from the northeast and has been smoothed with a 3 X 3 mean filter. A=Steamboat Mountains, B=Mount Bruce, C=Mount Berland (Brisco Range), D=Redstreak Mountain (Stanford Range), E=McKay Creek, F=benches. The outlines of Kootenay National Park and Dry Gulch Provincial Park are shown in grey.

forest cover maps do not provide coverage of federal land. Forest cover disturbances on the sheets used have been updated until 1995.

The difference in dates between the satellite images and the forest cover maps meant that care had to be taken when selected training regions from the forest cover data. Historic dates of disturbance (cuts, burns, pest infestations, etc.) included with the sheets were useful in ensuring that the training regions selected had not changed significantly since 1991. The data on forest disturbances did not extend back to the time of the first satellite image (1974). However, data from the forest cover maps on the estimated age of forest stands were useful in inferring forest cover when choosing training regions for the 1974 image.

3.2.4 Rangeland Cover

The Invermere District office of the British Columbia Ministry of Forests supplied the rangeland cover data in digital and paper format. Interpreted from aerial photographs and field visits, the maps delineate polygons of rangeland cover types and other land cover types at scales ranging from 1:20,000 to 1:30,000. Unlike the forest cover data, the rangeland maps are only produced for range management units and they do not provide coverage of private land. For the study region, maps and reports of four rangeland units were obtained: the Toby-Horsethief Range Unit (Weerstra, 1995); the Steamboat Range Unit (Smyth and Poriz, 1996); the Forster-Horsetheif Range Unit (Ellis, 1996a); and the Frances Creek Range Unit (Ellis, 1996b).

These four units do not provide complete coverage of the study region, but they do cover all of the important publicly owned rangeland areas on the west bank of the Columbia River (Smith, pers. comm.). Roads, rivers and other topographic features in the rangeland cover maps are taken from the TRIM database and the two are referenced to the same base (Smith, pers. comm.). With the exception of the Toby-Horsethief Range Unit, the rangeland cover maps are based on field surveys from the summer of 1996 (Ellis, 1996a; Ellis, 1996b; Smyth and Poriz, 1996). The Toby-Horsethief Range Unit map is based on field surveys from the summer and fall of 1994 (Weerstra, 1995). The difference in dates between the satellite images and the rangeland cover maps meant that care had to be taken when selecting training regions from the rangeland cover data. As little site-specific historic data were included with the rangeland maps and reports, training regions were only derived for the 1991 image from these sources.

3.2.5 Field Data

Field training sites were identified during a visit to the study region from late August to early September 1997. A Global Positioning System (GPS) unit — the Eagle Explorer™ — was used to record the position of selected sites in the field. Uncorrected, the GPS unit has an estimated horizontal position error of plus or minus 100 metres, 95% of the time. This translates to a minimum mapping unit of approximately 200 metres when using the GPS data, a resolution lower than that of both the 1974 and 1991 satellite images.

The low resolution of the GPS data made it necessary to adjust the boundaries of the training regions. The boundaries were visually matched to areas that were composed of image pixels with tones, colours and textures that were similar in shape and extent to the site as observed in the field. This adjustment was simple to make for the training sites that were greater in extend than the minimum mapping unit of the GPS; greater care had to be taken in adjusting the boundaries of site polygons that were less than 200 metres in width or length.

To meet the objective of mapping representative land cover types nine field sites were mapped (Figure 3.5). These sites represented closed forest, a small clearcut for the expansion of a golf course, the irrigated fairway of a golf course, irrigated crops, wetland vegetation, open forest (predominately Douglas-fir), grasslands and portion of the urban area of Invermere. The sites visited were selected based on their ease of identification on one or both of the satellite images (including the ability to identify the site as a single class from an unsupervised classification) and the study of airphotos. All but two of the sites were delimited by walking the boundaries and recording points with the GPS unit. Characteristics of the sites and any variation in cover were recorded and marked on a sketch map of the site. Two of the field sites — the urban site (Invermere) and the closed forest site (McKay Creek Valley), see Figure 3.5, — were too large to define by walking the perimeter. Because of their size and the variable nature of their cover, these two sties were subdivided and sampled.

A systematic point sample survey was undertaken to sample the McKay Creek and Invermere sites. As the areas to be sampled were subjectively chosen, the statistical significance of the sample's representativeness of the sites cannot be determined. The systematic sample method has the potential to be aligned with, or to completely miss, any periodicity in the data being collected (Berry and Baker, 1968). The urban site has a high periodicity in its spatial distribution — much of Invermere has a gridiron street network. However, the recording of characteristics was not limited to the sampled points but included a description of all features *visible* from the points. Given that the closed forest

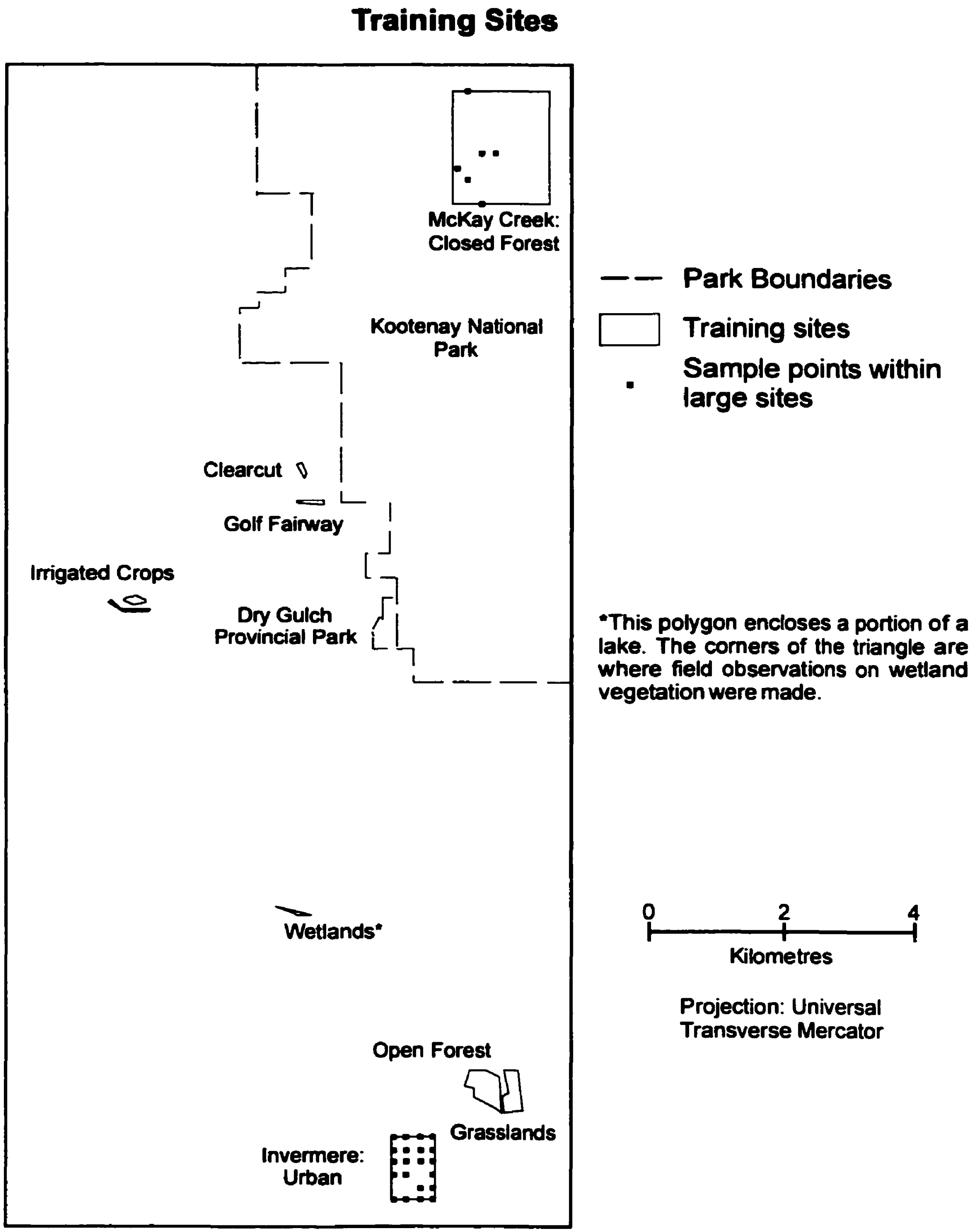

Figure 3.5 Training sites collected with the GPS unit. The area shown does not encompass the whole of the study region, only the training sites.

site is a natural feature lacking a periodic nature, the likelihood of sampling error from this source due to the choice of a systematic point sample is thought to be negligible.

A regular grid with an interval of 200 metres (the effective minimum mapping unit of the GPS unit) was placed over the areas to be sampled. The closed forest site grid was 1.4 km east-west by 1.8 km north-south and the urban site grid was 0.8 km east-west by 1.2 km north-south. The sample size chosen was 10% of the points in the grid for each site. The points of the grid were numbered in sequence and a series of randomly generated numbers were used to determine which points would be sampled. This resulted in the identification of 3 points (of 24 on the grid) for the urban site and 7 points (of 63 on the grid) for the closed forest site.

Not all of the McKay Creek sites could be visited. The GPS unit did not function well in the northern part of the sample site, presumably because of the steep, narrow sides of the valley and closed forest canopy which together degraded the signal reception. The closed forest canopy in the southern part of the sample site also made keeping a position lock with the GPS unit difficult, though it functioned better than in the northern areas. As a result, just five of the seven points could be located and described, only one of which was in the northern part of the site. These five points and the extent of the site can be seen in Figure 3.5. All of the points located, and virtually all parts of the valley that were traveled through while collecting the field data, were comprised of closed forest. At the sites visited, information on the relative proportion of major tree species, the approximate percentage of crown closure and any ground cover vegetation was recorded. The boundaries of the training region based on the closed forest site were modified to enclose only the sample points visited and their immediate surroundings.

Due to the variable nature of the characteristics of the sampled points in the urban site, more points were visited than those randomly selected to help discern the relatively built up areas from the dominantly residential areas. Identifying the relatively built up areas was important because of the difference in spectral signature between the built up areas (mostly road and buildings) and residential neighborhoods, which have a large proportion of landscaped vegetation. As a result, 21 of the 24 total points on the grid were visited. The visited sites are marked on Figure 3.5, along with the boundary of the sample grid. At each of these points information on lot size, building type, significant vegetation cover and any large features of interest — such as large open areas or a high density of buildings — was recorded.

3.2.6 Airphotos

Copies of black and white airphotos of Radium Hot Springs and the area to the southeast of the village were obtained and used to aid in the selection of training sites. The first set of three acquired was from 1973 and the second set was from 1991. The mosaic of 3 airphotos from the two dates covered approximately the same area of the study region. The airphotos from 1973 were especially useful for defining training regions, as they were the only concrete historical data on land cover close to the time the 1974 satellite image was acquired.

3.3 Image Corrections

In addition to the preprocessing described above in section 3.2.1, the satellite images were also rectified to a common projection and corrected for interference by haze. These corrections were the minimum necessary so that the images could be compared using the post-classification comparison method.

3.3.1 Rectification

The TRIM data projection (UTM Zone 11 North) was converted from NAD83 datum to NAD27 datum so that it would match the projection and datum to which the satellite image data had previously been rotated and aligned. Because the images were not corrected to a high enough level for comparison or use with the TRIM data, they were then rectified to the TRIM data using control points from identifiable features on the image. Road intersections, river bends, bridges, lake shorelines and airfield runways were among the features used.

Registration, or temporal registration (Maurer and Oberholtzer, 1979), matches the pixels of a slave image to those of a master image (Ehlers, 1997). Rectification matches remotely sensed data to an absolute coordinate systems, such as UTM (Ehlers, 1997). The satellite images were rectified to the TRIM data instead of registering one image to the other for several reasons. The difference in resolutions between the two (50 metres for the 1974 MSS data vs. 25 metres for the 1991 TM data) would require that the TM data be resampled to 50 metres before registration, which would result in a loss of information. Alternatively, the 1974 image could have been resampled to 25 metres but this would not add any new spatial detail to the data (Jensen et al., 1997) — it would only make registration possible. More importantly, the use of products derived from the DEM in the classification requires that the two images be registered to the coordinate system of the TRIM data. If registration were undertaken, the grids of the two satellite images and the DEM would have to be matched pixel to pixel.

If the DEM and the satellite images had to match on a pixel to pixel basis, the resolution of one of the satellite images and possibly of the DEM would have to be changed during the registration process. Instead, the two satellite images were rectified to the TRIM data. The choice of rectification over registration eliminated the need to resample the DEM and the need to change the resolution of one of the satellite images, which likely reduced any spatial or cell value error that can be introduced during resampling. The software used, ER Mapper®, allows for the integration of raster data sets with different resolutions and grids if the data are all rectified to the same coordinate system. This ability was used, in part, to investigate the results of comparing the two images at their original resolutions.

Precise registration is essential when comparing images (Jensen et al., 1997). The 1991 image was rectified to the vector TRIM data using 57 control points. Several iterations — selecting points, running the rectification, examining the fit and adjusting or adding points — were completed before an acceptable result was obtained. A good fit between the image and the vector data was sought to reduce error when comparing the two images. For the 1991 image, the cubic convolution model provided the best fit between the TRIM data and features on the image. Nearest neighbour interpolation was used because when an image is to be classified the subtle changes in Digital Numbers (DN) that occur with quadratic and cubic convolution interpolation methods should be avoided (Ehlers, 1997). The rectification resulted in an overall RMS error of 0.36 cell units, or approximately 9 metres.

The 1974 image was also registered to the TRIM data using 57 control points and nearest neighbor interpolation. Initially the control points used to rectify the 1991 image were loaded into the 1974 image, but several of the features used in the 1991 image could not be identified on the lower-resolution 1974 MSS data. Other identifiable features from the 1974 image were used to replace the ones that could not be identified. For the 1974 image, the quadratic model provided the best fit between the TRIM data and features on the image. The rectification resulted in an overall RMS error of 0.30 cell units, or approximately 15 metres.

Jensen et al. (1997) state that an RMS error of ≤ 1 pixel should be sought when rectifying images for comparison. Both images met these requirements for their respective resolutions. However, the 1974 image has an error of 15 metres, which is greater that half of the cell resolution of the 1991 image (12.5 metres). The 1974 image could have a spatial error of over one-half of the resolution of the 1991 image. This means that when image comparison takes place, over half of some of the 1991 cells could be compared with the incorrect 1974 cell. Given that the equivalent of four cells from the 1991 image are necessary to make up one cell from the 1974 image, the mis-registration of an image cell in the 1974 image could result in change detection errors for multiple cells in terms of the 1991 image resolution. Resampling the 1974 image up to a 25 metre resolution could result in a lower RMS error after rectification but this would likely be an underestimate of error as resampling to a higher resolution creates no new spatial information.

The difference in resolution between the two images causes problems other than the incompatibility of the two grids. The higher spatial resolution 1991 imagery allows for the identification of features that cannot be detected on the 1974 image, such as narrow roads, rivers, streams, and bridges. The difference in resolution also leads to problems when comparing the two images; ideally comparisons should be made with images that have the same spatial resolution (Jensen et al., 1997). For example, one of the larger cells of the 1974 image could be classified as open forest. One or more of the cells from the 1991 image that overlap the open forest cell from the 1974 image could be classified as grassland, while the remainder were classified as open forest. This change in classification could be a result of actual change or it could be that the 1974 pixel represented a mixed area and the 1991 image is a spatially more precise delineation of the boundary. This could lead to an exaggeration of change, a problem that will likely occur most often in areas of transition from one cover type to another.

3.3.2 Haze Correction

Atmospheric haze is an additive component — it adds brightness to an image, and thus increases DN values recorded by the sensor. This brightness is not added uniformly across sensor bands, as shorter wave bands are more sensitive to haze than longer wave bands (Chavez and Mitchell, 1977). This varying sensitivity to atmospheric haze would result in the production of inaccurate ratio values if atmospheric haze were not removed before the ratioing was completed (Holbed and Justice, 1981; Avery and Berlin, 1992). Atmospheric haze correction is not part of the *precision* or *systematic* level corrections applied to Landsat satellite images, although it must be removed before the ratioing of visible light bands in any satellite image (Holben and Justice, 1981). The removal of haze is important in this study as inter-band ratios were used in the classification process, as is described in the following section.

Atmospheric modeling can remove the additive haze component from satellite images, but this type of modeling requires *in situ* field measurements at the time of satellite overflight, information about the atmospheric conditions during the satellite overflight, or that targets of a certain material be in the image (Ahern et al., 1977;

Otterman and Robinove, 1981; Chavez, 1988). Information of this type is not available for either of the Landsat images used in this study. As a result, atmospheric haze removal was accomplished using Dark Object Subtraction (DOS), a method that only requires information from the image itself (Chavez and Mitchell, 1977; Chavez, 1988; Chavez, 1996).

The histogram method of DOS described by Chavez (1988) involves the determination of haze values from histograms of the image bands. Working under the assumption that at least some pixels in any image should have 0% reflectance, the sensor should not detect any radiance at these shadowed locations. The additive component of atmospheric haze causes the sensor to falsely record DN values at these locations. The DN value recorded by the sensor for the various bands at these locations is the value that should be subtracted from each of the bands to remove the haze component. Through careful study of the histograms of each of the bands for the satellite image, a sharp rise in the count of the pixels at a DN above zero can be determined for each band. This value is a first-order approximation of the haze in each of the bands.

Chavez (1988) presents an improved DOS technique — the relative scattering model — for the removal of atmospheric scattering, or haze, from multispectral data that is intended to reduce the over-correction noted as a problem in earlier methods. The problem of over-correction occurs when the image has minimal shadow conditions (Chavez, 1996). As the images used in this study include significant areas of shadow and 'black bodies' (in the form of deep lakes), and both the simpler DOS method and the relative scattering models described by Chavez (1988) produce very similar values when these shadows are present, the simpler DOS method was used for haze correction in this study.

It should be noted that before this value can be determined, the satellite image must first must be corrected for the satellite sensor's gains and offsets (Chavez, 1988). Corrections for sensor gains and offsets correction were included in the preprocessing (*precision* and *systematic* level corrections) done before the image was acquired by Kootenay National Park (Hord, 1982; NASA, 1998). Using the DOS histogram method described by Chavez (1988), the starting haze value for each of the bands in the two images was determined. These values are shown in Table 3.2. Histograms for the whole of the subscene rather than just the portion of the image comprising the study region were used to determine the haze value. This was done to ensure that a significant area of shadow was included in the frequency count provided by the histograms.

Table 3.2 Haze values as determined from band histograms.

Landsat 1 Sensor Band	Haze Value	Landsat 5 Sensor Band	Haze Value
MSS 4	16	TM 2	12
MSS 5	2	TM 3	7
MSS 6	0	TM 4	3
MSS 7	0		

The differential influence of haze across the image bands can be seen in Table 3.2. The longer wavelength bands (MSS 6, MSS 7 and TM 4) are minimally affected by the haze, while the shorter bands (MSS 4 and TM 2) contain significant haze. The haze values were subtracted from their respective bands in the two images. The subtraction of haze from the bands removed the offset of the band histograms, as can be seen in Figures

3.2 and 3.3. Before the haze corrections the histogram shape was virtually identical but the distribution did not start at zero as it does after the adjustment.

3.4 Classification Methodology

3.4.1 Band Ratioing

The mountainous nature of the study region makes the classification of the Landsat images difficult due to the interaction of atmospheric and topographic effects — varying air mass thickness, varying solar illumination angle and shadow (Sjoberg and Horn, 1983). The most evident of these problems is the topographic shadow caused by the moderately low sun angle in the two images: 51° in 1974 and 42° in 1991 (see Figures 3.2 and 3.3). In these shadowed areas skylight, or downwelling, is the dominant source of illumination providing information to the satellite sensor (Sjoberg and Horn, 1983; Proy et al., 1989). The inability of the classification algorithm using only the normal spectral bands to discern cover types in these shadow areas was identified early on — both unsupervised and supervised classifications of the 1974 and 1991 images were unable to spectrally distinguish the deep lakes and areas of shadow in the study region.

Band ratios have been used to minimize topographic effects for visual interpretation using colour composites (Chavez et al., 1982; Chavez and Mitchell, 1977) and they have been used for identifying cover type with greater success than with normal bands (Colby, 1991). Visually, band ratios give no appearance of shadows, unlike normal TM and MSS images. Homogeneous materials have the same spectral response whether in direct or diffuse illumination; the relationship between values across spectral bands generated for the same material in both shadowed and illuminated areas is the same. Because this relationship is the same, ratioing bands produces an image where homogeneous materials have the same value in both shadowed and illuminated areas. However, band ratios can represent a loss of information for materials with similar spectral reflectance curves — two materials with different DN values across two bands can have the same ratio value derived from those two bands (Avery and Berlin, 1992).

In this study, a combination of the normal (non-ratioed) bands and one additional band ratio was used in the classification. Two bands of DEM products were also added and used in the classification, these will be discussed in the following section. A band ratio was included with each of the two images to allow the classification algorithm to distinguish different materials in the shadowed areas. The normal bands were kept, rather than using a combination of only band ratios, so that materials with similar spectral reflectance curves could be distinguished. The retention of normal bands reintroduces the problem of topographic shadow (Avery and Berlin, 1992). To overcome the problem of reintroduced topographic effects, care was taken to ensure that training sites for the classes that occurred in shadow were selected in both shadowed and illuminated areas. In this way it was thought that the classification algorithm could distinguish materials in shadowed areas — primarily because of the information in the band ratios — and recognize materials in shadow and non-shadow areas as belonging to the same class.

The 6/5 ratio was selected for the MSS data for its usefulness in distinguishing among general types of material such as soil and rock, vegetation, and water (Avery and Berlin, 1992). Higher values in the TM 4/3 ratio represent greater amounts of vegetation. Because of this, the 4/3 ratio was selected to aid in distinguishing among closed forest (higher vegetation), open forest (moderate vegetation) and grasslands (low vegetation). Other classes of vegetation — wetlands, irrigated lands — are thought to be uncommon in the topographically steep shadowed areas and therefore identifiable with the normal bands. The band ratios were calculated by dividing the appropriate bands and then applying a linear stretch to set the value range of the output from 0-255. The ratios were then added to their respective images as an additional band for use in the classification.

3.4.2 DEM Products

The early attempts at classification showed that the classification algorithm had difficulty in distinguishing between certain land cover categories — urban and soil/rock, open forest and wetlands, irrigated lands and wetlands, urban and grasslands. This difficulty could be identified because of the unlikely location of land cover classes in early attempts at classification, such as urban areas at high elevations, large tracts of open forest in the valley bottom that were mixed with the wetland class, wetlands scattered over the usually dry mid-slopes, and urban areas in the midst of grasslands. This confusion was caused by the spectral similarity between these categories. The error was easily identified through an understanding of the distribution of land cover categories and the possible reasons for spectral similarity.

Topographic information has been added to the spectral information as this can improve the results of the classification process (Strahler et al., 1978). Slope derived from the DEM was incorporated with the Landsat data to help distinguish between the categories listed above. The slope values for the 1974 image were derived from a version of the DEM that had been resampled to a resolution of 50 metres. It was thought that the variation in slope between the mostly level urban and wetland land cover types would help distinguish these categories from the open forest, rock/soil and irrigated land categories. The result met with limited success — the addition of slope information only reduced the confusion by removing the spurious wetland and urban categories from areas of steep slope. Areas of confusion on the level mid-slope benches and in the wetlands persisted.

In an effort to further refine the classification, elevation data was also added to the integrated slope and spectral data sets. Again, the DEM used to add information to the 1974 data was first resampled to a 50 metre resolution. The elevation data added were not the raw DEM values, instead the DEM was first generalized by the application of a linear stretch which mapped the elevation values to a range of 0-255. The addition of the elevation band in the data sets used in the classification did improve the ability of the classification algorithm to distinguish among land cover classes. However, some confusion did persist. The details of the results of the classification are presented and discussed in the next chapter.

3.4.3 Training Site Selection

The addition of the band ratios and products derived from the DEM necessitated special care in selecting training sites. Given that the spectral signature of cover types would vary between shadow and non-shadow areas due to the topographic effects present in the non-ratio bands, representative sites from shadow and non-shadow areas were necessary. Duplicate sites for cover types found both within and outside of shadow areas were defined. In a similar manner, land cover types that occurred at varying slopes and elevations necessitated the delineation of multiple training regions so that the signature derived from the combined spectral and DEM products would be representative. This meant that training sites had to be selected in multiple sites for single categories to ensure that the spectral signatures used in the classification algorithm encompassed the variability of their respective land cover categories.

The selection of training sites for the classification was an iterative process. Statistics generated for the various classes were used to refine the training sites to improve the separability of the classes. The distance between class means and scattergrams that depicted the extent of categories in two-band space were the major tools used for revision. The classification algorithm (the maximum likelihood algorithm) was applied to the data sets and the results used to further refine the training sites. This process was repeated several times until the results of the classification were found to be acceptable.

The training sites used for the classification of the 1991 data set were derived from field visits, rangeland cover data, forest cover data and airphotos. The results of unsupervised classifications were also used as a guide in selecting training sites for both the 1991 and 1974 data. Selecting training sites for the 1974 data presented special problems, as the only data from close to the time of the satellite image acquisition were the 3 airphotos from 1973. The rangeland cover data were not used in the selection of training sites for the 1974 data set. Heavy reliance was placed on the airphotos from 1973 and visual interpretation of the 1974 satellite image and the unsupervised classification results. Training sites for the 1974 data set were also derived from the forest cover data when the information on stand age warranted. For example, deriving open and closed forest training sites where the forest cover data indicated an stand age of over 80 years was thought to be a safe approach.

Once the classification was completed, a set of verification training sites were delineated using the same sources of information and methods described above. These verification sites were located in areas that did not overlap with the first set of training sites. The verification sites were used to classify the two data sets, again using the maximum likelihood algorithm. The results of this second classification were used to test the accuracy of the initial classification, as described in the following section.

3.4.4 Error Analysis

The classification results and the results obtained using the verification sites were compared using cross-tabulation. The cross-tabulation procedure compares the two input images and produces a table that gives the proportional agreement between the two classifications along the diagonal, with errors of commission and omission represented by the off-diagonal values in the table. An overall percent correct can be derived by summing the diagonal values in the table.

Rosenfield and Fitzpatrick-Lins (1986) note that the overall percent correct "...appears to give inflated accuracy" (p. 226). Instead, they recommend the use of the Kappa Index of Agreement (KIA), which includes off diagonal elements in estimating error. The KIA provides an estimate of error that has been corrected for the agreement between two images that is attributable to chance (Bonham-Carter, 1994). The KIA coefficient was also calculated through the cross-tabulation procedure. The results of the cross-tabulation, including the overall percent correct and KIA are presented and discussed in the following chapter.

3.5 Limitations of Change Detection

Comparisons of land cover categories must be completed with an understanding of the limitations of the classification methodology. The biophysical characteristics and the cultural land-tenure practices of the study area must also be understood (Jensen et al., 1997). In this way, change quantified through the comparison of the two dates can be qualitatively related to processes influencing change. These qualitative relations are open to interpretation, but the evidence they provide is a crucial part of the picture of environmental change if degenerative patterns of change are to be halted.

Land cover analysis from remotely sensed imagery cannot provide information on all types of environmental change (Riitters et al., 1995), and therefore cannot answer all of the questions identified through the newspaper analysis. For example, concerns over water quality due to increased wastewater discharge associated with new residential development cannot be directly addressed by measuring change in land cover — water quality cannot be assessed visually. The growth of urban areas can be documented through the image analysis, but urban growth is not necessarily directly related to a decrease in water quality. From this example it must be understood that the limitations to the potential insights of the image analysis must be considered when interpreting the results. Relying on satellite images for the analysis of environmental problems has several inherent problems. The problems particular to this study include:

i. the inability to distinguish between all cover types (e.g. golf course from irrigated farmland);
ii. Landsat imagery cannot detect small features (roads, creeks, buildings, etc.);
iii. not all questions identified by the community can be answered: e.g. water quality problems, the status of wildlife, the extent of suburban development, and the privatization of lands;

iv. seasonal variations makes the comparisons of some categories difficult (e.g. agriculture, wetlands); and
v. the method used is historical; it includes no methods for prediction.

When the information generated in this study is transferred to the community for use, it must be emphasized that the limitations of the study necessitate the integration of this knowledge with existing local and scientific information. Reliance on this information as if it were a master plan would be a mistake, as the information presented cannot answer many important questions about the local environment. The information presented is appropriate to aid in answering the community questions identified in through contact with local ENGO's and the analysis of the local newspaper.

3.6 Analysis

The classification of the 1974 and 1991 data sets with the methodology described above produced two land cover images with which change can be detected. The change detected has been quantified using three methods:

i. a comparison of the change in area of each category from the two classified images to examine overall change between the two dates;
ii. a comparison the percent cover of each category from the two classified images to show the relative change in each category between the two dates; and
iii. the identification of particular types of change through querying the two classified images.

The first two methods allow for a general discussion of change by providing information on which categories have changed the most or least in terms of area and proportion. The third method of comparison is intended to quantify and locate change of the types identified as ones of concern through the newspaper record.

Chapter 4: Results

This chapter presents the results of the image analysis. The results of the image analysis are presented through a discussion of the relation between each of the land cover categories and the biophysical environment. Then the error analysis and its implications are presented and discussed for each of the land cover classes. Summary statistics describing net land cover change are presented and discussed, followed by a discussion of area-specific change. Finally, trends in land cover change based on questions identified in the newspaper record are presented and discussed.

4.1 Classification Results

With the context and methodolgy of the image analysis set, the discussion can now move to a description of the two classified images and a discussion of the relation between controlling factors and the distribution of land cover classes. The result of the classification of the 1974 MSS image can be seen in Figure 4.1; the classified 1991 image is shown in Figure 4.2. A 3 X 3 majority filter has been applied to both images to smooth the results. The distributions of the eight land cover categories in the classified images are individually discussed below. Differences related to the classification algorithm are discussed in this section; those attributable to environmental change are discussed in later sections.

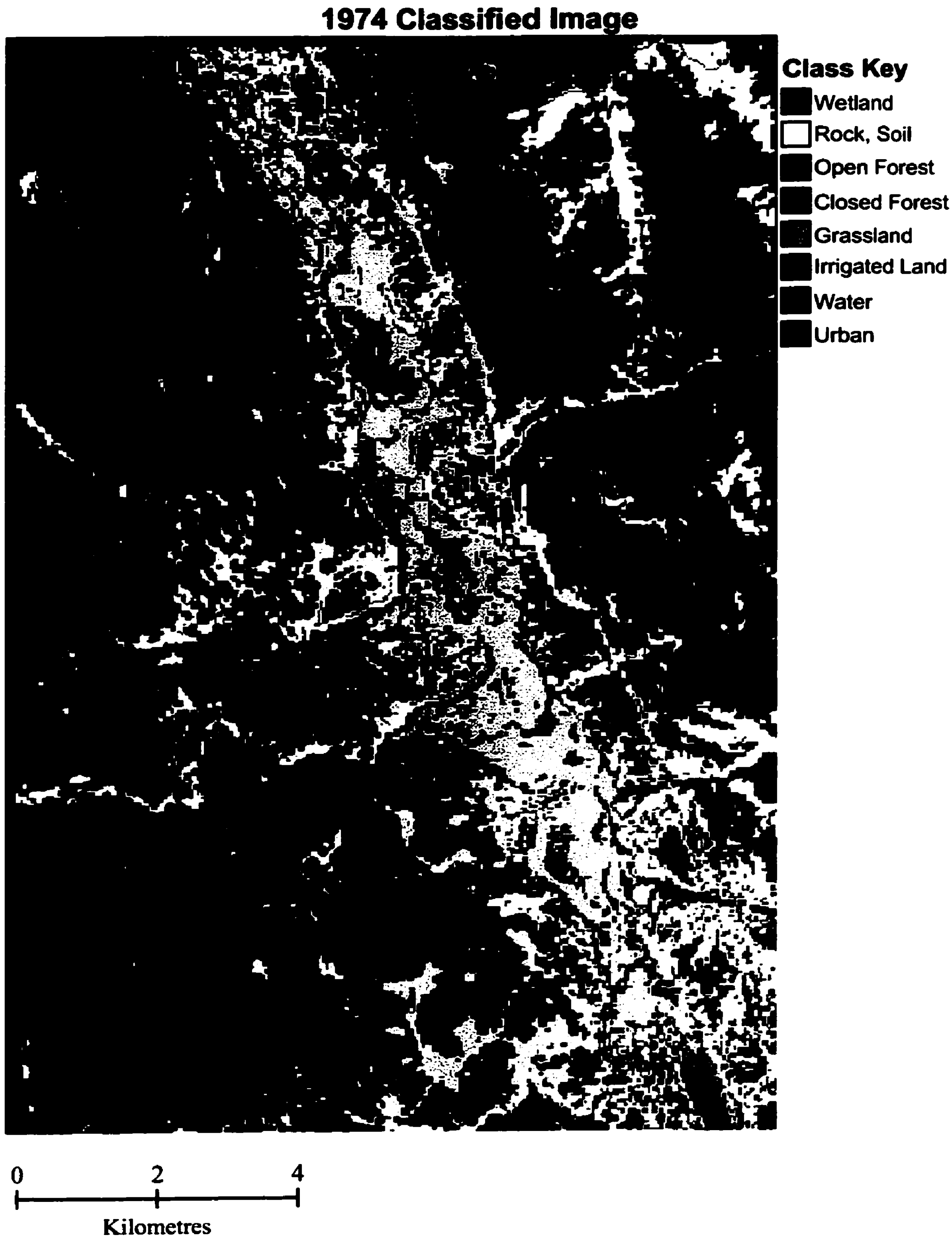

Figure 4.1 Classification of the 1974 image. The image has been smoothed with a 3X3 majority filter. Kootenay National Park and Dry Gulch Provincial Park are shown in red.

1991 Classified Image

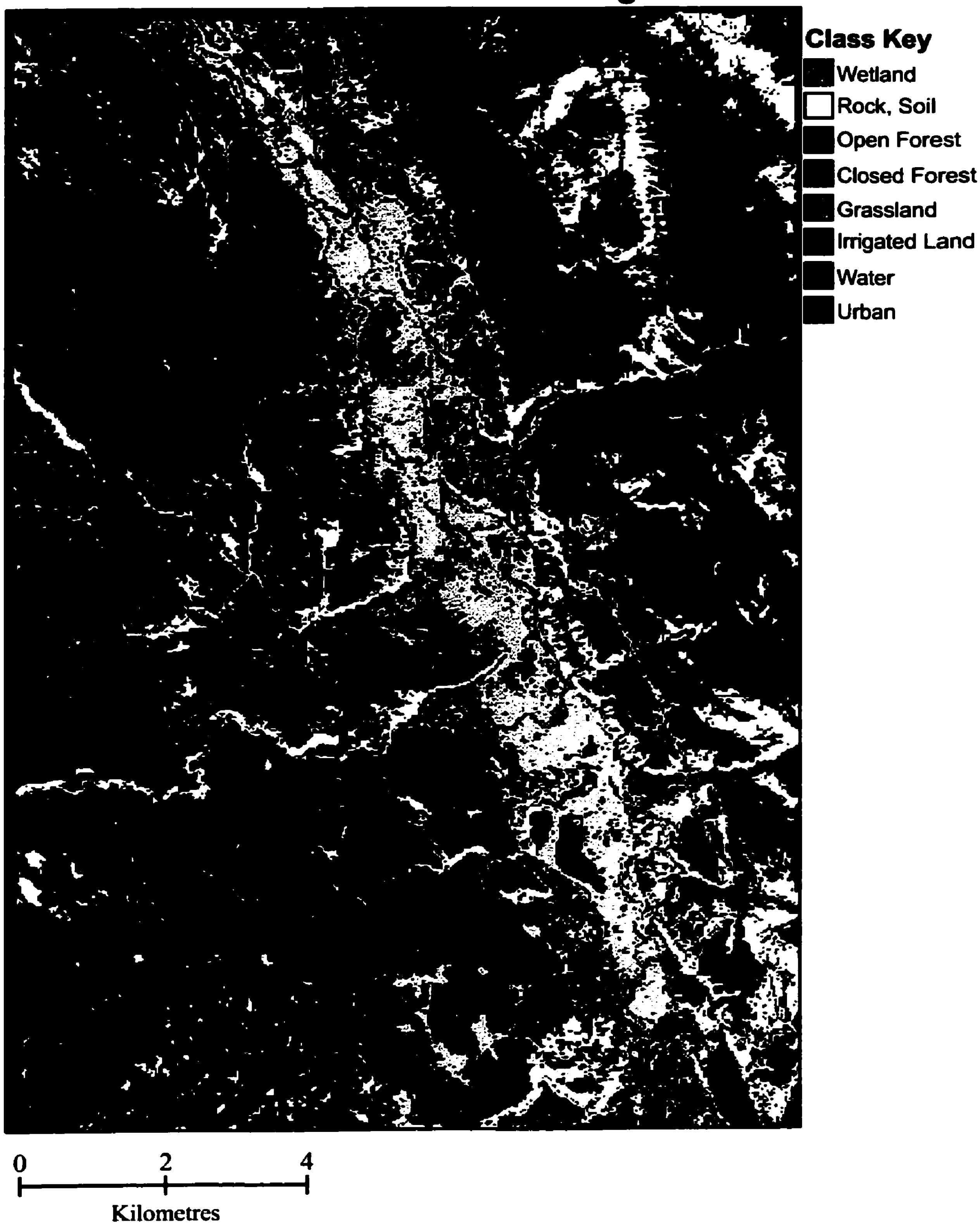

Figure 4.2 Classification of the 1991 image. The image has been smoothed with a 3X3 majority filter. Kootenay National Park and Dry Gulch Provincial Park are shown in red.

4.1.1 Closed Forest Category

Large tracts of closed forest are visible in the northwest and southwest corners of the study region. These tracts correspond with the slopes of Steamboat Mountain in the northwest and Mount Bruce in the southeast (see Figure 3.4 to locate topographic features described here and in later sections). Within Kootenay National Park continuous areas of closed forest are confined to the slopes of the Kootenay Ranges (the Brisco Range in the north and the Stanford Range in the south), with the notable exception of the forested McKay Creek valley. These tracts of closed forest are part of the Montane Spruce and Engelmann-Spruce Subalpine Fir biogeoclimatic zones. Together, these zones typically occur on mountainous areas over a range of elevation from 1250 to 2300 metres (Hope et al., 1991b; Coupé et al., 1991). The McKay Creek valley is likely a subzone of the Montane Spruce zone — the Montane Spruce Dry Cool zone — which is noted to occur "...in valley bottoms and lower valley slopes of the eastern Purcell and Rocky Mountains" (Hope et al., 1991b, p.187).

The patches of closed forest at lower elevations in the valley are likely stands of Douglas fir and lodgepole pine, part of the Interior Douglas-fir biogeoclimatic zone. These closed forest patches in the Interior Douglas-fir zone are limited by soil moisture (Hope et al., 1991a). The distribution of closed forest is also controlled by human activity such as ranching, settlement and logging. These human activities may have also removed areas of closed forest from the valley slopes. Some patches of closed forest in the low- and mid-slope areas may be mixed deciduous and coniferous stands that are present because of local soil and moisture regimes that differ than those typical of the Interior Douglas-fir zone, in which stands are typically coniferous (Hope et al., 1991a).

Closed forest groves in ravines on the slopes between the benches and the valley bottom that can be identified on the airphotos seem to be lost in the classification — most are classified as open forest. The inability of the classification to identify these groves could be due to their small size laterally (they appear on the airphotos as linear strips). They could also be more open with less crown closure than the mountain regions of closed forest — Hope et al. (1991a) note that climax stands of Douglas-fir often have an open canopy because of ground fires. Typically, these groves are located in the shadowed sides of the ravines, which could alter the spectral signature due to the difference in illumination. The preferential location of these groves on the north facing slopes of ravines is likely due to the greater moisture availability on these slopes which receive less solar illumination, as moisture is a limiting factor in the distribution of trees vs. grasslands in the Interior Douglas-fir zone (Hope et al., 1991a).

4.1.2 Open Forest Category

The large areas of open forest in middle and low elevations are part of the Interior Douglas-fir zone, consisting of drought-tolerant trees including douglas fir, ponderosa pine, and lodgepole pine (Parish et al., 1996). Moisture and human activity such as logging, settlement and ranching limit the drought resistant species. Their distribution is also controlled by edaphic and topographic conditions, and local fire history (Hope et al., 1991a). Some areas of open forest could be forests that are regenerating after natural or anthropogenic disturbances such as fire, logging or ranching. In Kootenay National Park, high elevation bands of open forest are likely related to steep slopes and avalanche paths that cannot support dense forest. These open forest classes could also be stunted trees (krummholz form trees) and the shrubs, herbs and bryophytes of the Alpine Tundra zone noted by Pojar and Stewart (1991).

Patches of open forest in wetland areas, especially those that occur as linear strips, are most likely the brush and trees which appear on river levees — either active or relict levees. During the field visit in 1997, non-wetland vegetation identified along the riverbanks of the Columbia and other raised banks included diamond willow trees, dogwood maple, and cottonwood trees. These types of vegetation most likely depend on the built up soil of the levees that rise above the water table for a place to grow in these otherwise wetland vegetation dominated areas. Patches of open forest in the wetland areas may consist of brush similar to that of the levees that have developed in slightly elevated areas of the wetlands. Alternatively, these patches could be dense areas of wetland vegetation, such as reed beds that may be spectrally similar to open forest areas.

4.1.3 Grassland Category

Significant areas of grasslands are limited to the lower elevation areas on the east side of Lake Windermere, the areas surrounding Radium Hot Springs, west of Invermere, and on the western side of the image between the Horsethief and Forster creeks. The last two of these areas are ranching areas, where the presence of grasslands is at least in part dictated by human use. There is some confusion between the urban and grassland categories, especially on the east side of Lake Windermere. Some of these areas are urban, such as the airfield to the northeast of Invermere and the strips of urban that parallel the highway, while others are likely confusion. The confusion between the grassland and urban categories could be caused by the fact that both consist of mixed vegetation and non-vegetation cover types. The urban areas are a mix of grass, shrubs, trees, and buildings, roads and driveways while the grassland areas are a mix of grasses, shrubs, and bare soil. These two categories likely have a similar spectral signature due to the fact that both are composed of vegetated and non-vegetated surfaces.

In the central valley, highways #95 and #93/95 tend to show up as linear strips of grassland. Portions of the highways also show up as soil/rock class. The identification of the highways as grassland may be a combination of spectral confusion (between grassland and asphalt) and the identification of grasslands that parallel the highway. The latter seems more likely given that the airphotos show a grassland strip of variable width on either side of the undeveloped portions of highway 93/95. The classification of parts of the highways as soil/rock is likely due to the similarity of the combined signature of the asphalt and gravel shoulders to that of the soil/rock category.

4.1.4 Wetland Category

From a comparison of Figures 4.1 and 4.2 to Figure 3.4 it can be seen that the wetland category is mostly confined to the valley bottom. Mixed in with the wetlands are some areas of open forest (discussed in section 4.2.2) and other areas of irrigated lands. The dominant controlling factor in the location of wetlands is the presence of slow-flowing water. The confusion between irrigated lands and wetlands is less than expected given the similar nature of the combination of materials (wet soils, vegetation) in these categories. The addition of the elevation information is what allowed the classification algorithm to distinguish between the wetland and irrigated land categories. Classification images produced before the elevation data was added showed large areas of wetland on the benches and many patches of irrigated land in the valley bottom.

4.1.5 Water Category

The lakes in the images are well defined in the classifications due to the easily identifiable spectral signature of deep water. The addition of the slope and elevation information has removed the confusion between the water bodies and areas of shadow that occurred in earlier classifications. Portions of the course of the Columbia River appear as a linear strip classified as water, but for large stretches the river is lost in the wetland class. The streams and creeks in the study region have not been identified by the classification. A combination of their location in shadowed areas, their small spatial extent and spectral confusion because of the high silt content make the streams and creeks difficult to identify.

4.1.6 Rock/soil Category

The banks of the Horsethief and Toby creeks stand out as strips of soil/rock that follow the stream courses. These streams are larger than most others, but the high clay banks presumably shadow the streams. The high return off of these banks — especially given their east-west orientation and the southerly illumination — is likely what causes them to be easily identified. The majority of other areas that have been classified as soil/rock, such as those in Kootenay National Park, are in high elevation areas that are of the Alpine Tundra zone. This zone is mostly soil and rock with little vegetation present (Pojar and Stewart, 1991).

4.1.7 Urban Category

The presence and extent of urban areas is controlled by human settlement patterns, which are influenced by biophysical, cultural and economic factors. The urban areas representing the town of Invermere and the village of Radium Hot Springs are well matched to the extent of the urban areas. The urban class on the slope south of Radium Hot Springs is misclassified — the airphotos show this area as sparse grassland and bare soil. The mill and lumber yard west of Radium Hot Springs are classified as urban, which is appropriate given that industrial areas were included as part of the urban class in the scheme used in this study. The urban area on the west side of the Columbia River north of Wilmer is not actually urban, on the topographic sheet which contains the study region this location is marked as an airfield, condition unknown.

4.1.8 Irrigated Land Category

As noted before, the addition of elevation information to the classification algorithm is what enabled the distinction between irrigated lands and wetland vegetation to be possible. The algorithm used to classify the images is likely overly sensitive to changes in elevation in the selected training sites for irrigated lands. A small difference in the mean elevation of the training sites for the verification classification may have resulted in an overestimate of the inconsistency for the irrigated land category in the 1991 image.

Northeast of the mill in Radium Hot Springs is an area of irrigated lands — this is noted as an agriculturally used area in the Village Plan (Village of Radium Hot Springs, 1992). Irrigated fields show up well near Wilmer and Edgewater. The size and extent of irrigated fields in the classifications depends on whether particular fields are in use or fallow at the time that the images were acquired. Within season variation, such as that which occurs when a crop is harvested and the irrigation stopped, could result in fields that were used during the growing season of 1974 and 1991 not being identified in the respective classifications. The picture of agricultural activity provided by the classification of the two dates is only a snapshot as a result, a series of images over the course of the growing season would be necessary for an accurate picture of agricultural activities.

4.2 Error Analysis

It is important to understand the limitations of the classifications so that the results can be interpreted properly. The measures of error obtained through the comparison of the original classifications with the classifications completed with the verification training sites are not equivalent to actual error that can be obtained from comparing the classifications with ground truth information. Instead they are a measure of the consistency between the classifications which were completed with the same algorithm and different training sites. Neither the original nor the verification classification is a more 'correct' picture of the environment than the other, but disagreement between the two points to inconsistencies that are a product of the classification methodology. The comparison of the classified images produced with the additional verification training sites to the original classifications produced an overall percent correct of 84.9% for the 1974 image and 83.4% for the 1991 image. Appendix I gives the proportional cross-tabulation results for the comparison of the 1974 and 1991 classifications.

The values of overall percent correct for the two dates are slightly less than the recommended level of accuracy for a classification scheme of 85% correct (Anderson et al, 1976). The error present in the classification scheme does not render it completely invalid — the information on land cover change must be examined in light of the higher than desirable level of error in the classification. Reworking the classification scheme could reduce the level of error, although this could result in the use of a scheme that is not based on the land cover categories of concern in the region. Another way to reduce error in the scheme would be to refine the classification algorithm with further preprocessing and possibly through the addition of other types of data. These potential improvements are discussed in the concluding chapter.

The KIA is a more reliable estimate of error than percentage correct in a classification scheme (Rosenfield and Fitzpatrick-Lins, 1986). The KIA obtained in the comparison of the original and verification classifications for the 1974 image was 0.7789, or 77.9% accurate. This estimate of accuracy is 7.0% less than the overall percent correct (84.9%) derived from the cross-tabulation. For the 1991 image, there a similar difference of 7.4% between the KIA (0.7600 or 76.0%) and the overall percent correct (83.4%). The KIA also provides a measure of agreement between each of the categories in the two images. The category values of KIA for the comparisons of the original and verification classifications are given in Table 4.1. As can be seen in Table 4.1, the accuracy of several of the categories varies by a large amount from the overall KIA values for the two comparisons.

Table 4.1 Kappa Index of Agreement (KIA) values for the land cover categories.

Category	KIA (1974)	KIA (1991)	Difference
Wetlands	0.8280	0.7547	0.0733
Rock/soil	0.7643	0.7632	0.0011
Open forest	0.7410	0.7096	0.0314
Closed forest	0.8242	0.7749	0.0493
Grassland	0.7607	0.8413	0.0806
Irrigated land	0.7794	0.6556	0.1238
Water	0.9034	0.9722	0.0688
Urban	0.4472	0.8818	0.4346
Overall	0.7789	0.7600	0.0189

The differences in reliability between the two dates are notably large for the grassland, irrigated land and urban categories (see Table 4.1). These differences could be due in part to the difference in spectral ranges and spatial resolution of the bands in the MSS and TM sensors. The lack of TM bands 1, 5, and 7 in the 1991 image and the difference in the band ratios used in the two images could also contribute to the variable reliability of the classification algorithm across the categories.

Like the overall percent correct values for the two images, the overall KIA of the two images does not indicate a large difference in the reliability of classification between the two dates. The following section discusses the variability in KIA for each of the categories. Potential causes of unreliability in the classification of each category are discussed, drawing on the values of the KIA from the error analysis and, when relevant, the distance between means statistics generated from the original classifications. The distance between means is calculated for each category of the classification based on the DN values of the pixels contained within the training sites defined for each category. See Appendix II for a complete listing of the distance between means values for the two classifications.

4.2.1 Closed Forest

While the difference in reliability between the two dates is not great (4.9%), as with all of the categories, it could result in false change being identified or actual change being missed. The 1974 classification of forest is more reliable (82.4%) than the overall KIA for the same year (77.9%) and the 1991 classification of forest (77.5%). The additional spectral information in the IR and NIR of the 1974 data set may have improved the ability of the algorithm to detect vegetation in the 1974 image. The later season overflight of the 1991 image (September 4, 1991 compared to August 3, 1974) may also be a factor. Vegetation is more likely to be under stress (due to a lack of soil moisture) or to have encountered frost later in the season and thus be less 'green' as it contains less chlorophyll. This makes the vegetation less distinctive in the NIR and IR spectral ranges. Indeed, with the notable exception of grassland, all of the vegetation categories in the 1974 image are more reliably classified than the same categories in 1991.

4.2.2 Open Forest

The KIA indicates that the classification of open forest was less reliable than that for closed forest — 0.7410 for 1974 and 0.7096 for 1991. The greater unreliability is likely due to the fact that the open forest class is a combination of two types of vegetation that are also part of other categories in the classification scheme: grasses and trees. The open forest category (like the grassland category) also contains bare soil as part of its cover. The training site statistics show that these related categories have similar parameters. From the training site statistics, the distance between the means for the open forest category and the related categories of closed forest, open forest and rock/soil are less than the distance between grassland and all other categories: 5.9 between closed forest and open forest, 6.5 between grassland and open forest, and 6.0 between rock/soil and open forest in 1974. The open forest class is an artificial division in the gradient between the grassland and closed forest categories. Land cover change detected from or to the open forest category could be due in part to the difficulty in choosing a break point in the continuum from open to closed forest.

4.2.3 Grassland

The grassland category had a difference of 8.1% between the two dates — 0.7606 for 1974 and 0.8413 for 1991. Grassland is the only vegetation category that was more reliably classified in 1991 than in 1974. This could be due to the low reliability of the 1974 classification of the urban category (44.7%), a class that was easily confused with the grassland category. The distance between means between the grassland and urban categories is the lowest of all comparisons between grasslands and other categories (4.4 in 1974 and 4.2 in 1991).

4.2.4 Wetland

The wetland category has a KIA for 1974 of 0.8280, for 1991 it is 0.7547. The difference between the two (7.3%) could be attributable to three factors:

i) the difference in spectral ranges in the bands between the 2 sensors;
ii) the difference in water levels between the two images (which can bee seen by comparing Figures 3.2 and 3.3); and
iii) the difference in time of overflight between the two images.

The lower water levels and later overflight of the time that the 1991 image was acquired indicate that the wetland vegetation was likely under more stress than at the time of the 1974 image. This could reduce the ability to separate the spectral signal of the wetland vegetation from other categories (notably water and irrigated land, which have signatures similar to that of the wetland category).

4.2.5 Water

Water was the most reliably classified category in the image analysis, with a KIA of 0.9034 in 1974 and 0.9722 in 1991. Given the high reliability in the classification of water, the difference of 6.9% between the two values of KIA is not considered significant. The lower reliability of the classification of water in the 1974 image could be due to the apparent higher water levels. Shallow-flooded areas could be more difficult to recognize spectrally due to the mixed signal being received from both the water surface and the ground beneath.

4.2.6 Rock/soil

The consistency of the classification algorithm for the rock/soil category is virtually identical between the two dates — 0.7643 for 1974 and 0.7632 for 1991, a difference of 0.1%. The large spectral difference between rock/soil and most other categories is likely the reason for the near-identical results.

4.2.7 Urban

The largest difference in the consistency of the classification algorithm between the two dates is in the urban category — 0.4772 for 1974 and 0.8818 for 1991, a difference of 40.5%. This large difference is likely due in part to the combined nature of the category — landscaped vegetation, roads and buildings make up the majority of surfaces that reflect information to the sensor. These surfaces are very similar to other categories in the classification: landscaped vegetation is similar to irrigated lands, roads are similar to grassland and rock/soil, and buildings are also similar to grassland and rock/soil.

The difference in spectral resolution between the two sensors is likely the largest contributing factor to the great difference in reliability between the two dates. The lower resolution of the 1974 image means that more of the urban pixels are a result of mixed surfaces. The higher resolution of the TM sensor results in more homogeneous urban pixels in the 1991 image. This is true for all categories, but two important differences between the urban category and all other categories emphasize this effect. The sharp boundaries between surfaces in urban areas are different than the dominantly gradational changes between other categories (e.g. the transitions from grassland to open forest and from open forest to closed forest). The categories that have sharper boundaries (such as irrigated lands) are more homogeneous in composition than urban areas.

4.2.8 Irrigated Lands

There is a difference in the consistency of the classification of irrigated lands of 12.4%. The later-season overflight of the 1991 image is thought to account for the reduced consistency in the 1991 classification. More of the vegetation on these irrigated lands is likely to have undergone moisture stress. This is possible because many crops could have been harvested by this point in the season and the irrigation stopped. The irrigation of vegetation on recreational lands (i.e. golf courses) is not likely to have halted in early September; these lands are not likely the cause of the majority of the difference in reliability.

4.3 Net Land Cover Change

With an appreciation of the levels of error in the classifications and the underlying biophysical factors which influence the distribution of the land cover categories, the amount of change between the two classified images can be presented and discussed. The net change between the two classified images is shown in Table 4.2. The net change is expressed in three ways:

i) the difference in area (ha) of each class between the two dates;
ii) the percentage of total area that each class comprised in 1974 subtracted from the percentage of total area that each class comprised in 1991 (% of image area); and
iii) the percentage of the total image area that each class represented in 1974 subtracted from the percentage of the total image area that each class represented

in 1991 (% of respective class). Due to the difference in resolution, the two images do not overlap perfectly at the edges and are therefore not exactly the same size. The values presented in Table 4.2 are only for the cells that are common spatially between the two images, a total area of 32,731 ha.

Table 4.2 Net land cover change, 1974-1991.

Land Cover Class	Net Change (ha)	Net Change (% of image area)	Net Change (% of respective class)
Closed Forest	-159.4	-0.5	-1.5
Open Forest	84.6	0.3	0.6
Grasslands	-583.7	-1.8	-23.2
Wetlands	384.7	1.2	22.5
Water	-232.1	-0.7	-22.6
Rock/Soil	155.4	0.5	7.9
Urban	244.7	0.7	31.3
Irrigated Lands	105.4	0.3	36.1

Given that the largest net change is -583.7 ha (grasslands), which is only 1.8% of the total area of the study region, the first two columns of Table 4.2 do not give the impression that substantial overall change in land cover has occurred between 1974 and 1991. However, the fact that the net loss of 583.7 ha of grassland represents close to a quarter (23.2%) of all the grassland in the study region is more telling of how much change has occurred. Net change in water (22.6%) is likely due to the apparent decrease in water levels at the time of acquisition of the 1991 image, as discussed in the error analysis above.

The closed forest and open forest classes do not show any significant net change at -1.5% and 0.6% respectively. The lack of observable net change is deceptive for the two forest classes, as is explained in the next section. The rock/soil category shows a slight net increase of 7.9%. The net change in urban area, an increase of 31.3%, points to significant urban growth. The net increase in wetlands of 22.5% is likely related to the lower water levels at the time of the acquisition of the 1991 image, as discussed above. Due to the difficulty in measuring change in irrigated lands, which is discussed in further detail in the following section, it is difficult to attach significance to the net increase of 36.1% shown in Table 4.2.

4.4 Area-Specific Cover Change

The above analysis discusses the amount and causes of net change in land cover. For example, the figure of -159.4 ha in Table 4.2 indicates the amount of closed forest present in the 1991 classification minus the amount present in the 1974 classification. This figure does not reflect all of the area that was closed forest in 1974 that has changed to other cover types. This is because areas that have filled in through forest ingrowth and those that were cleared at the time the 1974 image was acquired that have since regrown are included in the area of closed forest in the 1991 classification. To understand the trends in land cover change, figures that represent area-specific change must be calculated. The figures in Table 4.3 represent area-specific change; that is, the amount of change from each category in 1974 that has changed to every other category in 1991.

The data presented in Table 4.3 presents a much more complex picture of land cover change than those presented in Table 4.2. From this information it is possible to gain a more detailed insight into which categories have increased and which other categories they have replaced in the process. Error in the classification algorithm and the rectification of the two images does introduce 'noise' in the figures in Table 4.3. False change detection and missed change reduce the ability to explore subtle or slight changes in land cover. Concentrating on the larger amounts of change and with reference to the classified images (Figures 4.1 and 4.2), possible mechanisms of change for each of the categories are discussed below.

Table 4.3 Change by class, 1974-1991 (ha). Values represent the amount of the 1974 class (rows) that have changed to each type of the 1991 classes (columns). Classes are as follows: 1=wetland, 2=rock/soil, 3=open forest, 4=closed forest, 5=grassland, 6=irrigated land, 7=water, 8=urban. Values along the diagonal represent areas of no change.

To → **↓ From**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
1	1357.2	1.4	94.3	56.2	10.1	44.4	134.4	35.5	1733.5
2	24.6	1067.2	387.2	39.6	140.9	52.7	36.9	111.6	1860.7
3	196.0	642.7	9990.1	2717.4	398.2	59.4	58.9	164.8	14227.5
4	25.2	97.1	2996.0	7049.3	18.3	20.5	3.4	1.7	10211.5
5	3.4	123.2	970.5	8.2	1000.5	46.6	7.0	264.5	2423.9
6	26.9	1.4	84.9	13.9	16.5	109.2	0.1	26.2	279.1
7	285.5	4.8	100.0	2.7	45.2	3.2	454.5	95.3	991.2
8	285.5	34.0	38.8	0.1	136.7	18.1	2.8	253.1	769.1
Total	2204.3	1971.8	14661.8	9887.4	1766.4	354.1	698	952.7	32496.5

4.4.1 Closed Forest

The largest amount of change in the closed forest present in the 1974 classification was to open forest (2996.0 ha), followed by change to rock/soil (97.1 ha). Comparison of Figures 4.1 and 4.2 show that large amounts of closed forest have changed to open forest and rock/soil in the northwest and southwest portions of the image — areas on the slopes of the Purcell Mountains in the Engelmann Spruce-subalpine Fir zone described in Chapter 1. These changes were dominantly caused by forestry activities, though natural change is likely present in the form of fires or avalanche paths.

4.4.2 Open Forest

Open forest shows the largest change to closed forest (2717.4 ha), rock/soil (642.7 ha), and grassland (398.2 ha). Unlike the drastic changes in closed forest, it is difficult to pick out where the open forest category has changed. Close examination of Figures 4.1

and 4.2 reveals that many patches of closed forest at middle elevations and on the benches have increased in size, replacing former areas of open forest. This type of change is likely the process of forest ingrowth, which incrementally replaces open forest with closed forest and grasslands with open forest.

Changes from open forest to rock/soil could represent forestry activities. The majority of this change seems to be related to the increase in the area of the soil/rock class in the high elevation areas of Kootenay National Park and along the banks of the Horsethief and Toby creeks. This could be due to the higher resolution of the 1991 image, which allows the classification to pick out the narrow patches of rock along ridge lines in Kootenay National Park and the linear strips of clay banks along streams. The changes from open forest to grasslands are hard to discern on Figures 4.1 and 4.2, with the exception of the clearing of the area to the north of the golf course that lies alongside the boundary to Kootenay National Park.

4.4.3 Grasslands

A large amount of Grasslands have changed to open forest, in fact only slightly less have changed to open forest than have remained unchanged (970.5 ha compared to 1000.5 ha). Urban areas account for the second largest amount of change at 264.5 ha. The reduction of grasslands at the expense of open forest is easy to see in almost all of the patches of grasslands that occur in 1974 (Figure 4.1) when compared to 1991 (Figure 4.2). Similar to the loss of open forest to closed forest, the grasslands have mostly 'shrunk' from the edges inward, a result of the process of forest ingrowth. The change of grasslands to urban areas occurs in many patches within the grasslands. A good portion of this change is likely error because of confusion in the classification, as described in the error analysis. Part of this change is actual urban expansion, mostly within and to the east of Invermere.

4.4.4 Wetlands

The largest change in wetlands is to water (134.4 ha), followed by change to open forest (94.3). As discussed in the preceding section, the change from wetland to water is likely due to lower water levels in the 1991 image. The higher resolution of the 1991 image likely allows the classification to detect the course of the Columbia River and the patches of open forest along the river levees which were more difficult to detect in the 1974 classification. This can be seen in Figure 4.2, which better delineates both the linear strips of open forest and the course of the Columbia River.

4.4.5 Water

Water changed to wetland (285.5 ha) and open forest (100.0 ha). Similar to wetland, change in the water class is mostly due to the change in sensor resolution and water levels between the two dates. The change in water levels is what caused the classification to pick up wetland in 1991 that was likely submerged in 1974, while the increase in resolution allowed the classification to detect the linear patches of open forest.

4.4.6 Rock/Soil

The rock/soil class has showed significant change to open forest (387.2 ha) and grassland (140.9 ha). The change from rock/soil to open forest is difficult to detect through visual comparison of Figures 4.1 and 4.2. A number of small patches that occur throughout the benchlands in 1974 have decreased in area or disappeared altogether. These patches are likely disturbances such as small cuts or fires that have grown over in the intervening period. The change from rock/soil to grasslands is likely due to similar changes, though confusion between these two classes may have added to the change.

4.4.7 Urban

The most significant change in the urban class was to wetlands (285.5 ha). This is a difficult change to explain. The most likely cause is error in the classification of urban in 1974. In Figure 4.1, urban areas where Toby Creek enters the wetlands are likely misclassified stretches of silty water that have been more appropriately classified as wetland in the 1991 image. There is also a surprising amount of change to grasslands (136.7 ha), although this is likely error, as discussed above in the section on grasslands.

4.4.8 Irrigated Lands

Irrigated lands display the least amount of change of all the classes, with the largest amount of change being to open forest (84.9 ha). The changes seem to be in the patch of irrigated land to the west of Radium Hot Springs adjacent to the mill and the ones along the highway north of Radium hot springs. These changes could represent fields that have been abandoned on which the process of forest ingrowth has started.

4.5 Trends in Land Cover Change

Trends in land cover change are identified through the analysis of area-specific change. Unlike the analysis above, the trends are identified by choosing the 'from' and 'to' classes that best approximate trends in land cover change that are of concern. The following sections use area-specific comparisons of the two classified images to examine 7 trends in land cover change: forest loss, forest ingrowth, urban expansion, expansion of irrigated lands, loss of irrigated lands, and wetland loss. A figure that shows the extent of each of these trends is presented and discussed below.

4.5.1 Forest Loss

The areas shown as forest loss in Figure 4.3 are those which were classified as closed forest in the 1974 image that have been classified as open forest, rock/soil, or grasslands in the 1991 image. The net change in closed forest (-159.4 ha) is small when compared to the loss of closed forest as defined above, which was 3118.8 ha. This discrepancy is possible because of the forest ingrowth that occurred in grassland areas, the regrowth of forest in areas formerly cleared, and the misclassification of closed forest in both the 1974 and 1991 images.

The majority of the forest loss depicted in Figure 4.3 is attributable to forestry activities. Areas that have changed from closed forest to rock/soil, open forest, or grasslands should best represent forest loss resulting from forestry activities. Closed forest that has changed to open forest over the 17 year period has likely been selectively cut or completely cleared and partially regrown. Those patches that have changed to grasslands or rock/soil likely represent recent cuts that have not yet regenerated. Fire or avalanches could also have cleared these patches.

The boundaries of the large tracts of forest loss in both the northwest and southwest portions of the image match well with the forest cover polygons, the landscape units used to manage forests. Forestry activities are also indicated by the linear edges of some of the areas of forest loss — especially in the southwest portion of the image on the slopes of Mount Bruce.

The linear patches of forest loss within Kootenay National Park are likely a combination of natural change and error due to confusion between the open and closed forest classes. Natural change is possibly related to avalanche paths at high elevations

Forest Loss

Figure 4.3 Forest loss. Areas shown as loss are those which were classified as closed forest in the 1974 image that have been classified as open forest, rock/soil, or grasslands in the 1991 image. The outlines of Kootenay National Park and Dry Gulch Provincial Park are shown in grey. A greyscale composite of the 1991 image is shown in the background.

within the park. The McKay Creek maintenance compound appears to have expanded between the two dates, resulting in a small amount of forest loss. Linear strips of forest loss along the banks of Horsethief and Wilmer Creeks could be due to bank erosion removing the linear stretches of forest or confusion in the classification. The fact that the southern banks cast shadows over the streams at the time of the acquisition of the images could be a contributing factor to confusion along the streams.

The Springs at Radium golf course southeast of Radium Hot Springs has expanded and resulted in forest loss at the boundary of Kootenay National Park. The expansion involved the cutting of forest for additional holes at the course prior to 1991, but the construction of fairways and greens had not yet commenced during the field visit in 1997. During the field visit, it was noted that the small patches of clearcuts had become vegetated with grasses, shrubs and small (~0.5 to 2 m in height) conifers.

The patches of forest loss in the wetland areas in the northern part of the study region are likely attributable to confusion between the open and closed forest classes and the wetland class. Some of this change may be natural, where other vegetation has replaced areas of closed forest along levees as the Columbia River meandered across its floodplain in the wetlands.

4.5.2 Forest Ingrowth

The second largest change in terms of area at 972.2 ha, forest ingrowth is shown in Figure 4.4. The areas shown as ingrowth in figure 4.4 are those which were classified as grasslands in the 1974 image that have been classified as open forest in the 1991 image. The two classified images were also queried to show where grassland in the 1974 image had changed to closed forest in the 1991 image, but this query resulted in virtually

Figure 4.4 Forest ingrowth. Areas shown as ingrowth are those which were classified as grasslands in the 1974 image that have been classified as open forest in the 1991 image. The outlines of Kootenay National Park and Dry Gulch Provincial Park are shown in grey. A greyscale composite of the 1974 image is shown in the background.

no areas of forest ingrowth. Forest ingrowth in the Interior Douglas-fir zone has resulted from regrowth after logging in the 1920's and slash fires in the early 1930's, and from subsequent fire control (CORE, 1994).

The majority of the forest ingrowth that can be seen in figure 4.4 has occurred at the periphery of grassland and other open areas that appear in a light grey colour on the underlying colour composite of the 1974 MSS image. Linear areas of forest ingrowth can be seen along portions of Highway #95 which runs north from Radium Hot Springs. These strips of ingrowth could be natural ingrowth that has occurred in cleared areas next to the highway. There are also small patches of forest ingrowth that occur in the ravines that are present where there is a break in slope between the benches along the eastern edge of the wetlands and the valley bottom. These ravine patches of forest ingrowth can be distinguished from those that occur on the flat tops of the benches by comparing Figures 4.4 and 2.4. These patches of ingrowth may be natural ingrowth in the ravines or confusion in the classification algorithm.

4.5.3 Urban Expansion

The expansion of urban areas is greater than anticipated at 705.3 ha (Figure 4.5). Areas classed as expansion are those which were not classified as urban in the 1974 image have been classified as urban in the 1991 image. The figure of 705.3 ha is an over-estimate of urban expansion because of the misclassification of some bare soil, grassland and silty water areas as urban in the 1991 classification. These erroneously classified patches add significantly to the urban area in the 1991 classification and exaggerate the expansion of urban area. The higher resolution of the 1991 image makes roads easier to identify as urban, adding to the area of the urban category. Urban expansion can be seen

Urban Expansion: Invermere and Wilmer

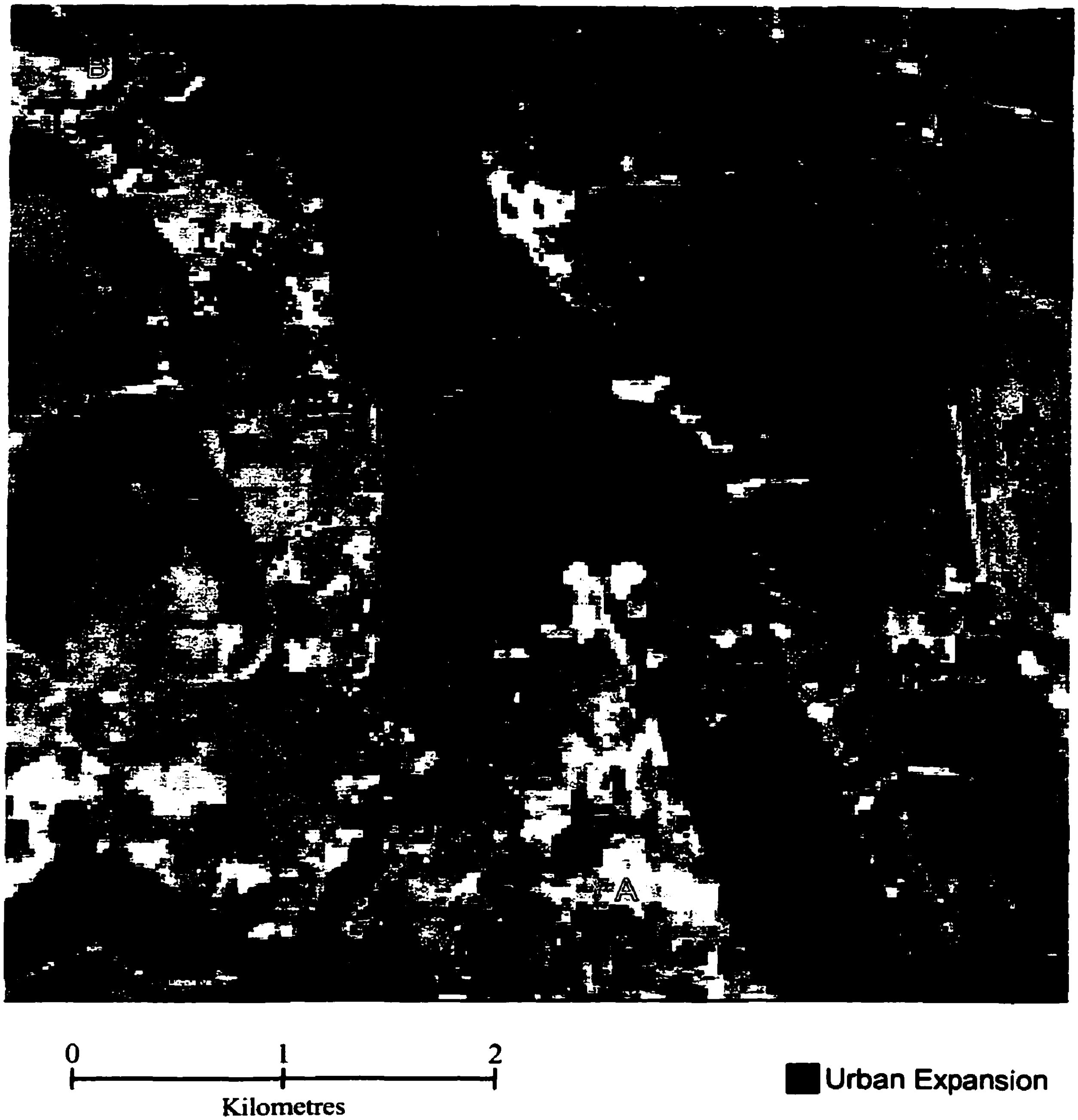

Figure 4.5 Urban expansion surrounding Invermere and Wilmer. Areas classed as expansion are those which were not classified as urban in the 1974 image have been classified as urban in the 1991 image. A=Invermere, B=Wilmer, C=sewage treatment ponds and buildings, D=railway tracks. A greyscale composite of the 1991 image is shown in the background.

both within and at the edges of Invermere and Wilmer in Figure 4.5. Expansion at the northern edge of Invermere is related to commercial and light industrial activities. Other areas of expansion visible in Figure 4.5 are housing developments in Windermere and Wilmer.

4.5.4 Expansion of Irrigated Lands

Irrigated land expansion consists of 3 different types of irrigated land: agricultural, recreational, and urban/suburban. Areas classified as irrigated land expansion are those which were classified as irrigated land in 1991 which were not classified as irrigated land in 1974. The expansion of irrigated land is shown in Figure 4.6; the expansion covers an area of 244.9 ha. Expansion could be misidentified because of the method of use and difference in overflight dates. Fallow fields in 1974 could show up as irrigated in 1991 — not all of the fields have necessarily been cleared since 1974, but they have been categorized as expansion because fallow fields typically show up as grassland in the 1974 classification. Recreational lands, typically golf courses, are less likely to be falsely classified as expansion due to the use of the courses over 3 seasons and thus continuous irrigation. The difference in dates — August 3, 1974 and September 4, 1991 — could result in an underestimation of the irrigated land expansion for agricultural uses. More fields are likely to have been harvested in September than in August, resulting in the underestimation of irrigated land size in 1991.

4.5.5 Loss of Irrigated Lands

The seasonality of agricultural irrigation can be illustrated by identifying areas of irrigated land 'loss'. Areas classified as irrigated loss are those areas which were classified as irrigated lands in 1974 which were not classified as irrigated lands in 1991, a

Expansion of Irrigated Lands

Figure 4.6 Expansion of irrigated lands. Expansion areas are those which were classified as irrigated land in the 1991 image that were not classified as irrigated land in the 1974 image. The outlines of Kootenay National Park and Dry Gulch Provincial Park are shown in grey. A greyscale colour composite of the 1991 image is shown in the background.

loss of 169.8 ha (Figure 4.7). This loss could be related to fallow fields — fields that were irrigated in 1974 may not be classified as irrigated in 1991 if they are fallow, but they have not necessarily been removed from agriculture permanently. These patches of loss are likely fields that are fallow for the 1991 season or that were cleared and the irrigation stopped before the acquisition of the image. It is doubtful that recreational and suburban uses have stopped between the two dates given the high investment and more permanent nature of these activities.

The expansion of irrigated lands (244.9 ha) minus the loss of irrigated lands (169.8 ha) still leaves an expansion of 75.1 ha. This net expansion figure could represent an overall increase in the area of irrigated land, rather than just a fluctuation due to seasonal agricultural practices. If agricultural irrigation has remained relatively constant, the increase in the amount of irrigated land could be caused by the development of golf courses. One new course can be seen in Figure 4.6, to the south of Radium Hot Springs.

4.5.6 Wetland Loss

For reasons noted previously (sections 4.4.4 and 4.4.5), the overall area of wetland increased between 1974 and 1991. The increase in wetland area is a combination of natural change and the use of satellite images to define the extent of the wetlands. The wetland loss identified as a concern is permanent in nature — wetlands that have been drained for urban or industrial use. To identify areas that may have been drained, the areas of wetland loss shown in figure 4.8 are those areas which were classified as wetlands in the 1974 image which have been classified as urban in the 1991 image (Figure 4.8). The total area of wetland loss identified was 35.5 ha. This figure is an overestimate of wetland loss as areas of misclassified urban appear in the wetlands. This

Figure 4.7 Loss of irrigated lands. Areas shown as loss are those which were classified as irrigated land in the 1974 image that were not classified as irrigated land in the 1991 image. The outlines of Kootenay National Park and Dry Gulch Provincial Park are shown in grey. A greyscale composite of the 1974 image is shown in the background.

Wetland Loss

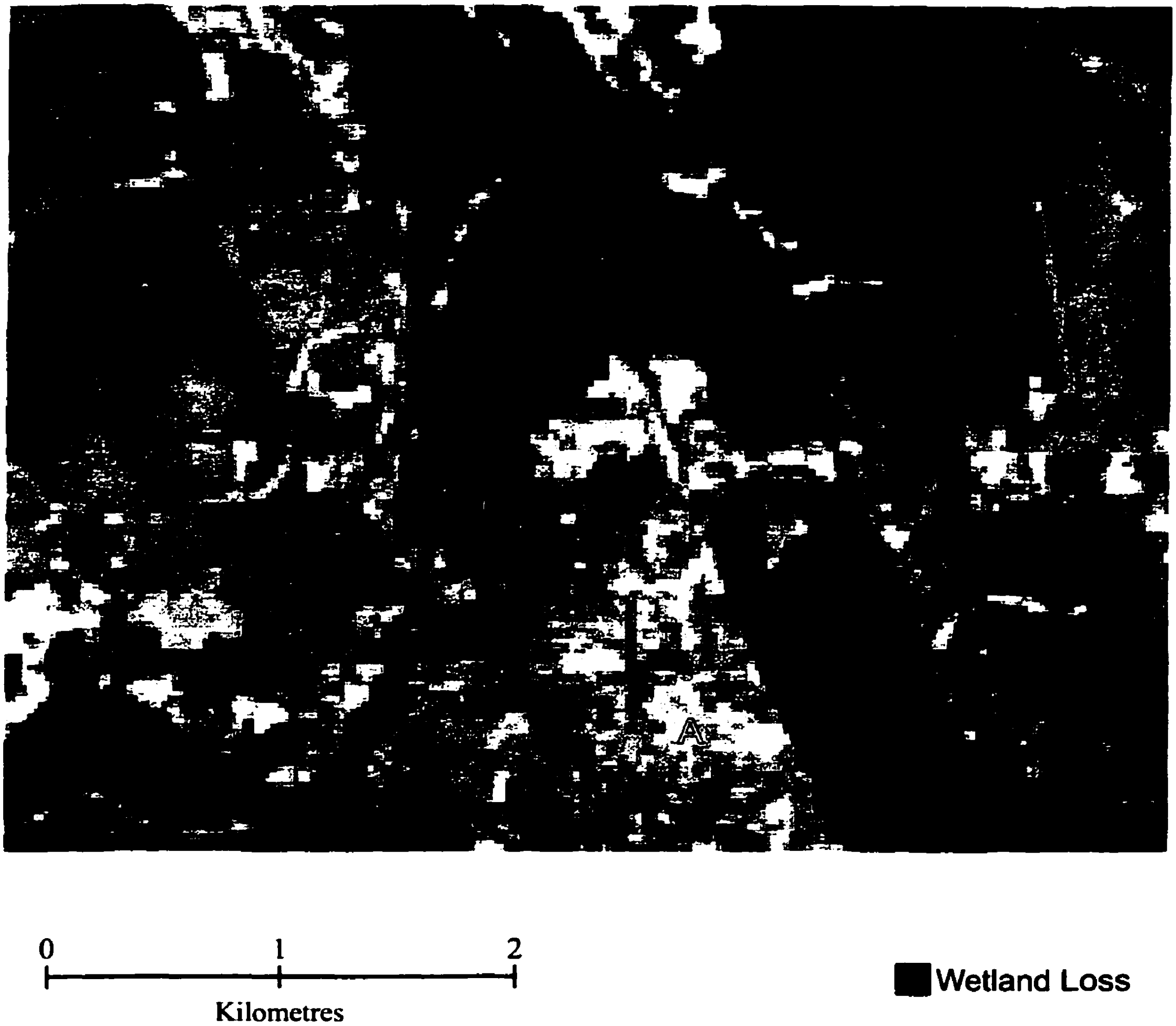

Figure 4.8 Wetland loss. Areas classed as loss are those which were classified as wetlands in the 1974 image which have been classified as urban in the 1991 image. A=Invermere, B=railway tracks, C=sewage treatment ponds and buildings. A greyscale composite of the 1991 image is shown in the background.

can be seen in Figure 4.8 north of Invermere where Toby Creek flows through the wetlands to join with the Columbia River. Portions of areas near the river have been classified as urban in 1991 and have thus appeared as wetland loss. This misclassification is likely due to low water levels revealing banks and the high silt content of the creek. As noted in the error analysis section, the rock/soil and urban categories have a similar spectral signature, which has likely led to the misclassification of these banks and silty stretches of the river as urban.

Areas of wetland loss that are not error can be seen in Figure 4.8. The sewage treatment plant constructed outside of Invermere can be identified as an area of wetland loss. The expansion of the industrial/commercial areas in the Athalmer area can be seen as two patches of wetland loss on the northern edge of the urban area. Similarly, a patch of wetland loss can be seen at the northern edge of Lake Windermere. These are likely areas that have been drained or filled to allow for the construction of buildings in this area of mixed light industrial and commercial use.

False change from wetland to urban is present in the railway tracks that cross the wetland — these tracks existed in 1974 but cannot be detected on the lower resolution MSS data. Similar false change has occurred where the roads that cross the wetlands can be better detected in the 1991 image.

Chapter 5: Conclusions

While this study has taken place in an academic setting, it has been designed as an effort that could be undertaken by an ENGO concerned about environmental change. Given this, many of the problems encountered here would likely have to be faced by an ENGO that embarked on a similar project. The problems encountered (and the solutions attempted) that are documented in this final chapter are illustrative of the barriers to fairness and competence in public participation faced by groups that wish to answer their own questions about environmental change.

The conclusions begin with a discussion of the barriers to accessing and utilizing information that were encountered. These barriers are discussed for each of the 7 categories identified by Meredith (1997), plus one additional category – access to the Internet. The discussion then moves to an evaluation of the methodology used to detect change with the satellite images; suggestions for alternate methods and areas requiring more research are also presented. A discussion of the roles of both ENGO's and GIS in the study then follows. The chapter concludes with an evaluation of the products of the study according to the metacriteria of fairness and competence.

5.1 Barriers to Accessing and Using Spatial Information

5.1.1 Lack of Awareness of Information Sources

Despite being in what is commonly described as a 'data-rich' era, digital spatial information, or geodata, particular to a local area and a specific set of questions are difficult to locate. The Internet, while a powerful means of communication, does not provide an exhaustive index of geodata. Official sites for accessing geodata, such as GeoAccess Canada or the United States' National Spatial Data Infrastructure (NDSI), provide a good index of national and regional data sets, especially those created by federal agencies. Local data other than topographic information tends to be ignored, except for the provision of links to other data providers like provincial and state governments.

Fortunately, the main information resource in this study (the two satellite images) were known earlier in the study. The existence of the ancillary data (airphotos, topographic data, rangeland data, forest cover data) were discovered after the commencement of the study. Fairly good coverage of digital topographic data and airphotos are standard for most of southern Canada, it was only the rangeland and forest cover data that were unsuspected data sources that became available through personal contacts established during the study. Additional data that was discovered but not directly used in the analysis includes the coverage of protected areas for British Columbia (used in the construction of Figure 1.1) and a coverage of ecoregions. Both of these were discovered via the Internet.

The study did not suffer from a lack of awareness of information sources. However, this is an area where the academic setting likely made a difference. High speed Internet access and easy access to experts familiar with data sources made the task of data acquisition easier for the author than would be typical for an ENGO. However, it is interesting to note that the rangeland and forest cover data were discovered through informal networking via ENGO's rather than Internet searches or formal requests. From this, it seems that good links, both formal and informal, among the public, academic and ENGO sectors are the best way to achieve a comprehensive awareness of information sources.

5.1.2 Legal Barriers to Data Access

Legal barriers, essentially related to copyright issues, are often cited as barriers to data sharing (Onsrud and Rushton, 1995). Much data sharing, or even the creation of new data sets, takes place unofficially, with legal questions set aside. The digitizing of maps is a good example – once someone creates a digital version of a hardcopy map that is copyrighted, have they broken the law? What if the digital version is redistributed to colleagues or posted on a public web site for general access? The legality of this kind of data sharing is doubtful, but it is not an uncommon practice.

The data used in this study were not denied use on legal grounds, though the satellite and topographic data have restrictions on their use as they are sold commercially. It is only through informal networks and by giving assurances that the data would not be put to any uses that infringe on copyright that these data could be obtained. The rangeland and forest cover data used in this study are not generally available to the public in digital format, but neither is their use by the public restricted. The data are sold in paper format at low cost ($10 per map sheet). Again, informal networking permitted the access to these data in digital format.

5.1.3. Financial Barriers to Data Access

Data costs in this study were mostly related to the purchase of the airphotos and equipment to collect the field data. Financial barriers were encountered in this study: the costs of collecting more accurate field data (both equipment and labour costs) were prohibitive, as would be the costs of obtaining a time series of remotely sensed data with which agricultural change could be accurately assessed. Cost barriers were associated with legal barriers when commercial data were involved. They study region was defined by the extent of the two digital topographic map sheets obtained at no charge. Expanding the study region by adding topographic sheets was possible, but the cost was prohibitive ($600 per sheet). Fortunately, the two sheets obtained covered the majority of the areas of interest.

As occurs in many ENGO's, labour in this study was on an unpaid basis; the labour 'cost' is the amount of time that can be spent given other commitments. The author of this study had the advantage of being a funded student, many ENGO's use purely volunteer labour for the majority of activities undertaken. There was no direct financial support for many of the activities required for this study, such as travel and lodging costs. This can be considered similar to the situation faced by many small ENGO's.

It is difficult to assess the total costs of this study as compared to those that would be incurred by an ENGO that decided to undertake a similar study. Access to a well-equipped computer lab with sophisticated software is not the norm for an ENGO, but it is common support for many students and a definite advantage in this study. The field GPS used in this study, while relatively inexpensive (approximately $280), is another 'free' resource available to the author that would need to be purchased by most ENGO's.

Despite the financial barriers faced in this study, acquiring data and access to equipment to undertake a land cover analysis are not insurmountable barriers. The study attempted to use only free or inexpensive data sets. All of the data used in this study were acquired with an expenditure of less than $100. This figure does not include the costs of access to information infrastructure, such as computing resources, GIS software and the GPS unit used to collect field data. Informal networking, volunteer labour, and connections with the research community could allow an ENGO to access the resources necessary to undertake a study similar to the one described here.

5.1.4 Technical Limits on Data Management

Translating the data used in the study from its native format into the format of the GIS software used was very difficult for particular data sets. The TRIM data were especially difficult to translate as they were in a government (British Columbia) format that was not directly readable by any software available to the author, resulting in the need to find a third-party software package and an operator who understood the data format. To complete the translation of the TRIM data from the Ministry of Environment, Lands and Parks (MOEP) format into a format the ERMapper® software program could read, three different software packages were used. The raster Digital Elevation Model (DEM) and vector topographic features were imported into to PAMAP® (a GIS software package that could read the MOEP format) and then exported in text format (ASCII). Unfortunately, the formatting that PAMAP wrote could not be read by ERMapper® without errors, so the data were brought into SYSTAT® (a statistical software package that can deal with large files). Within SYSTAT® the data were reformatted and exported again in text format, where it finally could be read into ERMapper®. The DEM data were then projected so that they would have the same datum as the systematic and precision corrected satellite imagery.

The vector topographic data were read into PAMAP® along with the DEM data, and subsequently exported to the Drawing Exchange Format (DXF). ERMapper® can read DXF format files, but it cannot project vector data. The data were read into MapInfo®, as it was the only GIS package available that could project the data into a datum that matched that of the satellite data. From there the data were exported again to DXF format, then read into ERMapper®.

While these procedures do not sound extremely complicated, the process was technically challenging. It should be noted that the methods used here are not the only possible solutions to data translation problems. There are other solutions to the problems described here; this approach was used because it was the simplest one found given the resources at hand. Unfortunately, an ENGO is not as likely to have access to all of the resources used by the author, especially the 4 different software packages used. Some of the problems encountered could also have been solved using freeware or shareware that is available in the public domain. This avenue requires more time and effort to discover what resources exist and which ones are appropriate for the problem at hand. Fortunately the conversion of the rangeland and forest cover data presented fewer problems, in part because of the experience with translating the TRIM data.

5.1.5 Lack of Paradigms for Data Interpretation

The lack of one commonly used methodology for classifying remotely sensed data in topographically steep areas was a problem in establishing the methodology for the study. As described in Chapter 3, topographic shadows complicate the classification of data and many different approaches have been used. Additionally, the lack of a large body of literature on cross-platform cover change detection and the nature of this type of analysis necessitated the use of post classification detection. Post classification detection is a commonly used method, but unfortunately all of the error present in both classifications is carried through to the detection of change (Jensen et al., 1997).

Methodologies are constantly changing, both in change detection and environmental analysis in general. It is difficult to enter an unfamiliar field and attempt to apply the best available procedures to solve a problem in that field. ENGO's would need to put significant effort into a study that used satellite images if they did not hold prior expertise in this field. Links with the academic and public sectors that provide avenues for ENGO's to have their questions asked and answered with current scientific techniques may be a more efficient method of problem solving.

5.1.6 Lack of Means of Managing Non-conventional Data and Information

No efforts were made to incorporate non-conventional information in the GIS analysis in this study. This was in part because of the effort needed to collect data of this type, such as local environmental knowledge, and because of the lack of adequate data models for representing non-conventional information. Community questions derived from the newspaper record are a form of local environmental knowledge used in the study. Many of these questions were actual suspicions about what was happening in the study region rather than just questions. For example, residents would see forest ingrowth on the local scale, such as on a ranch or in a field. From this and other sources of information they could draw the conclusion that forest ingrowth was a problem in the valley. Evaluating the veracity of this conclusion through the change detection analysis and representing the results as a map is an abstract form of representing local environmental knowledge. This is not representing non-traditional data or information, rather it is confirming local environmental knowledge with conventional data and analysis.

5.1.7 Barriers in Data Presentation

Data presentation barriers were found in attempts to present a comprehensive map of all change. Because of the numerous possible combinations of change between the two dates, attempts to construct a map that showed all change merely produced confusing results. The barriers to presentation here were not access to proper equipment or people with cartographic skills, but the complexity of the results. Satisfactory results were obtained by producing maps of individual trends of change, but these do not convey the full range of change in a single convenient form.

5.1.8 Access to the Internet

Access to the Internet was invaluable during this study. Internet access provided an inexpensive and rapid means of contacting people at a distance. Through the File Transfer Protocol (FTP), the Internet provided a method to retrieve public and non-public data sets. Except for the satellite images that were delivered on CD-ROM, all of the digital data from external sources were obtained via FTP. The World Wide Web (WWW) was a useful research tool for methodologies of analysis. More importantly, information crucial to solving technical problems, such as data translation, was only available over the WWW. Technical documents describing data formats and software tools for data translation are seldom found anywhere but over the Internet. Additional resources, such as email-based discussion list on GIS, can provide useful aid in technical problem solving. ENGO's embarking on any GIS project should look at the Internet as a powerful tool for data access and problem solving.

5.2 Change Detection Methodology

The classification of the satellite images and the change detection analysis produced useful products to answer the community questions identified in the newspaper record. The results confirmed the community perceptions that forest practices had removed large areas of forest, that forest ingrowth was a significant process in grassland areas, and that urban expansion and wetland loss had occurred. However, the results did have problems. The error level was slightly higher than desired, which gives less confidence to the results. The inability to separate crop cover from golf courses and other irrigated areas combined with the limited time series did not permit a detailed analysis of agricultural and recreational change, one of the questions identified in the newspaper record.

The differing spectral and spatial resolutions of the two images contributed to noise in the change detection. The difference in spatial resolution resulted in visible noise in the results of the change detection analysis. As suspected, a close examination of the change images revealed that false change detection is present along the borders of some classes. Small features, such as roads, also produced false change because of the higher resolution of the 1991 data. Filtering the data with a majority filter before comparing the images eliminated much of the false change, although some did persist.

Additional preprocessing of the satellite data may have improved the classification results. Removal of the influence of varying illumination due to topographic effects on the recorded DN's could have aided the classification of topographically steep areas. However, the review of the literature on remote sensing in topographically steep areas revealed no established method for this type of correction.

The methods described were for specific tasks, such as identifying different forest cover types in mountainous areas, rather than for change detection, and the applicability of these methods for general classification was questionable. A partial solution was found through the addition of band ratios and topographic information to the classification.

Additional topographic information, such as landscape classifications, could be useful to train the algorithm to be sensitive to local morphology. Landscape position, such as distance from water bodies or morphological form, may be useful in the classification of land cover in mountainous areas. Similar to the problem of topographic shadow, no established methodology for adding topographic information to a classification algorithm was identified. As the development of new methodologies was not the focus of this study, experimentation in new classification techniques was not undertaken.

5.3 Role of Environmental Non-Governmental Organizations

Cooperation with ENGO's in this study was essential. While the newspaper analysis served as a proxy for community concerns and provided the basis for determining the environmental questions of concern, conversations with members of active ENGO's in the area highlighted the interconnectedness of problems. The information produced here on environmental change is difficult to disseminate to the general public. Reaching key members of active ENGO's in the region is a much simpler task.

Members of ENGO's may not have the time or commitment necessary to acquire the knowledge necessary to question the assumptions and the methodology of the image analysis. However, the results of the image analysis, when presented in the form of maps, are broadly accessible. The local environmental knowledge that ENGO's and residents possess is an ideal 'tool' with which maps of environmental change can be assessed. Errors in the classification and false or missed change detection will be apparent to those who are familiar with the distribution of different cover types within the study region.

5.4 Role of Geographic Information Systems in Data Analysis

Curry (1998) states that users of GIS must move beyond the technical challenges to put GIS in a broader context. Towards this end, this study has answered community-defined rather than institutional-defined questions about the local environment. While technical problems are important to solve so that a study can be completed, and much time and effort was necessary in this study to overcome these problems, technical prowess or software mastery does not necessarily produce useful results. A simple study that answers to a social need for information is more useful than a technically sophisticated study which is not designed to answer questions that have been grounded in a broader social context. For example, a detailed inventory of land use and cover for the study region would be a useful planning tool. However, without a historic component, an inventory such as this cannot address community concerns about environmental change.

As described above (section 5.2), a lack of standard methodologies in remote sensing and the limitations of the data prevented the image analysis from achieving definitive answers to all of the questions identified. Research in new methodologies in remote sensing is not a wasted effort; advances in technical fields are what allow the kind of analysis presented here to be undertaken at all. If GIS is going to better meet the needs of environmental problem solving, gaps in methodologies need to be identified so that further research can take place.

Section 5.1 described the barriers to accessing and utilizing spatial information that were faced in this study. These barriers can be overcome if ENGO's have access to the following tools when utilizing GIS:

i. access to GIS technology (hardware and software);
ii. opportunities for training in GIS;
iii. access to the Internet;
iv. resources for solving technical problems and data access.

It is possible that some ENGO's may not need or want to undertake the task of implementing a GIS. If this is the case, for the spatial arguments of the ENGO to be present in a decision making process, an independent third part with access to the tools listed above could provide the services with a GIS. In this situation, the ENGO should have opportunities to provide feedback on the spatial information created or being used. If possible, local environmental knowledge should be represented in the system.

5.5 Fairness and Competence

Webler and Renn's (1995) criteria for meeting the standards of fairness and competence are intended to be applied to a decision making process. As such, the criteria are very detailed and specific to decision making processes. The products of this study are not intended for a particular process. Instead, they are provided to answer community questions about the local environment. In this case, the metacriteria of fairness and competence, as described in Chapter 1, are more applicable than the process-specific criteria proposed by Webler and Renn (1995). The following discussion uses the metacriteria to evaluate the usefulness of the products of this study for answering community questions.

5.5.1 Fairness

Towards the improvement of fairness, this study provides access to spatial data important for environmental decision making. Rather than providing the tools directly to ENGO's or residents, the author acted as a third party to provide these services. Community input was limited to the extraction of concerns from the newspaper record and contacts with ENGO's. Ideally the study would have also incorporated local environmental knowledge as discussed in the preceding section. However, the limitations of GIS in representing these data and the long time required for data collection made this impossible.

The products of this study are useful for incorporation with local environmental knowledge. Residents' and ENGOs' local knowledge can serve as a type of ground truth for the change images produced. The maps of trends in land cover change will become part of the perceived world of those exposed to them; the maps will become integrated with their own perceptions of the local environment.

The results of the analysis, when combined with local environmental knowledge, form a good base of information on environmental change. With better understanding of local environmental change, local ENGO's (and residents) can participate fully in debates about patterns of change. If a common, agreed upon understanding of environmental change emerges in a decision making process, participants will be able to move on the value debates necessary to formulate a response to negative trends.

5.5.2 Competence

Competence requires that the best available procedures are used for selecting knowledge (Webler, 1995). This implies that participants have the ability to understand the implications of the knowledge acquired, not necessarily all of the technical details of how the knowledge was produced. The technical nature of the land cover change detection makes it difficult for residents or ENGO's to question the study because those not trained in remote sensing and GIS are not aware of the implications of the assumptions made in the study. The limitations of the study have been described and the assumptions presented, but this is a large amount of relatively technical material for a person with no training in the field to absorb.

The difficulty in presenting a technically intricate report is not uncommon. Webler (1995) notes that decision making processes need to use preexisting knowledge to increase the level of competence of the participants in the process. Given that participants are often decision makers or members of the public, few are likely to be experts in the multitude of scientific fields that are often required for environmental decision making. Participants in a decision making process can seldom, if ever, understand all of the assumptions in all of the reports necessary to solve a complex environmental problem. Although it is perhaps more likely that collaborative efforts would be more efficient, given access to data and tools, ENGO's could act as competent providers of spatial information in a decision making process. Useful information, such as the information on land cover change described in this study, could be produced by an ENGO.

5.6 Summary

The image analysis and change detection produced useful results for answering community questions about environmental change, though not all community questions could be satisfactorily answered. As an example of a type of project that could be undertaken by an ENGO, the study was successful in overcoming barriers to accessing spatial information. While the case study was specific to the problem and region chosen, the types of problems encountered and methods used to overcome them are illustrative for an ENGO which is attempting to use spatial information to answer questions about the environment.

Fairness and competence seem to be reasonable criteria for measuring the effectiveness of public participation. As the ability of ENGO's to utilize spatial analysis techniques improves, so will the ability of the ENGO's – and the citizens they represent – to participate in environmental decision making in a manner that is both fair and competent. This work has shown some of the means of, as well as problems in, moving towards that goal.

Appendix I

1974 Comparison Proportional cross-tabulation of the classification (columns) against the verification classification (rows) for the 1974 image. Categories are as follows: 1=Wetland, 2=Rock/soil, 3=Open forest, 4=Closed forest, 5=Grassland, 6=Irrigated land, 7=Water, 8=Urban. See below for a detailed explanation of how to read the table.

	1	2	3	4	5	6	7	8	Total
1	0.0407	0.0007	0.0017	0.0024	0.0	0.0016	0.0017	0.0	0.0487
2	0.0	0.0347	0.0039	0.0	0.0026	0.0	0.0023	0.0010	0.0445
3	0.0085	0.0186	0.3861	0.0126	0.0215	0.0029	0.0023	0.0	0.4526
4	0.0	0.0004	0.0404	0.3046	0.0	0.0005	0.0001	0.0	0.3460
5	0.0002	0.0038	0.0008	0.0	0.0512	0.0	0.0020	0.0078	0.0657
6	0.0008	0.0	0.0003	0.0	0.0	0.0040	0.0	0.0	0.0052
7	0.0021	0.0	0.0	0.0	0.0	0.0	0.0208	0.0	0.0229
8	0.0	0.0027	0.0	0.0	0.0022	0.0	0.0024	0.0070	0.0145
Total	0.0524	0.0608	0.4332	0.3196	0.0775	0.0090	0.0316	0.0159	1.0

1991 Comparison Proportional cross-tabulation of the classification (columns) against the verification classification (rows) for the 1991 image. Categories are as follows: 1=Wetland, 2=Rock/soil, 3=Open forest, 4=Closed forest, 5=Grassland, 6=Irrigated land, 7=Water, 8=Urban. See below for a detailed explanation of how to read the table.

	1	2	3	4	5	6	7	8	Total
1	0.0445	0.0001	0.0061	0.0029	0.0004	0.0032	0.0001	0.0007	0.0579
2	0.0	0.0515	0.0021	0.0003	0.0097	0.0	0.0	0.0025	0.0667
3	0.0103	0.0091	0.3798	0.0438	0.0037	0.0013	0.0013	0.0051	0.4543
4	0.0	0.0035	0.0449	0.2679	0.0	0.0004	0.0001	0.0	0.3168
5	0.0004	0.0008	0.0	0.0	0.0436	0.0	0.0006	0.0058	0.0513
6	0.0004	0.0001	0.0	0.0	0.0	0.0	0.0226	0.0001	0.0232
7	0.0004	0.0001	0.0023	0.0003	0.0002	0.0074	0.0001	0.0005	0.0113
8	0.0	0.0002	0.0	0.0	0.0017	0.0	0.0003	0.0170	0.0191
Total	0.0560	0.0653	0.4352	0.3152	0.0593	0.0252	0.0123	0.0316	1.0

The values in the diagonal cells in the tables above represent the proportion of image pixels in agreement between the two classifications. For example, in table 3.1 the value of 0.0407 from the cell located at the intersection of column category 1 and row category 1 indicates that 4.07% of the image was classified as wetland in both the original classification and the verification classification. Values off of the diagonal represent disagreement between the two classifications – change.

Appendix II

Distance Between Means (1974). Calculated from training regions, values are in Digital Numbers (DN).

	Closed Forest	Irrigated	Grassland	Open Forest	Rock/soil	Urban	Water	Wetlands
Closed Forest	0	11.8	15.0	5.8	12.4	19.9	11.2	22.0
Irrigated	11.6	0	12.0	9.7	10.7	12.8	14.4	10.9
Grassland	15.0	12.0	0	6.6	5.9	4.4	9.4	13.2
Open Forest	5.9	9.7	6.6	0	6.0	10.3	7.5	13.0
Rock/soil	12.4	10.7	5.9	6.0	0	8.0	9.8	21.8
Urban	19.9	12.8	4.4	10.3	8.0	0	9.8	14.3
Water	11.2	14.4	9.4	7.5	9.8	9.4	0	4.7
Wetlands	22.0	10.9	13.2	13.0	21.8	14.3	4.7	0

Distance Between Means (1991). Calculated from training regions, values are in Digital Numbers (DN).

	Closed Forest	Irrigated	Grassland	Open Forest	Rock/soil	Urban	Water	Wetlands
Closed Forest	0	10.9	16.0	5.1	13.4	17.3	12.7	22.1
Irrigated	10.9	0	10.9	6.2	13.5	11.1	13.6	8.3
Grassland	16.0	11.0	0	7.2	9.0	4.2	8.1	13.8
Open Forest	5.1	6.2	7.2	0	7.8	9.0	7.9	11.2
Rock/soil	13.4	13.5	9.0	7.8	0	10.9	14.3	26.7
Urban	17.3	11.1	4.2	9.0	10.9	0	7.7	12.3
Water	12.7	13.5	8.1	7.9	14.3	7.7	0	8.6
Wetlands	22.1	8.3	13.8	11.3	26.7	12.3	8.6	0

References Cited

Adam, N.R. and A. Gangopadhyay, 1997. *Database Issues in Geographic Information Systems*. Boston: Kluwer.

Ahern, F.J., D.G. Goodenough, S. Jain, V.R. Rao and G. Rochon, 1977. "Landsat Atmospheric Corrections at CCRS" in: *The Proceedings of the Fourth Canadian Symposium on Remote Sensing*, Quebec: May 1977, pp.583-595. As cited in Chavez, 1988.

Anderson, J.R., E.T. Hardy, J.T. Roach and R.E. Witmer, 1976. "A Land Use and Land Cover Classification System for use With Remote Sensor Data". U.S. Geological Survey Professional Paper 964. As cited in Sabins, 1997.

Anon., 1974. "Purcell Study Almost Complete". *The Windermere Valley Echo*. Vol. 18, No. 1, p. 11.

Anon., 1974b. "Report From Victoria". *The Windermere Valley Echo*. Vol. 18, No. 9, p. 2.

Anon., 1974c. "New Plan Replaces 'Farmland Freeze'". *The Windermere Valley Echo*. Vol. 18, No. 44, p. 4.

Anon., 1979. "Old Logging Being Checked". *The Windermere Valley Echo*. Vol. 23, No. 2, p.12.

Anon., 1989a. "Snow Based Opportunities in Kootenays Focus of Study". *The Windermere Valley Echo*. Vol. 33, No. 7, p. 3.

Anon., 1989b. "Forest Licence Conversion Creates Controversy". *The Windermere Valley Echo*. Vol. 33, No. 11, p. 1.

Anon., 1989c. "RDEK Notes". *The Windermere Valley Echo*. Vol. 33, No. 41, p. 3.

Anon., 1991. "RDEK Wants to be Model". *The Windermere Valley Echo*. Vol. 35, No. 43, p. 10.

Avery, T.E. and G.L. Berlin, 1992. *Fundamentals of Remote Sensing and Airphoto Interpretation*. New York and Toronto: Macmillan Publishing Company.

BC Stats, 1996a. "Fact Sheets: Regional Districts Only". URL: http://www.bcstats.gov.bc.ca/DATA/DD/facsheet/rd.htm. Accessed on February 1, 1999.

BC Stats, 1996b. "Fact Sheets: Communities Only". http://www.bcstats.gov.bc.ca /DATA/ DD/facsheet/mun.htm. Accessed on February 1, 1999.

BC Stats, 1998. "Census 96: Sub-Census Divisions". URL: http://www.bcstats.gov.bc.ca/data/cen96/csd96a.htm. Accessed on January 31, 1999.

Berry, B.J.L. and A.M. Baker, 1968. "Geographic Sampling" in: *Spatial Analysis: A Reader in Statistical Geography*. Berry, B.J.L. and D.F. Marble (Eds.), 1968. Englewood Cliffs, New Jersey: Prentice Hall.

Bond, S., 1991. "Golf Course Boom Means Ag Base Loss". *The Windermere Valley Echo*. Vol. 35, No. 37, p. 7.

Bonham-Carter, G.F., 1994. *Geographic Information Systems for Geoscientists: Modelling with GIS*. New York: Pergamon.

British Columbia Round Table on the Environment and the Economy, 1993. *Towards Sustainability: Learning for Change*. Victoria: Government of British Columbia.

British Columbia Round Table on the Environment and the Economy, Commission on Resources and Environment, Fraser Basin Management Program, National Round Table on the Environment and the Economy, 1994. *Local Round Tables: Realizing Their Full Potential*. Ottawa: National Round Table.

Brookfield, H., 1982. "On man and ecosystems". *International Social Science Journal*, Vol. 34, pp. 375-393.

Chavez, P.S., Jr., 1988. "An Improved Dark-Object Subtraction Technique for Atmospheric Scattering Correction of Multispectral Data". *Remote Sensing of Environment*, Vol. 24, pp. 459-479.

Chavez, P.S., Jr., 1996. "Image-Based Atmospheric Corrections-Revisited and Improved". *Photogrammetric Engineering and Remote Sensing*, Vol. 62, No. 9, pp. 1025-1036.

Chavez, P.S., Jr., and W.B. Mitchell, 1977. "Computer Enhancement Techniques of Landsat MSS Digital Images for Land Use/Land Cover Assessments". *Remote Sensing of Earth Resources*, Vol., 6 pp. 259-275.

Chavez, P.S., Jr., G.L. Berlin, L.B. Sowers, 1982. "Statistical Method for Selecting Landsat MSS Ratios". *Journal of Applied Photographic Engineering*, Vol. 8, No. 1 pp. 23-30.

Clément, G., C. Larouche, D. Gouin and P. Morin, 1996. "Open Geospatial Datastore Interface (OGDI)". Unpublished report.

Cobb, I., 1991. "Elkhorn Proposal in Limbo". *The Windermere Valley Echo*. Vol. 35, No. 46, p. 1.

Colby, J.D., 1991. "Topographic Normalization in Rugged Terrain". *Photogrammetric Engineering and Remote Sensing*, Vol. 575, pp. 531-537.

[CORE] Commission on Resources and the Environment, 1994. *East Kootenay Land Use Plan*. British Columbia: Commission on Resources and Environment.

Coullahan, R., 1996. " Implementing a Data and Information System for the Human Dimensions of Global Environmental Change Programme: Context, Challenges and Progress". *Advances in Space Research*, Vol. 17, No. 8, pp. 49-58.

Coupé, R., A.C. Steward and B.M. Wikeem, 1991. "Engelmann Spruce-Subaplpine Fir Zone" in: *Ecosystems of British Columbia*. Meidinger, D. and J. Pojar (Eds.), 1991 (pp. 223-235). Victoria: Province of British Columbia, Ministry of Forests.

Curry, M.R., 1998. *Digital Places: Living with Geographic Information Technologies*. London and New York: Routeledge.

Dietz, T. and P.C. Stern, 1998. "Science, Values and Biodiversity". *Bioscience*, Vol. 48, No. 6, pp. 441-444.

Drury, S.A., 1990. *A Guide to Remote Sensing: Interpreting Images of the Earth*. Oxford and New York: Oxford University Press.

Ede, R., 1984. "The Settlement Plan". *The Windermere Valley Echo*. Vol. 28, No. 28, p.2.

Ehlers, M., 1997. "Rectification and Registration". In: *Integration of Geographic Information Systems and Remote Sensing*. Star, J.L., J.E. Estes and K.C. McGwire (Eds.), 1997, pp. 13-36. Cambridge and New York: Cambridge University Press.

Ellis, R.A., 1996a. *An Assessment of Grazing Capacity in the Forster-Horsethief Range Unit*. Report submitted to the Invermere District Office of the Ministry of Forests by Westworth, Brusnyk & Associates Ltd, October, 1996.

Ellis, R.A., 1996b. *An Assessment of Grazing Capacity in the Frances Creek Range Unit*. Report submitted to the Invermere District Office of the Ministry of Forests by Westworth, Brusnyk & Associates Ltd, October, 1996.

Gardner, J.E., 1993. "Environmental Non-Government Organizations (ENGOs) and Sustainable Development" in: *Environmental Stewardship: Studies in Active Earthkeeping*. Lerner, S. (Ed.), 1993, pp. 10-42. Waterloo: Department of Geography publication series #39.

Geographic Data BC, 1998a. "GeoData BC-TRIM". URL: http://www.env.gov.bc.ca/ gdbc/ trim.htm (accessed on: June 22 1998).

Geographic Data BC, 1998b. "TRIM I". URL: http://ldbcweb.landdata.gov.bc.ca:8001/ LdbcSystem/index (accessed on June 22, 1998).

Goodchild, M.F., 1998. "What Next? Reflections from the Middle of the Growth Curve". In: *The History of Geographic Information Systems: Perxpectives from the Pioneers*. T.W. Foresman (Ed.), 1998, pp. 369-381.

Habermas, Jurgen, 1973. "Wahrheitstheorien" in: *Wirklichkeit und Reflexion: Walter Schutz zum 60 Geburtstag*. H. Fahrenbach (Ed.), 1973, Neske: Pfullingen, pp. 211-263. As cited in Webler, 1995.

Holben, B. and C. Justice, 1981. "An Examination of Spectral Band Ratioing to Reduce the Topographic Effects on Remotely Sensed Data". *International Journal of Remote Sensing*, Vol. 2, No. 2, pp. 115-133. As cited in Chavez, 1988.

Hope, G.D., W.R. Mitchell, D.A. Lloyd, W.L. Harper and B.M. Wikeem, 1991b. "Montane Spruce Zone" in: *Ecosystems of British Columbia*. Meidinger, D. and J. Pojar (Eds.), 1991 (pp. 183-193). Victoria: Province of British Columbia, Ministry of Forests.

Hope, G.D., W.R. Mitchell, D.A. Lloyd, W.R. Erickson, W.L. Harper and B.M. Wikeem, 1991a. "Interior Douglas-fir Zone" in: *Ecosystems of British Columbia*. Meidinger, D. and J. Pojar (Eds.), 1991 (pp. 153-166). Victoria: Province of British Columbia, Ministry of Forests.

Hord, R.M., 1982. *Digital Image Processing of Remotely Sensed Data*. New York and London: Academic Press.

Jefferson, D., 1989. "Land Use Groups Told to Work Together". *The Windermere Valley Echo*. Vol. 33, No. 4, p. 12.

Jensen, J.R., D. Cowen, S. Narumalani and J. Halls, 1997. "Principles of Change Detection Using Digital Remote Sensor Data" in: *Integration of Geographic Information Systems and Remote Sensing*. Star, J.L., J.E. Estes and K.C. McGwire (Eds.), 1997, pp. 37-54. Cambridge and New York: Cambridge University Press.

Kelly, C.C. and W.D. Holland, 1961. *Soil Survey of the Upper Columbia River Valley in the East Kootenay District of British Columbia*. Report No. 7 of the British Columbia Soil Survey. Kelowana: British Columbia Department of Agriculture. As cited in Weestra, 1995.

Maloney, C., 1991. "Hunter Invests in a Healthy Elk Population". *The Windermere Valley Echo.* Vol. 35, No. 7, p. 1.

Maurer, H.E. and J.D. Oberholtzer (Eds.), 1979. *Synthetic Aperture Radar/Landsat MSS Image Registration.* NASA Reference Publication 1039.

McLean, A. and W.D. Holland, 1958. "Vegetation Zones and their relationship to the Soils and Climate of the upper Columbia Valley". Canadian Journal of Plant Science, Vol. 38, pp. 328-345.

Meredith, T.C., 1997a. "Public Participation in Community-Based Biodiversity Conservation". Paper presented at the Society for Human Ecology Conference, October 1997, Bar Harbor, Maine.

Meredith, T.C., 1997b. "Information Limitations in Participatory Impact Assessment". In: *Canadian Environmental Assessment in Transition.* A.J. Sinclair (Ed.), 1997, pp. 125-154. Waterloo: Department of Geography, University of Waterloo.

Meredith, T.C., 1998a. "Empowerment, Marginalization, and Public Participation in Community-Based Biodiversity Conservation: Mexican and Canadian case studies of spatial information management". URL: http://www.ncgia.ucsb.edu/varenius/ ppgis/papers/meredith.html. Accessed on December 2, 1998.

Meredith, T.C., 1998b. "Boosting in British Columbia: The Creation and Rise of Invermere". *Urban History Review/Revue d'histoire urbaine*, Vol.16, No. 3, pp. 271-279.

Meredith, T.C.; C. Moore; L. Gartner and W. Smith, 1994. *Canadian Critical Environmental Zones: Concepts, Goals and Resources.* Canadian global Change Program Technical Report Series No. 94-1. Ottawa: Canadian Global Change Program.

Miller, R., 1996. "Information Technology for Public Policy". In: *GIS and Environmental Modeling: Progress and Research Issues.* Goodchild, M.; L. Steyaert; B. Parks; C. Johnston; D. Maidment; M. Crane; and S. Glendinning (Eds.), 1996. Fort Collins: GIS World Books.

Monmonier, M., 1991. *How to Lie with Maps.* Chicago and London: The University of Chicago Press.

Muehrcke, P.C., 1986. *Map Use: Reading, Analysis, and Interpretaion.* Madison: JP Publications.

NASA, 1998. National Landsat Archive Production System (NLAPS): Systematic Format Description Document. URL: edcwww.cr.usgs.gov/glis/hyper/guide/ nlapssys3.html (accessed on June 17, 1998).

National Wetlands Working Group, 1988. *Wetlands of Canada*. Environment Canada Ecological Land Classification Series No. 24. Environment Canada: Ottawa. As cited in Pojar, 1991.

Onsrud, H.J., and G. Rushton (Eds.), 1995. *Sharing Geographic Information*. New Brunswick: Center for Urban Policy Research.

Otterman, J., and C.J. Robinove, 1981. "Effects of the Atmosphere on the Detection of Surface Changes from Landsat Multispectral Scanner Data". International Journal of Remote Sensing, Vol. 2, No. 4, pp. 351-360. As cited in Chavez, 1988.

Parish, R., R. Coupé and D. Lloyd, 1996. *Plants of Southern Interior British Columbia*. Vancouver: Lone Pine Publishing.

Parks Canada, 1998. *Banff, Jasper, Kootenay and Yoho - National Parks Official Visitors' Guide - Kootenay Park Highlights*. URL: http://www.worldweb.com/ParksCanada-Banff/Guide/ knphigh.htm. Accessed on July 8, 1998.

Ph.D. Associates, 1994. *Digital Chart of the World CD-ROM*. North York and Princeton: Ph.D. Associates.

Pickles, J. (Ed.), 1995a. *Ground Truth: The Social Implications of Geographic Information Systems*. New York and London: The Guilford Press.

Pickles, J., 1995b. "Representations in an Electronic Age: Geography, GIS and Democracy". In: *Ground Truth: The Social Implications of Geographic Information Systems*. Pickles, J. (Ed.), 1995. New York and London: The Guilford Press.

Pojar, J. and A.C. Stewart, 1991. "Alpine Tundra Zone" in: *Ecosystems of British Columbia*. Meidinger, D. and J. Pojar (Eds.), 1991 (pp. 263-274). Victoria: Province of British Columbia, Ministry of Forests.

Pojar, J. and D. Meidinger, 1991. "British Columbia: The Environmental Setting" in: *Ecosystems of British Columbia*. Meidinger, D. and J. Pojar (Eds.), 1991 (pp. 39-67). Victoria: Province of British Columbia, Ministry of Forests.

Pojar, J., 1991. "Non-Tidal Wetlands" in: *Ecosystems of British Columbia*. Meidinger, D. and J. Pojar (Eds.), 1991 (pp. 39-67). Victoria: Province of British Columbia, Ministry of Forests.

Proy, C., D. Tanré and P.Y. Deschamps, 1989. "Evaluation of Topographic Effects in Remotely Sensed Data". *Remote Sensing of the Environment*, Vol. 30, pp. 21-32.

Reed, B., 1989. "Kootenay Diversion Not on Hydro's List". *The Windermere Valley Echo*. Vol. 33, No. 19, p. 14.

Renn, O. and T. Webler, 1995. "A Brief Primer on Participation: Philosophy and Practice" in: *Fairness and Competence in Citizen Participation: Evaluating Models for Environmental Discourse*. Renn, O., T. Webler and P. Wiedemann (Eds.), 1995, pp. 17-33. Boston: Kluwer.

Renn, O., T. Webler and P. Wiedemann, 1995. "A Need for Discourse on Citizen Participation" in: *Fairness and Competence in Citizen Participation: Evaluating Models for Environmental Discourse*. Renn, O., T. Webler and P. Wiedemann (Eds.), 1995, pp. 1-15. Boston: Kluwer.

Resource Inventory Branch, British Columbia Ministry of Forests, 1998. "Resource Inventory Digital Data Sales". URL: www.for.gov.bc.ca/resinv/products/DigData/brochure.htm (accessed on July 27, 1998).

Riitters, K.H., R.V. O'Neill, C.T. Hunsaker, J.D. Wickham, D.H. Yankee, S.P. Timmins, K.B. Jones and B.L. Jackson, 1995. "A Factor Analysis of landscape Pattern and Structure Metrics". *Landscape Ecology*, Vol. 10, No.1, pp. 23-39.

Rinffuss, R.R. and P.C. Stern, 1998. "Linking Remote Sensing and Social Science: The Need and The Challenges" in: *People and Pixels: Linking remote Sensing and Social Science*. D. Livernman, E.F. Moran, R.R. Rindfuss, and P.C. Stern (Eds.), 1998, pp. 1-27. Washington: National Academy Press.

Rosenfield, G.H. and K. Fitzpatrick-Lins, 1986. "A Coefficient of Agreement as a Measure of Thematic Classification Accuracy". *Photogrammetric Engineering and Remote Sensing*, 52 (2): 223-227.

Sabins, F.F., 1997. *Remote Sensing: Principles and Interpretation*. New York: W.H. Freeman and Company.

Schowengerdt, R.A., 1997. *Remote Sensing: Models and Methods for Image Processing*. New York and Toronto: Academic Press.

Sjoberg, R.W. and B.K.P. Horn, 1983. "Atmospheric Effects in Satellite Imaging of Mountainous Terrain". *Applied Optics*, Vol. 22, No. 11, pp. 1702-1716.

Skyes, L., 1994. "Next Steps for National Mapping Agency (Ordnance Survey)". *The Geographical Magazine*. Vol. 66, October, p. 5.

Smyth, C.R. and J.A. Poriz, 1996. *An Assessment of the Carrying Capacity in the Steamboat Range Unit*. Report submitted to the Invermere District Office of the Ministry of Forests by Environmental Insight, December, 1996.

Star, J.L., J.E. Estes and K.C. McGwire (Eds.), 1997. *Integration of Geographic Information Systems and Remote Sensing*. Cambridge and New York: Cambridge University Press.

Strahler, A.H., T.L. Logan and N.A. Bryant, 1978. "Improving Forest Cover Classification Accuracy from Landsat by Introducing Topographic Information" in: *Proceedings, 12th International Symposium on Remote Sensing of Environment*. Ann Arbor: Environmental Research Institute of Michigan, pp 727-742.

Thompson, D., 1991. "Significance of Wetlands Not Recognized-Naturalist". *The Windermere Valley Echo*. Vol. 35, No. 18, p. 6.

Tulloch, D., 1998. "Environmental NGOs: Community Access to Technology as a Force for Change". URL: http://www.ncgia.ucsb.edu/varenius/ppgis/papers/Tulloch.html

Village of Radium Hot Springs, 1992. *Official Community Plan*. Bylaw No. 50, June, 1992.

Ward, B., 1966. *Spaceship Earth*. New York: Columbia University Press.

Webler, T., 1995. "'Right' Discourse in Citizen Participation: An Evaluative Yardstick". In: *Fairness and Competence in Citizen Participation: Evaluating Models for Environmental Discourse*. Renn, O., T. Webler and P. Wiedemann (Eds.), 1995, pp. 35-86. Boston: Kluwer.

Weestra, B.G., 1995. *Toby-Horsethief Range Unit Forage Assessment Research Project*. Report submitted to the Invermere District Office of the Ministry of Forests by Biota Consultants, February, 1995.

Wings Over the Rockies, 1997. "Columbia Valley Bird Festival". URL: http://www.adventurevalley.com/wings/. Accessed on January 31, 1999.

World Commission on Environment and Development, 1987. *Our Common Future*. as cited in British Columbia Round Table on the Environment and the Economy et al., 1994, p. 6.

Personal Communications

Smith, D., Invermere Branch of the British Columbia Ministry of Forests. August, 1997.