IMPROVEMENT IN LANDSAT LAND-COVER CHANGE RESULTS USING TIME SERIES CLASSIFICATIONS AND MULTI-TEMPORAL LAND-COVER CLASSIFICATION AND ACCURACY COMPARISON USING A RULE-BASED LOGIC: A CASE STUDY IN SOUTHERN PRIMORSKY KRAI, RUSSIA

by

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Table of Contents

List of Tables

List of Figures

IMPROVEMENT IN LANDSAT LAND-COVER CHANGE RESULTS USING TIME SERIES CLASSIFICATIONS AND MULTI-TEMPORAL LAND-COVER CLASSIFICATION AND ACCURACY COMPARISON USING A RULE-BASED LOGIC: A CASE STUDY IN SOUTHERN PRIMORSKY KRAI, RUSSIA

Abstract

Primorsky Krai is a unique area where a very rich and important ecosystem provides vital life to many endangered flora and fauna. This northern temperate forest is located near the Pacific Ocean providing a moderating climate for a unique blend of taiga and broadleaved tree species. Forest management of this region has changed over the past 35 years, during the timescale of this analysis, as a result of the Soviet Union break up and new timber demand from nearby China. The Primorsky Krai region is specifically valuable due to its unique mammal species, notably the Siberian Tiger, one of the only locations on earth where they are still found. It is very important to preserve this ecosystem.

To analyze how this forested region has changed, time-series Landsat data were analyzed for a representative path/row (path x, row x) footprint of 185km x 185k. Image data from 1976, 1989, 1998/1999, and 2009 were classified using a hybrid classification method. Resulting land cover maps indicate represent four important times during Russian history: during the Soviet Union (1976), near the time of transition (1989), in a post-Soviet transitioning economy (1998/1999), and during a more recent time of new management practices and new global forest demands (2009). Accuracy of the automated classification was assessed using a set of pixels for each class that had been selected based visual interpretation Landsat imagery and in comparison with very high spatial resolution data from Google Earth and other ancillary data. Maps were then compared to analyze land-cover change over the three periods 1976-1989, 1989-1999, and 1999-2009. Change direction from one land cover to another were analyzed further and checked

for illogical changes that might have resulted from classification error. Multiple dates were compared with one another using a combination of logic related to land use and forest succession logic and a more general process of elimination. Classification results were improved based on accuracy assessment and change detection. This technique could prove useful with time series land-cover analysis.

The main human disturbance is wetland to agriculture change in the western portion of the study site. Most of the agriculture changes occur in the lowland areas near Lake Khanka where wetlands are prevalent. Selective logging and forest succession change is more common in the eastern portion containing the dense forests of the Sikhote-Alin Mountains. Selective logging for hardwood species has historically occurred in this area and possesses a potential threat to the overall preservation of habitat area. The results, showing trends in agricultural change and logging, show overall less forest disturbance than hypothesized. This is an important finding that could support past and current logging management of this area and may also have significant implications for endangered species preservation.

Two protected wetland regions of the study site; Khankaiskii and Xingkaihu in China, are analyzed further for agricultural development that may have occurred before and after preservation status. Overall most agricultural expansion near Lake Khanka occurs between 1976 and 1989, although some expansion occurs between every date. The establishments of the Khankaiskii nature preserve in 1997 and the Xingkaihu nature preserve in 2007 appears to have had a positive impact on restoring wetland areas in the region surrounding Lake Khanka. Areas of recent agricultural expansion are noted and should be studied further.

1. Introduction and Research Objectives

1.1 Introduction

The Russian taiga is twice as large by area as the Amazon Forest and contains approximately a quarter of the world's timber reserves (Cushman, S. A. and D. O. Wallin, 2002). It also contains some of the largest patches of intact forests in the world (Bradshaw, Warkentin, et al., 2009). The Primorsky Krai study site is a part of this vast forest, containing a mix of mountain forest conifers and lowland broadleaved species. Southern Primorsky has a mix of both boreal forest and broadleaved forests due to its proximity to the climate moderating Pacific Ocean and it's further south location. The mixing of coniferous and broadleaved forests presents a very species rich area of both flora and fauna which is vital to protect. It is also one of the few places in the world that supports such a diverse group of large mammals that rely on the forests of Primorsky Krai for food and habitat. The Himalayan Brown Bear, Ussuri Black Bear, Amur Tiger, Amur Leopard, Lynx, and Wild Boar all exist in Primorsky Krai. Numbering approximately 600 individuals as of 2006, the Amur Tiger, also known as the Siberian Tiger, is found only in the region surrounding Primorsky Krai and nowhere else in the world (Carroll, C. and D. G. Miquelle, 2006).

These forests have been at risk to logging due to their use in domestic markets (i.e. within Russia) and especially recently, due to their proximity to Korea, Japan, and Chinese markets. Selective harvesting for Korean Pine and other hardwood species has been common here in the past and presents an issue with forest regeneration. In addition, the vast extent of wetlands in this region provide habitat for aquatic species and birds. Many of these wetlands have been and continue to be converted to agriculture. Little long term data is available on detailed land-cover changes in this region of the world.

There is a growing body of literature of multi-temporal remotely sensed data being used to classify forest change in many different parts of the world. The research in this document is part of a larger NASA Land-Cover Land-Use Change (LCLUC) project. The goals are to observe changes in landscape and land-based resources in Central Siberia and the RFE (Russian Far East). The project also aims to model past, present, and future consequences of various economic drivers for land-cover change and carbon (Bergen et al. 2003b; Krankina et al. 2004). Siberia specifically has been of interest, making up a very large portion of the global taiga boreal forest. Landsat data has been used in various studies to quantify changes occurring in this region (Miller, et al., 2002, Bergen, et al., 2008, Bergen, et al., 2013, Bergen, et al., 2003).

This study uses varies satellite remote sensing classification techniques using Landsat to look at how forest changes have occurred over important socio-economic time periods in Primorsky Krai. The findings of this study have important implications for the continued preservation of this important ecosystem. With potential future pressures for increased logging from nearby China, it is important to study both the rate of forest succession and the recovery and history of theses disturbances over time.

1.2 Research Goals and Objectives

The main goal of this study was to quantify land cover and land-cover change in the Primorsky study area by classifying land cover at four strategically chosen dates over a 35 year span (1975-2010). Then, land-cover change results were analyzed for the three time periods between each temporal pair of images. These change characteristics included both natural disturbance and succession and human disturbance, although we were mainly interested in human disturbance. Finally, we applied multi-date land use and forest transition logic to improve upon the results of the single-date classifications. Specifically the objectives were to:

1) Acquire four Landsat images from the dates close to 1975, 1990, 2000, and 2010 for the study site area; Geometrically and atmospherically correct imagery; Collect training and testing data.
2) Using a land-cover classification scheme, classify imagery at each single date using a hybrid supervised, unsupervised, and manual classification approach. Compute single-date accuracy statistics for each date and assess confusion matrices. Refine classifications and produce a final classification.
3) Using a change classification scheme, create forest- and land-cover change data for each of three time periods 1975-1990, 1990-2000, and 2000-2010. Analyze the results of the change direction matrices produced for each date pair.
4) Develop a logic script to improve change direction using forest transition logic for each of the three change direction time periods. Compare before and after results of both single-date classification (i.e. repeat accuracy assessment) and also change direction (compare n of pixels classed into change categories).
5) Analyze final results for ecological implications.

1.3 Thesis Overview

This study investigates landscape changes over four distinct dates. During the Soviet Union (1976), near the time of transition (1989), in a post-Soviet transitioning economy (1999), and during a more recent time of new management practices and new global forest demands (2009). Each separate dates is classified using hybrid classification techniques. Changes between these dates are analyzed. The thesis is organized as follows: Section 2 describes the study sites climate, location, history, flora and fauna, typical forest disturbances and forest succession rates, Lake Khanka, forest management and areas of wildlife preservation, relationship with China, and GIS data used. Section 3 describes the classification of the four distinct dates. This includes pre-processing procedures, overall classification methods, accuracy assessments and change detection. Section 4 details the change direction improvement using a combination of rule-based logics. The accuracy assessment and change detection results are compared before and after logic statements. In Section 5, the implication of the results are viewed. Notable trends over the four periods of Russia's socio-economic history are analyzed and discussed.

2. Study Area

2.1 The Primorsky Krai Study Site

The study site is located within the Russian Federation in the south-west of the Primorsky Krai region. It includes Lake Khanka, and a small part of the Chinese Heilongjiang Province in its north-western corner (Figure 1). This area is characterized by cold air blown in from Siberia during the winter, creating cold, dry weather. Temperatures commonly average -10^{o}C during the winter and can reach -45^{o}C in the mountains. During the summer, humid air coming from the south creates hot, rainy weather along the coastlines (up to 20^{o}C). Precipitation is modest throughout the year but peaks during the summer, with an annual average of 600-850mm (Newell, J., 2004).

The Sikhote-Alin Mountain range is found throughout Primorsky, and extends south into the study site area, mostly seen in the eastern portion of the study site. The average elevation throughout the Krai is 500m but can reach over 900 meters at the highest mountain tops, where Alpine tundra is found. Many rivers drain this mountain range, flowing into the Amur River to the West and the Sea of Japan to the southeast. During intense summers, these rivers often flood; an event worsened by the conversion of wetlands to agriculture and practices of agriculture in the area.

The center coordinates of the test site are: 44^{o} 37’ 20” N, 133^{o} 34’ 40” E. The study site is comprised of the area within Landsat WRS2 path 113 row 29.

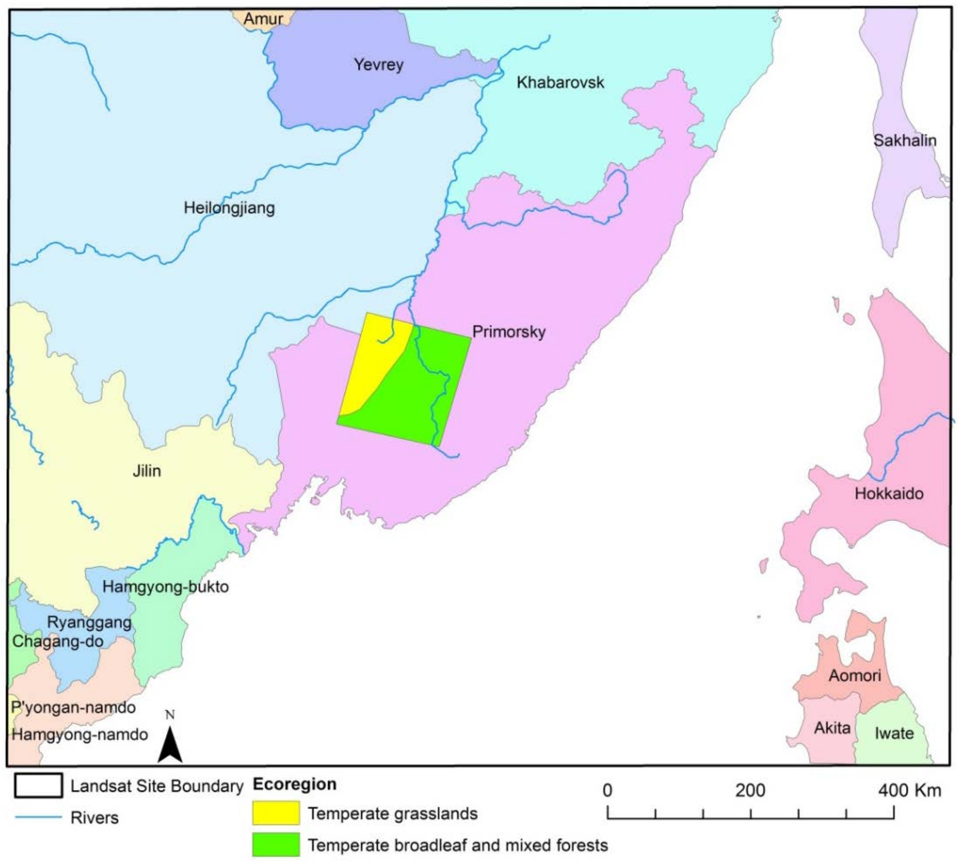


Figure 1: The region surrounding the Landsat study site (Landsat WRS-2 path 113 row 29) Administration layer derived from GADM (Global Administration Areas); eco-regions from Olson, David M., et al. (2001); rivers from VMAP0, (GISLAB)

2.2 Flora and Fauna

Primorsky Krai hosts over two thousand species of flora and the largest amount of endangered flora and fauna species of any RFE territory. This is partly due to this area not being glaciated during the Pleistocene and also that it sits between two biomes, the temperate forest biome to the south, and the boreal forest biome to the north (Cushman, S. A. and D. O. Wallin, 2002). This area is home to the Siberian Tiger (*Panthera tigris altaica*), which is almost exclusively found in the Sikhote-Alin Mountains (Carroll, C. and D. G. Miquelle 2006. Cushman, S. A. and D. O. Wallin, 2002). Figure 2 shows the range of the Siberian Tiger in Primorsky. The tigers prefer the dense vegetation found within the Sikhote-Alin mountain range, such as that in the the eastern side of the Primorsky Landsat study site.

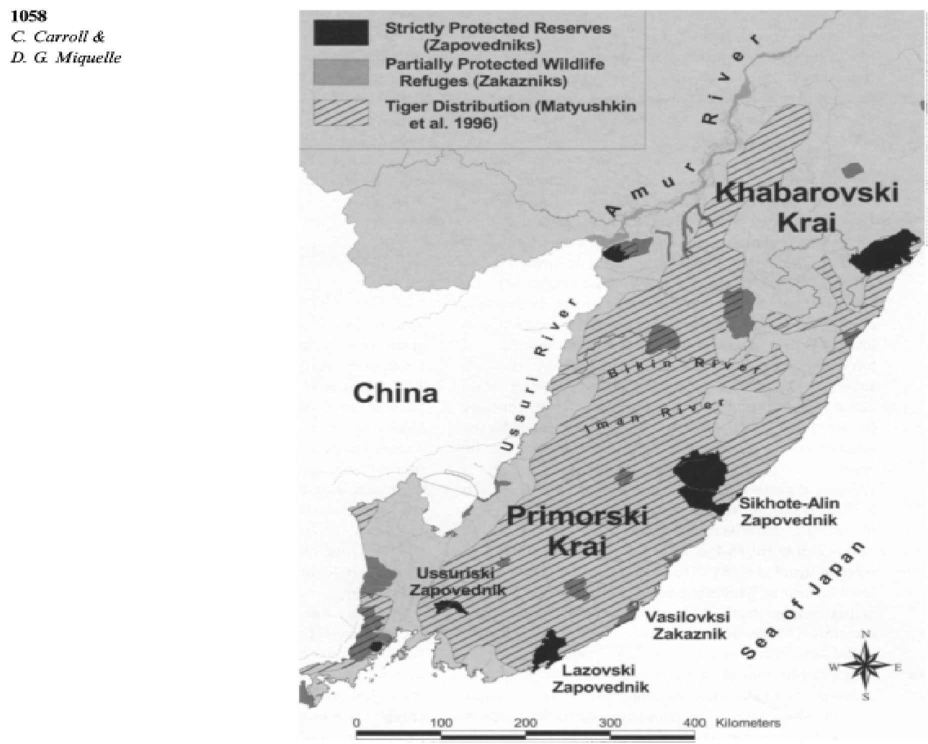


Figure 2: Location of Siberian Tigers shown with Protected Reserves (Carroll, C. and D. G. Miquelle, 2006)

Primorsky Krai is one of the more densely forested regions in RFE, with an average of 77% forest coverage. The forests in the southern part of Primorsky Krai are quite different from the northern part of Primorsky Krai. Forests gradually change from pine-needle dominated forests in the north to conifer-broadleaved forests, particularly Korean Pine, Mongolian Oak, Amur linden, and Manchurian ash in the south. Asian ginseng (*Panax ginseng*) is a widely used herbal medicinal plant now practically extinct in China and North Korea, but still found in the southern mountains of Primorsky (Newell, J., 2004). The vegetation of the Landsat study site can generally be divided into two categories. The lowland grasses and broadleaved trees, which have largely been converted to agriculture, are located mostly on the western side. The eastern side of the site has mostly upland mixed forests (Figure 3).

Wetlands are a very important ecosystem of this region for agriculture and migrating bird wildlife. Canals divert the water from wetlands, small inland lakes, and Lake Khanka to water rice plantations and drain fields for other forms of agriculture. Many migrating birds, some of which are threatened with extinction, find food and habitat in these wetlands. Agriculture expansion could potentially cause a problem with these important ecosystem areas.

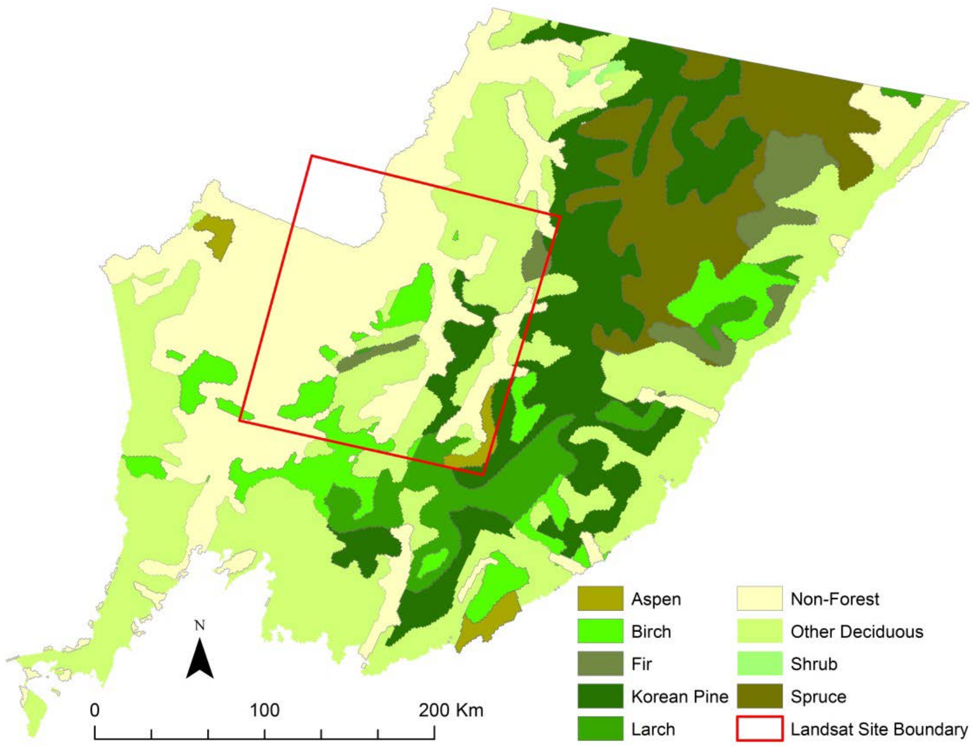


Figure 3: Dominant tree species of the study site. (International Institute for Applied Systems Analysis, Global Forest Database, 1993)

2.3 Socio-Economic History

Russian expansion into the Primorsky area began in the mid-19th Century when the federal government offered incentives to settlers (Newell, J., 2004).

Several towns and settlements were quickly established to take advantage of the promising resources in the area. Inhabitants of these areas have historically been involved in hunting, fishing, and cultivation. The creation of ports along the Sea of Japan, as well as the construction of the Trans-Siberian Railway, increased trading demand with Pacific Rim neighbors such as Japan and China in the late 19^{th} Century (Newell, J., 2004). The improved trading business boosted the prevalence of coal mining and timber production during the late 19^{th} Century. Due to the region bordering the Sea of Japan, food production, mainly fish processing, has dominated timber production as the most important economic sector recently. However, this proximity to easily accessible trading routes along with heavily forested areas threatens the region's ecosystems, as more logging companies could move into the area

2.4 Disturbance

Fire and primary forest succession are major components of the land-cover change found in the Primorsky Krai region. The warm, dry weather in the summer in combination with mixed forest creates suitable conditions for natural and human-induced wildfires, which frequent the region as a whole. Because this area is largely uninhabited or sparsely populated, most of the forest disturbance can be explained by fire (Cushman, S. A. and D. O. Wallin, 2000). Recurrent fires convert large expanses of forest into less valuable grasslands; reducing the amount of natural regeneration and threatening the mixed forests unique to the area.

Logging has also been an issue in some areas due to the long-term timber production practices that have historically taken place. In 1996 there were approximately 12 million hectares of forest land in Primorsky Krai (Cushman, S. A. and D. O. Wallin, 2000). When the Soviet Union collapsed, timber harvest in this region decreased dramatically. It is estimated that 10 million m^3 per year during the1980s were harvested and approximately just

2.6 million m^3 in 1994 was harvested (Cushman, S. A. and D. O. Wallin, 2000). Most of the harvesting that takes place has historically been selective harvesting. In many ways, selective harvesting is better than more traditional harvesting methods like clear cutting for the ecosystem, although it removes the primary forest species which can only be regained through decades of succession. In 1949, an estimated 4 million ha of Korean Pine existed in Primorsky Krai, only 2 million ha remained in 1995 (Cushman, S. A. and D. O. Wallin, 2000).

Lastly, another form of human-driven disturbance in this region is related to agriculture practice. Surrounding Lake Khanka and the river valleys nearby, agriculture change is common as the wetlands change between years. Temporary agricultural practices in grassland or wetland areas take place and is an issue when wetlands are drained. This removes habitat used by important migratory bird species and other wetland species.

2.5 Forest Dynamics

Forest succession in this region generally follows a pattern from young, to broadleaved, and then to mixed. Some areas, mostly within the Sikhote Mountains also have coniferous climax forests. Succession takes place over decades to centuries and usually more slowly for the later stages (e.g. deciduous to mixed) and relatively faster for the earlier stages (e.g. young to deciduous). Mixed forest is the primary forest type for most of the Landsat study site. After a disturbance in a spruce/fir mixed primary forest, the first trees that grow are typically birch, aspen, and larch (Cushman, S. A. and D. O. Wallin, 2002). It is important to note this forest succession since it will aid in the classification process.

2.6 Lake Khanka

Occurring in the northwestern part of the Landsat site is Lake Khanka, a large lake covering approximately 4,000 km^2 and with an average depth of just 4-5m. This lake provides an important source of water needed for irrigation and canals used in agriculture for surrounding populations in both Russia and China. Most of the drainage basin lies in Russia (95%) and most of the connected rivers are in Russia as well. On the Primorsky Krai side, the lake's natural vegetation is mostly forest steppe; an ecosystem type which creates suitable conditions for agricultural practices. Many of the areas surrounding the lake are protected due to the habitat and species rich wetlands. These wetlands provide a vital stop along the Northeast Asian Flyway. It is important to monitor these areas for potentially illegal agricultural or development practice.

2.7 Relationship with China

Immediately to the west and northwest of the study site, lies the Heilongjiang Province of China. In fact, a small portion of the northwest corner of the Landsat scene is in the border of Heilongjiang. The Amur River flows through Primorsky Krai and marks the border between Russia and China. The area surrounding Lake Khanka on the China side is much more populated, the Heilongjiang Province totals at over 38 million people. The nearest administrative region, of which a small portion resides in the Landsat scene, contains approximately 1.8 million people, most of which reside in the city Jixi, 19 miles from the Primorsky Krai border. The Heilongjiang province contains a portion of China's largest intact forest. This region is very important for the timber industry, where Korean Pine is often selectively harvested. As China's population continues to grow and industrialize, demand for timber has increased.

In 2000 Primorye Customs exported 443,000 cubic meters of hardwood to China (Lebedev, 2005). Since the 1980's the RFE has ranked among the top 3 timber suppliers to China. One of the reasons being that good quality hardwood used for decoration is very depleted in Northeast China. Between 1997 and 2003 China's log imports increased by over 4 times from 4.5 to 25.5 million cubic meters and is expected to grow (Lebedev, 2005). This growth comes with rapidly increasing per capita consumption of solid wood (for flooring and furniture), pulp and paper products, and wood used for building purposes.

2.8 Forest Industry, Management, and Wildlife Preservation

The northern temperate forests of these regions have generally had low human population densisites in the past so management may not have been very common until the 1970's. The study site's forests are very dense and difficult to access unless near a railroad or road. Most of the harvesting that takes place and has taken place in the past is selective harvesting for hardwood species. Table 1 details the volumn harvested in 2002 and 2003 derived from Lebedev. Figure 4 shows the Leskhoz (Forest Service Management units) overlaid on the study site for reference.

Table 1: Forest harvest in Primorsky Krai by Leskhoz (Forest Service Unit) in 2002-2003 (1,000m3). Timber removed for maintenance not included. Derived from Lebedev, 2005

Forest Service Unit (Leskhoz)	**Total vol. 2002**	**Total vol. 2003**
Anuchinskii	85.7	75.4
Arsenevskii	18.1	21.8
Ivanovskii	11	11.5
Kirovskii	23.9	26
Koksharovskii	79.1	95.9
Mikhailovskii	144.6	126.2
Spasskii	10.5	14.3

Chernigovskii	0	0.7
Chuguevskii	133.9	186.8
Shumninskii	71.8	95.6
TOTAL	**578.6**	**654.2**

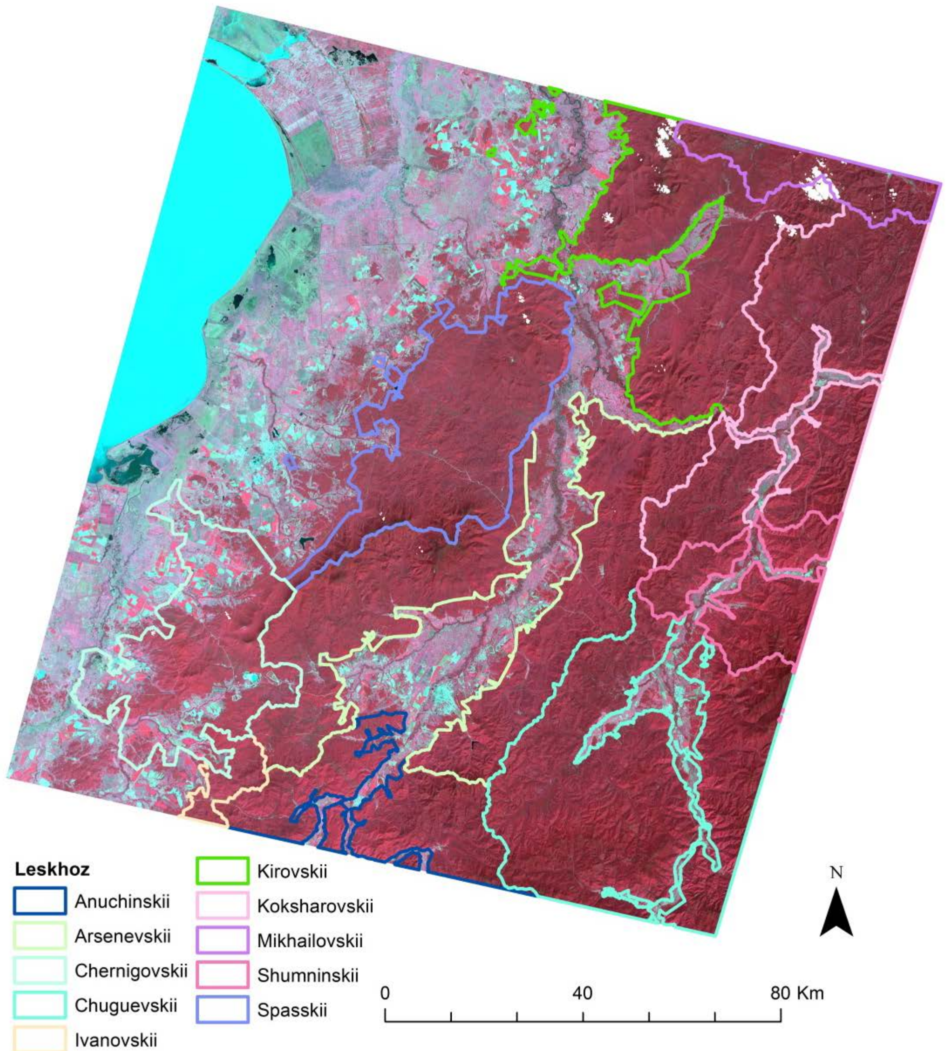


Figure 4: Leskhoz (Forest Service Units) overlaid on the Landsat p113r29 site false color infrared Landsat image composite at (August 31, 2009). Russian Forest Service, 2007

The highest amounts of timber harvested during the early 2000's were in the Chuguevskii Leskhoz in the southeast corner of the study site and the Mikhailovskii Leskhoz in the Northeast corner. Parts of the Leshkoz' extend beyond the study site, which Table 1 includes. This data gives a good reference that be compared with classification results.

A few notable regions of preserved areas exist throughout the study site and are worth examining in light of human disturbances that may take place. Bordering Lake Khanka shown in the light blue regions in Figure 5 is the Khankaiskii Nature Reserve established in 1997. This reserve consists of mostly wetlands and meadow ecosystems. Over 334 birds have been identified within the region, most of them endangered, although the protected area also encompases parts of China near Lake Khanka and is much larger than what is shown in Figure 5 (Khankaiskii Nature Reserve). Also notable are 9 species of vascular plants, rare to the RFE area. Agricultural activities range from partially to totally prohibited in this area. Located in China is the Xingkaihu Nature Reserve, also bordering Lake Khanka with similar ecosystems as the Khankaiskii Nature Reserve, founded in 2007 (UNESCO). In the south-central part of the Landsat scene lies The Tikhii (formerly Daubikhe) National Specific Sanctuary. Established in 1957 on an area of 23,000 ha, its focus is to protect water fowl and their habitats. It is located between the Sinegorka and Arsenievka rivers shown in purple in Figure 5 (Primorye Protection). This area will also be important to monitor for agricultural activity.

Other preserved areas of note are the two Saline Soil Preservation/Management regions located in the southeastern (light blue and light purple in Figure 5) area of the Landsat image. These areas are Provincial Wildlife Refuges.

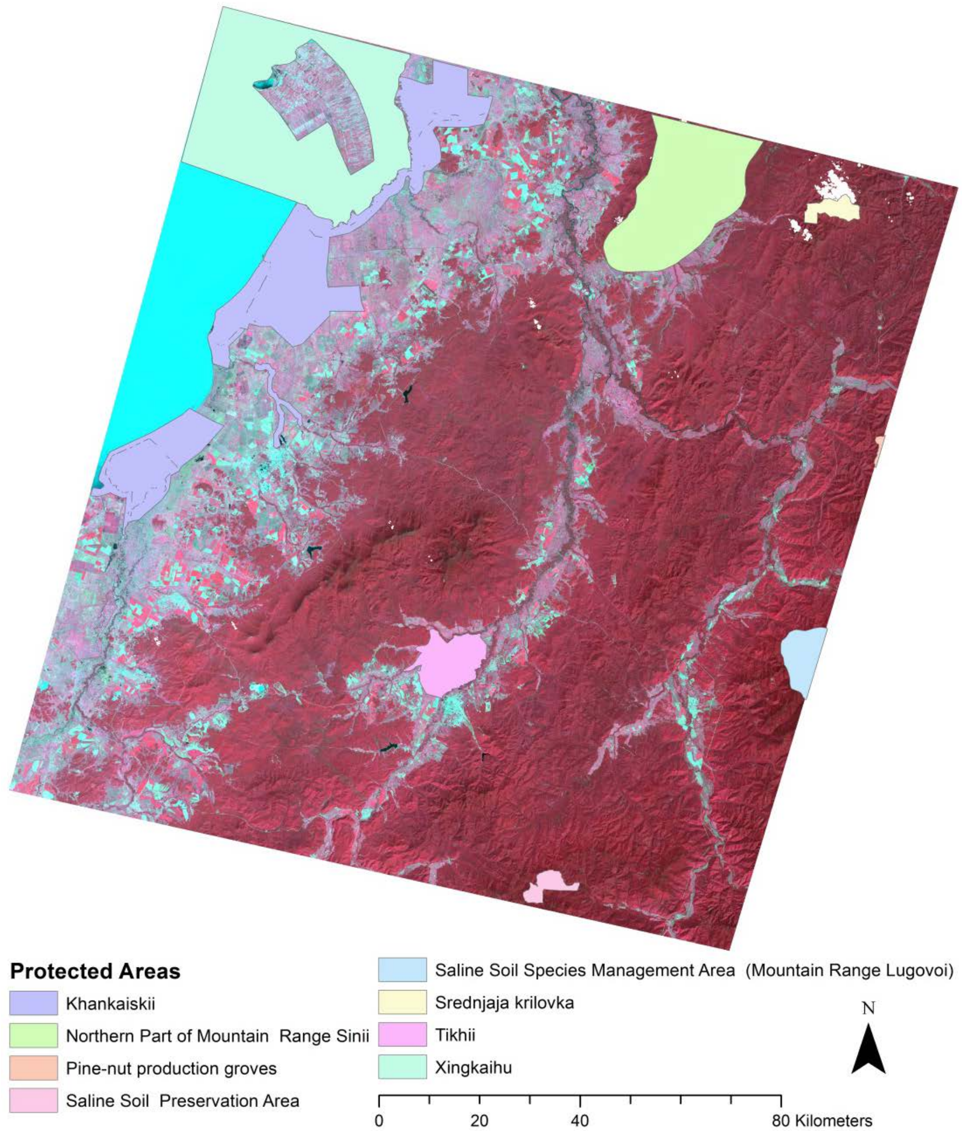


Figure 5: Protected regions shown over Landsat p113r29 study site. Color infrared Landsat image at (August 31, 2009). Simonov, 2008.

2.9 GIS Database

To aid in land-cover classification, spatial data were acquired or created to be used as ancillary data and as inputs to the classification procedure (Table 2). Using ArcGIS, roads and urban areas were digitized from 1:200,000 scale Russian topographical maps from the year 1975 (Roskartografia, 2001, ESRI). Roads (paved, dirt, winter, and forest roads) were derived from the 1975 topographic maps and analyzed for expansion in the following years using the Landsat imagery (Johnson, et al, 2013). Settlements (cities, towns, and villages) were also digitized from the 1975 topographic maps to aid in classification. Urban areas after 1975 were adjusted for growth, change, or abandonment using visual inspection of the subsequent Landsat imagery and during the classification procedure. Features were attributed using a modified Anderson Land-Cover Land-Use Classification Code (LCLUC) (Appendix A; Anderson et al. 1976) and names translated from the topographic maps. Hydrology data was downloaded as a shapefile from the global Vector Map 0 database for this region (GISLAB). Hydrology, settlements, and roads are shown in Figure 6.

Table 2: Ancillary data used in the study

Name of Ancillary Data	**Date(s)**	**Source**	**Description**
ASTER DEM		ASTER L1B	Digital Elevation Model 30m
VMAP0 Hydrology	1991-1993	GISLAB	Rivers
Roads	1976, 1989, 1998/1999, 2009	Johnson, et al, 2013,	Digitized from Russian topographic maps
Urban Areas	1976, 1989, 1998/1999, 2009	Wang, 2013	Digitized from Russian topographic maps
Protected Areas	2007	Simonov, 2008	Wildlife preservation areas
Leshkoz	2007	Russian Forest Service	Forest management boundaries
Google Earth	2009-2013		Used to create testing and training data
Administration Units		GADM	Country and state boundaries
Eco-regions	1999-2000	Olson, David M., et al. (2001)	General biomes of the globe

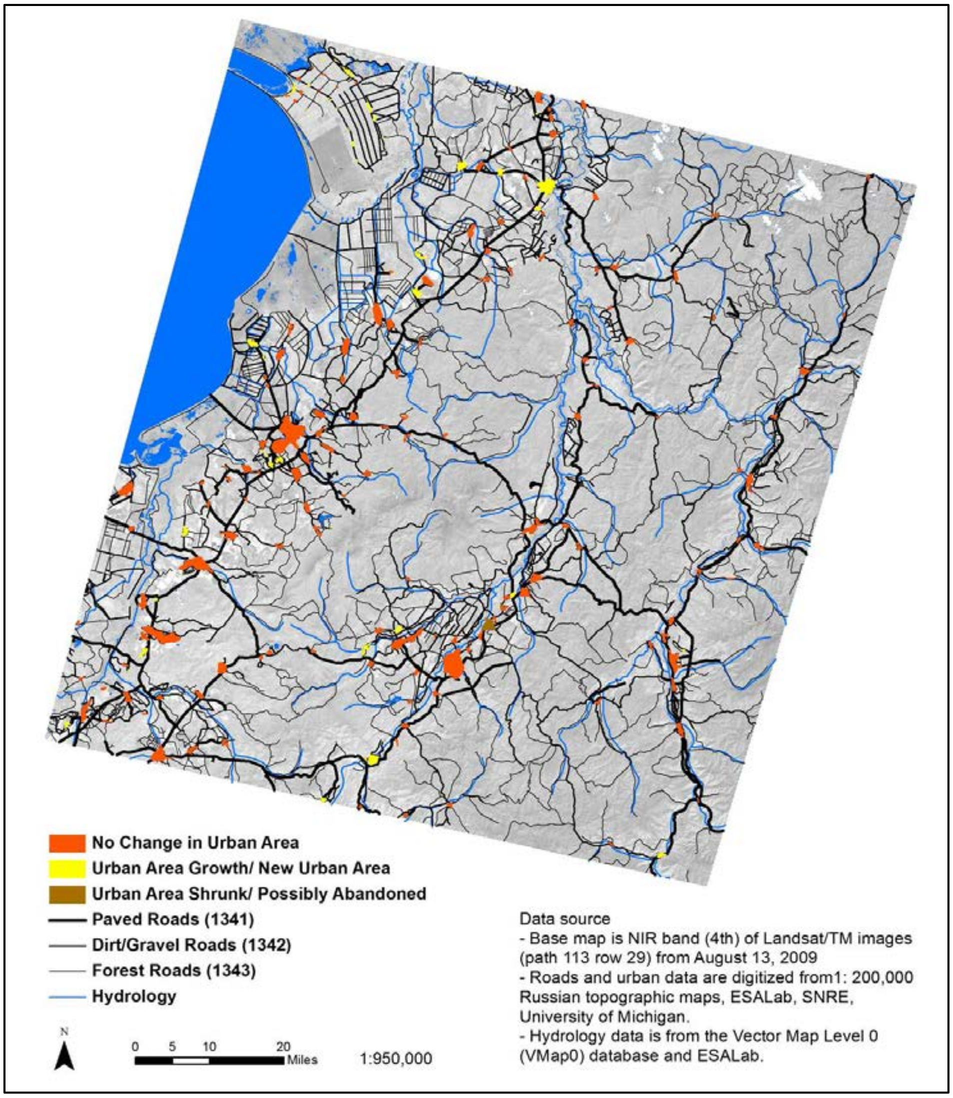


Figure 6: Urban and road infrastructure from 1976-2009 is shown. Roads and settlement areas are derived from 1:200,000 Russia Topographic Maps, Hydrology is from the VMAP0 database. These are shown overlaid on the Primorsky Landsat p113r29 Site band 4 for August 31, 2009 (Johnson, et al, 2013, Wang, 2013).

A 30 meter ASTER Digital Elevation Model (DEM) was downloaded from the NASA Reverb | ECHO website (ASTER L1B). The DEM was downloaded as raster tiles, mosaiced together, and reprojected to the study sites working projection using ArcGIS. It was important to have a DEM of good spatial resolution due to its potential use in the classification procedure as a derived feature, which we expected would assist with accounting for shadowing effects. This DEM was resampled to 60m when used for classifying the 1976 MSS Landsat image.

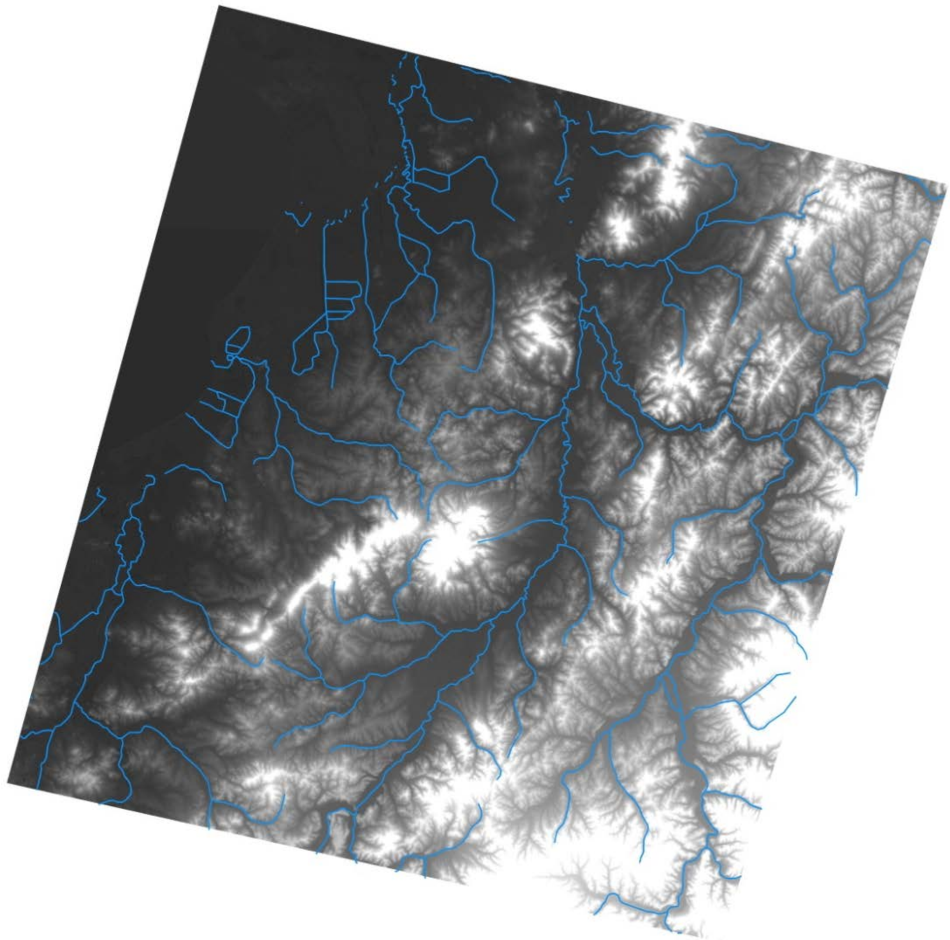


Figure 7: ASTER Digital Elevation Model (DEM) downloaded from Reverb | ECHO shown with hydrology overlaid as reference (ASTER L1B, GISLAB).

Data were reprojected to a Universal Transverse Mercator (UTM) projection using zone 53N if necessary. The projection used in this GIS database and for all data in the study is based on the parameters shown in Table 3. Additional data including the nature reserve regions and eco-regions data were downloaded from various sources and were used as ancillary data but not in the classification process (Table 2).

Table 3: Projected coordinate system used in study

Spatial Reference	WGS_1984_UTM_Zone_53N
Linear Unit	Meter (1.000000)
Angular Unit	Degree (0.0174532925199433)
False_Easting	500000
False_Northing	0
Central_Meridian	135
Scale_Factor	0.9996
Latitude_Of_Origin	0
Datum	D_WGS_1984

3.0 Summary

The Primorsky Krai study site is an important area mainly for flora and fauna preservation. To more fully understand the land cover from 1976-2009 past disturbances should be studied and forest dynamics should be understood. By analyzing the results, comparisons between eras can be made with respect to land-cover change. Forest recovery from disturbance can be better understood.

3. Land-Cover Classification and Change Detection

3.1 Introduction

The Landsat program was launched in 1972 to provide imagery to better monitor earth's environment. Since this time period, multiple Landsat satellites have been launched to improve monitoring techniques, with the most recent being Landsat 8 launched in February 2013. Time series information can be generated by comparing data derived from imagery of the same area on earth (Landsat scene) over time (Cohen and Goward, 2004). In this study, four separate years (1976, 1989, 1998/1999, and 2009), from May-August during leaf-on vegetation season, were viewed. The same Landsat scene (except for the Landsat MSS scene based on the WRS-1 row/path number but of a similar area) was used. Land-cover change, derived from classifications of each date, was measured between the three time periods; 1976-1989, 1989-1998/1999, and 1998/1999-2009. Change statistics were generated for each of these time periods between land cover types. Image processing and classifications for all four decades were completed in 2013-2014.

3.2 Methods

3.21 Image Pre-processing

Landsat MSS and TM were exclusively used for this study (Table 4). The use of multiple sensors was required due to the differences in temporal coverage by each sensor, neither of which span the entire 35-year time period of the study. Imagery was selected within approximately +/- two years of the year 1975, the year 1990, the year 2000, and the year 2010. Imagery that was the best quality, where clouds and haze were the least, representing a season with leaf-on vegetation, were chosen closest in date to each of the four years. Even though the best imagery available was chosen, each date required radiometric and atmospheric image corrections.

Table 4: Landsat scenes used for land-cover classification

Decade	Instrument	Path/row	Acquisition date
2010	TM	WRS-2	31 August 2009
2000	TM*	WRS-2	29 May 1998 21 September 1999
1990	TM	WRS-2	9 September 1989
1975	MSS	WRS-1	30 June 1976 (p122r29)

** The lack of completely cloud-free image necessitated the use of multiple scene dates for the decade of 2000. Approximately half of each image date was classified separately and later combined.*

The TM images downloaded from GLOVIS (The USGS Global Visualization Viewer) were already geometrically corrected using standard terrain correction (level 1T). The use of ground control points and a DEM were used by the USGS for geodetic accuracy. The images already contained the desired project coordinate system (WGS_1984 spheroid and datum, Transverse Mercator (UTM) Zone 53N projection). The MSS image was spatially registered to the TM images.

3.211 Radiometric Correction

Radiometric normalization was applied for all dates except 1976 using the COST without Tau (Dark Object Subtraction) normalization and atmospheric correction method (Chavez, 1996). The COST method is an image-based atmospheric correction procedure, to remove the influence of scattered light (path radiance) and arrive at standardized and calibrated actual Earth surface reflectance using the following equation:

$$\rho_{BandN} = \frac{\pi\,((L_{BandN} * Gain_{BandN} + Bias_{BandN}) - (H_{BandN} * Gain_{BandN} + Bias_{BandN})) * D^2}{E_{BandN} * (COS((90 - \theta) * \pi / 180))}$$

Where,
rBandN = Reflectance for Band N
LbandN = Digital Number for Band N
HbandN = Dignal Number representing Dark Object for Band N
D = Normalized Earth-Sun Distance
EbandN = Solar Irradiance for Band N

This equation was used to create a .gmd (graphical ERDAS model) by the Remote Sensing/Geographic Information Systems Laboratory website founded by Utah State University in 1987 to radiometrically correct imagery (Appendix C, Leica Geosystems, 2013, RS/GIS Laboratory).

3.212 Cloud-Masking

Clouds and cloud shadows were identified based on spectral signatures and masked from the database. Heavy haze was removed with clouds, while light haze was addressed later via the classification process. Cloud removal was done using a combination of manual digitization and unsupervised classification for each date. Obtaining a cloud-free image from near the decade of 2000 presented the most difficulty. Two images, one from May of 1998 and one from September of1999 each had to be cloud masked separately. Approximately half of each image was used to comprise the full Landsat scene extent. These images were classified separately and later combined using a mosaic technique. Atmospheric and radiometric corrected images are found in Appendix D.

3.22 Image Classification

Each of the four geometrically corrected, cloud-free, and atmospherically corrected images were classified individually using a hybrid classification approach and informed by several ancillary datasets. The goal was to produce the most accurate land-cover classifications for each date. The Landsat MSS 1976 image was classified using 60m resolution and the Landsat TM images, 1989, 1998/1999, and 2009 was classified using 30m resolution. Appendix B shows the classification scheme used along with descriptions of species derived (Bergen, et al., 2008).

Land cover classes used included: Coniferous, Mixed, Deciduous, Young, Cut, Burn, Agriculture, Wetland, Urban, and Water. Insect and Bare, land cover classes considered in previous RFE studies, were also potential classes but later removed since they do not apply to this area of Primorsky. After the classification procedure was complete a 3x3 majority filter was used to smooth the results. The majority filter was created using the Majority Filter tool in ArcGIS. Training and testing data, classification steps, and the accuracy assessment and change detection of classification results are described below.

3.221 Training and Testing Data

Training and testing data were created for each separate class, developed in the ESAlab at the University of Michigan. The classification scheme is located in Appendix B. The training and testing pixels were initially selected by an independent researcher, and then refined by the author as needed. The classes of all pixels were assigned using ancillary data comprised of Google Earth and topographic maps (Table 2). GPS coordinates within the Landsat scene were cross-referenced with Google Earth to determine accurate ground cover. A total of ~350 testing sites were chosen. The number of testing sites varied slightly for each date. Testing data were created as individual points in an ArcGIS shapefile format.

The number of training sites also varied for each date. Initially 65 separate training sites were created for each date but later modified where necessary for accuracy improvements. Training polygons were created using the Region Grow function in ERDAS Imagine where a search radius of 25 pixels was chosen. Region Grow allowed for the creation of a polygon made up of similar DN (Digital Number) reflectance pixels up to a radius of 25 pixels in size. Region Grow was used multiple times for each training polygon of each class.

3.222 Unsupervised Classification

Unsupervised classification was used to classify water and to separate the image spectrally for easier supervised classification. Unsupervised classification was based on the Landsat spectral bands (excluding thermal) as well as derived features. Only the water class was able to be separated using unsupervised classification due to the spectral similarities of other classes. An ISODATA algorithm was used to create 30 clusters using the best set of bands or derived features to identify water for each date. For each date, band ratio 5/2, principle component 1, and tasseled cap 2 was used. Derived features considered for use included; principal components, tasseled cap, NDVI, and band ratios.

A common water extent was created to best depict this class since changes from water to wetland or vice versa between years was not of interest in this study. This common extent was accomplished by combining the1989, 1998/1999, and 2009 water unsupervised classification results into one shapefile, showing just the overlapped areas. Landsat MSS data was excluded due to its coarser resolution of 60m. Rivers from 1998/1999 were manually digitized around since they represented the most accurate unsupervised classification out of any other year. These rivers were clipped from the classified 1998/1999 image and mosaiced to the combined water extent layers for the other three dates. This common water extent was then used for all three dates. Flooded wetlands, spectrally indistinguishable from permanent water were classified as wetland in each year. This is particularly important for 1989 since it was during a very flooded time.

Although only water could be classified correctly, unsupervised classification helped subset the image to make supervised classification easier. Since most of the wetland and agricultural areas were on the west side of the image, forest was able to be separated from most wetland and agricultural areas using unsupervised classification. These subsets were then classified separately using a supervised procedure and later mosaiced back together.

3.223 Supervised Classification

Mixed, Coniferous, Deciduous, Agriculture, and Cut classes were classified using supervised classification. Supervised classification was iterative, with the easiest classes to identify beginning first, using derived features and various bands in a layer stack. Supervised classification was done using a Maximum Likelihood Parametric Classification Rule in ERDAS. The forest subset was classified using the layer stack: bands3-6, NDVI, and Hillshade which gave less shadowing effect. Many methods of topographic correction exist (Hantson, S. and E. Chuvieco, 2011). Hillshade was chosen due to its ease of availability and improvement on classification results. Hillshade creates a shaded relief raster from a DEM by considering illumination source angle and shadows (ESRI). Output values are from 0-255, where 0 values represent shadows. Azimuth and altitude information were collected from each dates Landsat header file and used, along with the DEM, as inputs to create a Hillshade raster in ArcGIS. Including both NDVI and the DEM derived layer improved accuracy up to 5% with the similar resolution Linear Imaging Self Scanning Sensor (LISS-III) imagery in a study in the Himalayas (Saha, 2005). Each forest class, Cut, and any remaining Wetland areas were classified in the forest subset using the bands3-6, NDVI, and Hillshade layer stack.

The wetland and agriculture subset was further subdivided with a combination of manual digitization of classes using ArcGIS and iterations of training polygons for further supervised classifications. The wetland extent for each date was manually digitized using the Russian topographic maps and other Landsat dates as reference. Once wetland was removed agriculture and any other remaining classes were then identified using supervised classification. Classes were mosaiced together along with the forest subset.

3.224 Manual Digitization

Due to the spectral similarity of wetland, agriculture, and cut, the wetland classes were manually digitized before supervised classification. Many of the wetland, agriculture, and cut areas are spectrally similar and separating them from each other by supervised classification methods was unsuccessful. The confusion between wetland and agriculture was larger due to the siting of agriculture being often mixed in with or nearby wetland areas. These areas were separated by using image interpretation techniques such as site, association, texture, shape, and pattern. These classes were also easy to manually identify based on the image context and ancillary data. Once wetland was removed from the image, the other classes were much easier to classify.

The Russian 1:200,000 topographic maps were used to manually digitize the urban locations and were assumed to represent the earliest date (map data date varies, most is likely from the 1980's). This polygon layer was then used for all four dates, modified only by any growth in urban in the later images (Wang, 2013).

3.225 Accuracy Assessment

Testing pixels were compared to their classified values separately for each date. ERDAS was used to create a matrix union between the testing pixels and land cover maps from each site. The Matrix Union tool was used in ERDAS, which showed how the testing pixels and classification results overlapped with one another. Using this output both errors of omission and errors of commission could be quantified for each land-cover type. User’s, producer’s, and overall accuracy were also created for each date as well as a kappa statistic, indicating the difference between observed results and chance.

3.23 Change Detection

The four classified images were compared on a pixel-by-pixel basis over three time intervals: 1976-1989, 1989-1998/1999, and 1998/1999-2009. Based on the nine classification classes, there are total of 89 possible changes that could be observed between scene pairs. However, only a subset of these potential changes represents meaningful forest- and land-cover change. Meaningful changes were grouped into seven categories (Table 5). Non-logical changes are assumed to be mostly errors and are classified as error/noise. The change categories include: No Change, two disturbance types (Burned and Logged), Development (natural to Urban or Agriculture, and Agriculture to Urban), and three types of forest succession. “Regenerated Type I” areas are those which experienced an unknown disturbance sometime between scene acquisition dates, and have already had time to begin to re-vegetate. “Regeneration Type II” encompasses areas which were classified as disturbed (Cut or Burn) at the first data and observed as regenerating by the second. “Forest Succession” is the natural change of forest from one class to another from a disturbance originating before a previous date, or before the earliest date.

Table 5: The table provides the class names and compositions of the land-cover change categories used in the study: 1-Conifer, 2-Mixed, 3-Deciduous, 4-Young, 5-Cut, 6-Burn, 8-Wetland, 9-Agriculture, 10-Urban, 12-Water. (Modified from Bergen et al. 2008)

	Change Category	From Class (Time 1)	To Class (Time 2)
1	No Change	1,2,3,4,5,8,9,10,	same as time 1
2	Logged	1,2,3,4	5
3	Burned	1,2,3,4,5,6,8,9	6
4	Regenerated Type I	1,2,3	4
		1,2	3
5	Regenerated Type II	5,6	4,3,2
		9	8,4,3
6	Forest Succession	4	3,2
		3	1,2
		2	1
7	Development	1,2,3,4,5,8	9,10
		9	10
8	Other/Noise	Various combinations	Various combinations

3.3 Results and Discussion

3.31 Single-Date Image Classification Results

In each of the four dates (1976, 1989, 1998/1999, and 2009), the majority of the Primorsky study site is covered by mixed forest (as shown in Figures 9-12). Total forest amounts typically cover 61.59-65.19% (depending on image date) of the total study site (Table 6) and less than 10% of that amount is classed as either Deciduous or Conifer. Agriculture is very extensive along flood plains of Lake Khanka and the nearby river valleys, in total covering 18.45-21.46% of the site. Agriculture notably increases from 1976 to 1989 by 3%. Wetland is also prominent at 11.76-15.08% of the site. Logged areas make up a small percentage of disturbances in this area of Primorsky, characterizing 0.12%-0.57% of the landscape. Cuts are highest in 1976 and 1989 and decrease in 1998/1999 and 2009. Figure 8 shows the proportion of total land-cover including water for each date.

Table 6: Total amount of each land cover class in the site

	Class	1976	1989	1998/ 1999	2009
Forest Type, Successional State, Disturbance Class (%)	Conifer	2.86	3.67	2.44	2.85
	Mixed	54.76	53.91	57.13	52.76
	Deciduous	6.71	2.59	4.62	6.14
	Young	0.06	0.81	0.85	0.79
	Cut	0.46	0.57	0.12	0.26
	Burn	0.01	0.00	0.00	0.00
	Insect	0.00	0.00	0.00	0.00
	Total Forest	***64.87***	***61.56***	***65.16***	***62.80***
Other Land Cover (%)	Wetland	14.98	15.07	11.76	14.88
	Bare	0.00	0.00	0.00	0.00
	Urban	1.68	1.87	1.74	1.78
	Agriculture	18.47	21.50	21.34	20.54
	Total	***100.00***	***100.00***	***100.00***	***100.00***

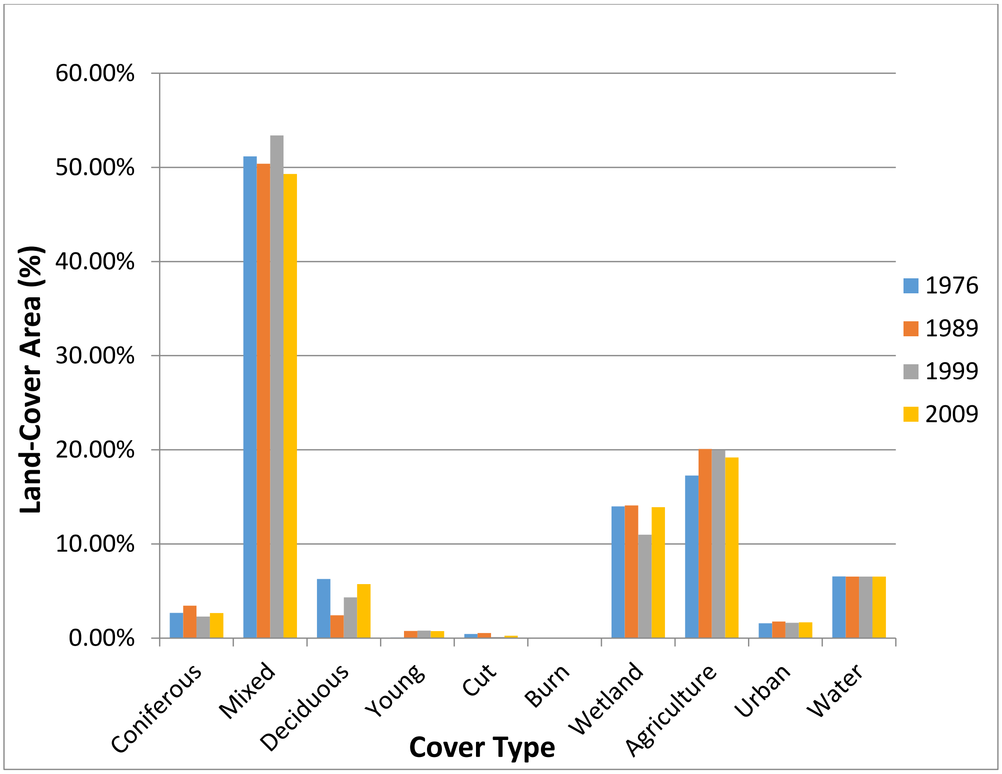


Figure 8: Land cover type proportions for each of the four dates; 1976, 1989, 1998/1999, and 2009 in the Primorsky Krai Landsat study site. Figure includes water.

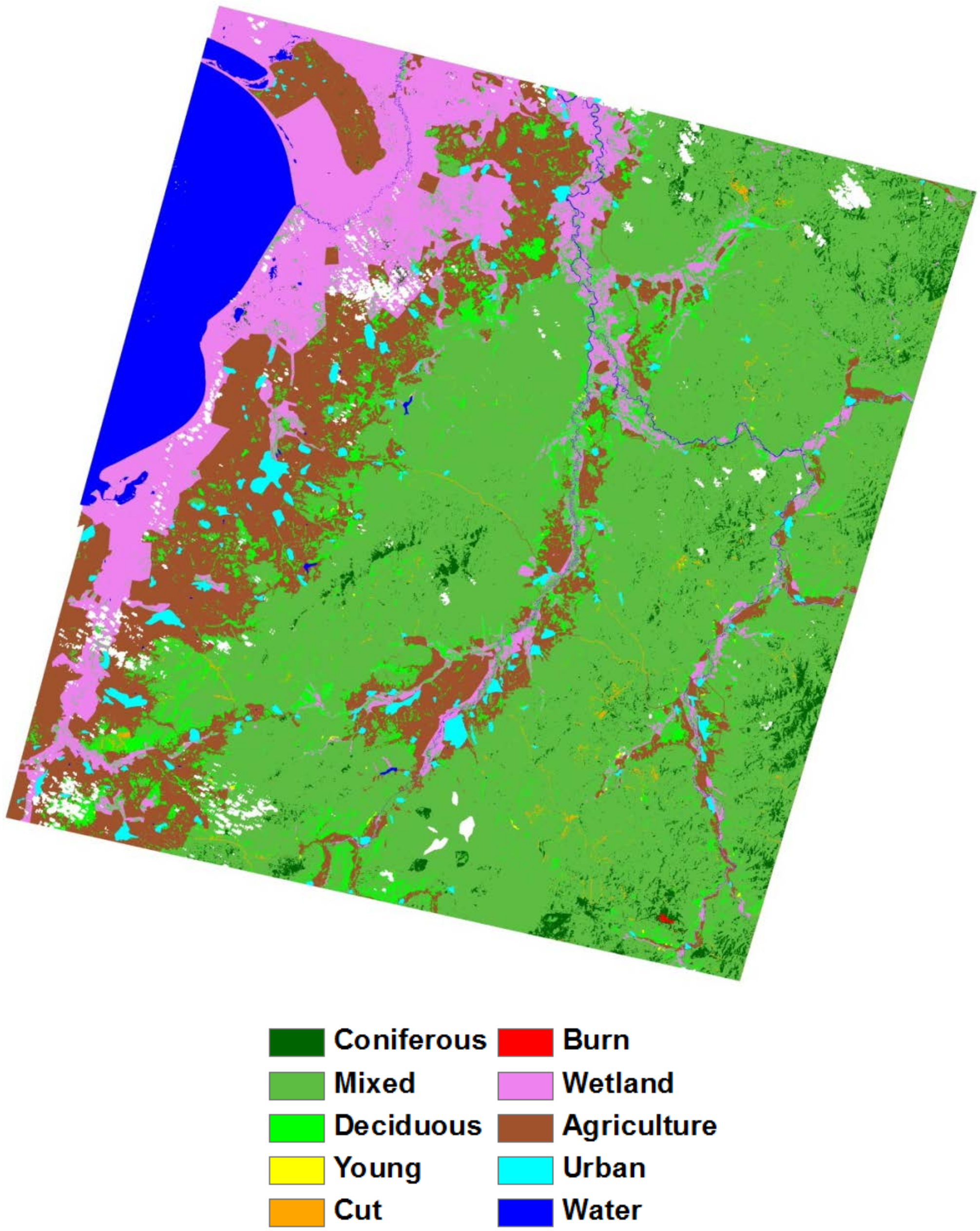


Figure 9: Landsat MSS land-cover classification results from June 30, 1976 (p122r29, WRS-1)

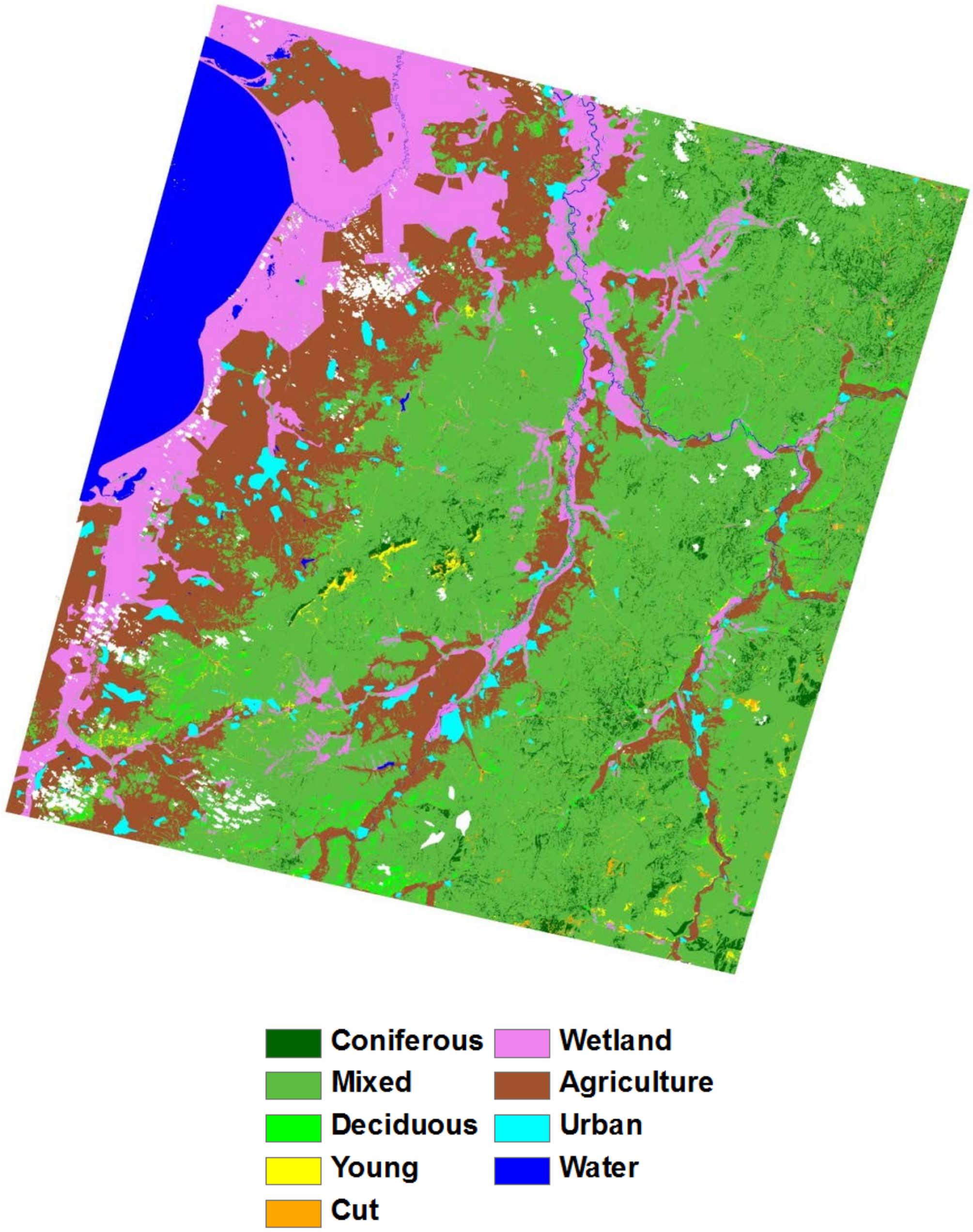


Figure 10: Landsat TM land-cover classification results from September 9 1989 (p113r29, WRS-2)

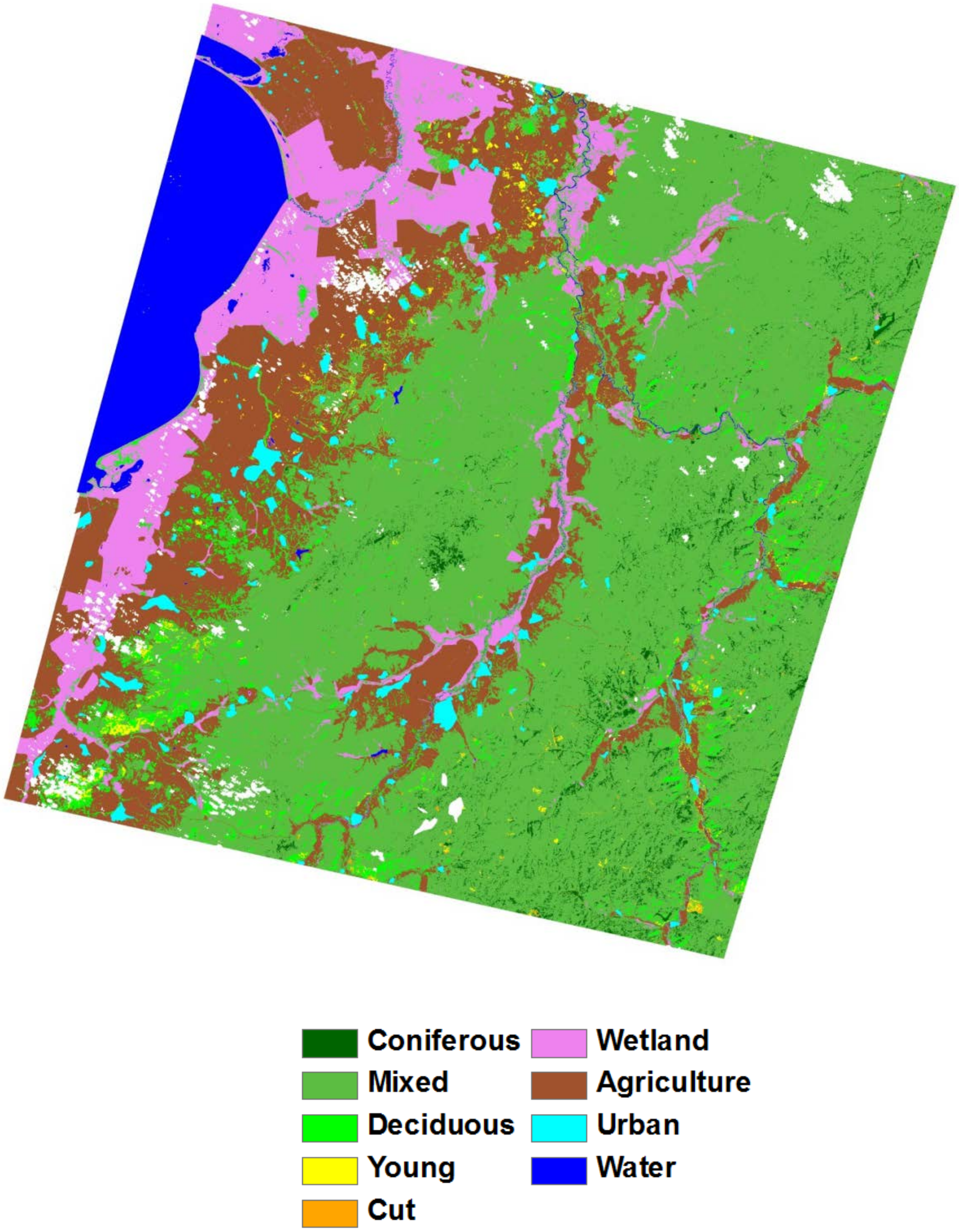


Figure 11: Landsat TM land-cover classification results from May 29, 1998 and September 21, 1999 (p113r29, WRS-2). Dates were classified separately and later combined.

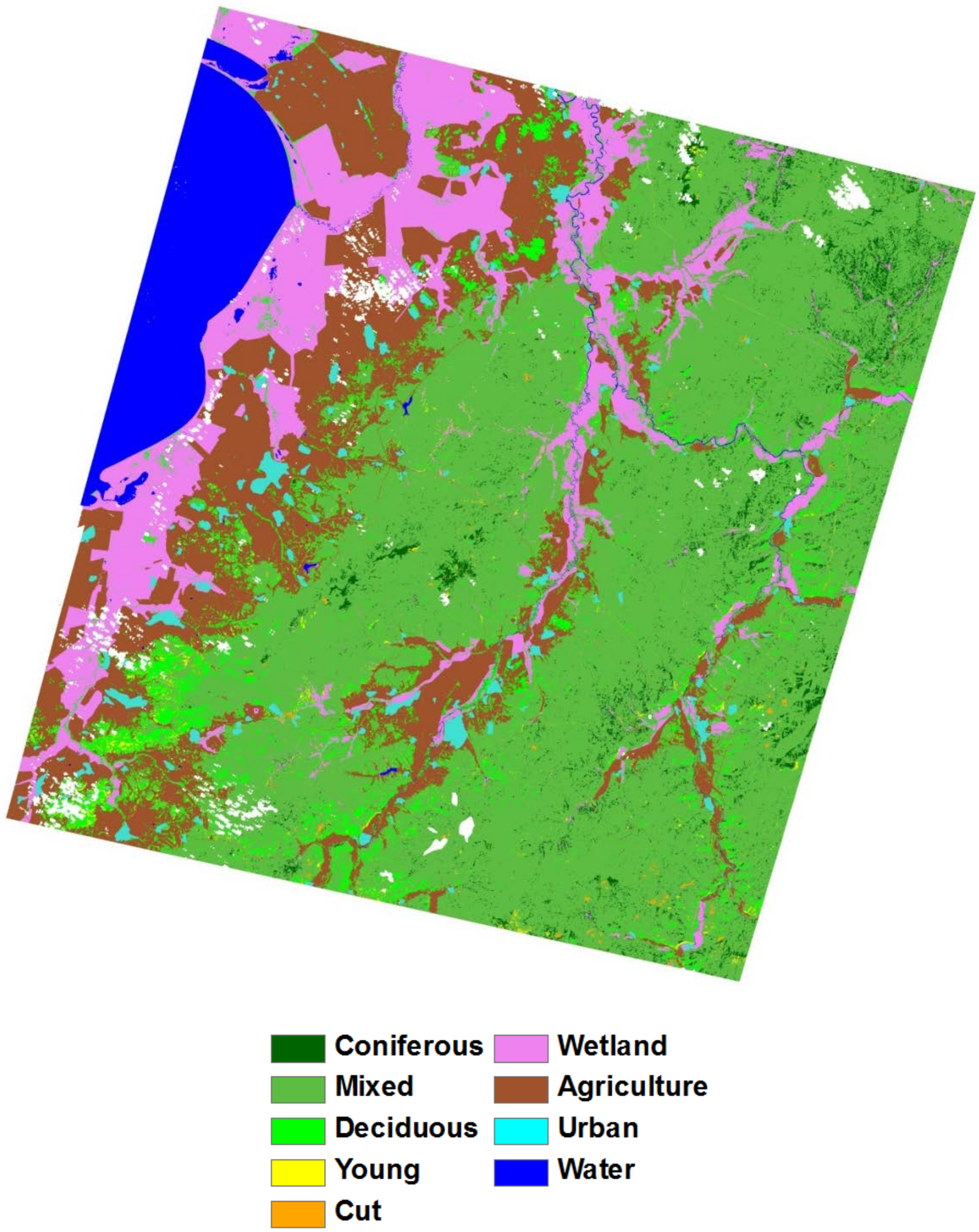


Figure 12: Landsat TM land-cover classification results from August 31, 2009 (p113r29, WRS-2)

3.311 Accuracy Assessment

Overall producer's accuracy is high (>89%) for all four periods (Table 7). Landsat MSS has slightly lower overall accuracy which can be expected from the coarser resolution of the imagery. Several land-cover types had confusion.

The largest producer's error occurs with the coniferous and deciduous classes for most of the dates. The forested area was difficult to classify due to the study sites location in the Sikhote-Alin Mountains. Confusion between shadowing of forest types was an issue that was only partially corrected by including the DEM-derived Hillshade layer in the supervised classification layer stack. Attempts at correcting this confusion are undertaken in the next section where forest succession is compared to change direction using these classification results. Cut also has a low producer's accuracy at 79.2% in 1976 and 69.6% in 1998/1999. This may be due to both the small size of cut areas and low number of cuts in the region. Full accuracy tables are provided in Appendix F.

Table 7: Producer's accuracy for all land cover classes shown with number of testing sites.

Class	N	1976	N	1989	N	1998/ 1999	N	2009
Conifer	25	76.0	25	80.0	25	80.0	25	76.0
Mixed	100	99.0	100	99.0	98	100.0	100	93.9
Deciduous	50	83.3	50	75.0	50	83.3	50	91.7
Young	25	84.0	25	100.0	25	100.0	24	91.3
Cut	25	79.2	24	91.7	25	69.6	22	95.2
Burn	5	100.0	n/a	n/a	n/a	n/a	n/a	n/a
Insect	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Wetland	30	86.7	30	93.3	30	83.3	31	93.5
Agriculture	50	85.7	49	89.6	50	95.9	49	93.8
Urban	25	100.0	25	100.0	25	100.0	25	96.0
Bare	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Water	23	87.0	25	100.0	25	96.0	25	92.0
Overall		***89.3***		***92.3***		***91.9***		***92.2***
KHAT		***0.87***		***0.91***		***0.90***		***0.91***

3.312 Change Detection

Forest- and land-cover change was quantified by preforming a matrix union comparing two subsequent images. The Matrix Union tool was used in ERDAS, which showed how the first and subsequent date classification results overlapped with one another. The output from the Matrix Union created change matrices for the three time periods 1976-1989, 1989-1998/1999, and 1998/1999-2009 (Appendix G). Most of the region has no change between each time period (Table 8). Change generally increases from 1976-2009, showing that disturbance has generally decreased since 1976. Development is the highest from 1976-1989 mainly due to agricultural growth during this time. Regeneration I and Regeneration II steadily increase from 1976-2009 which hints at pre 1976 disturbance occurring in this region as well as disturbance between years. The pre-1976 disturbance can also be seen by the larger amount of Forest Succession from 1976-1989. Noise/error includes misclassification and “other” change categories not of interest (e.g. wetland to forest change). Noise/error is highest between the earlier time periods and lowest from 1998/1999-2009. This may be due to the quality of imagery and classification improvement since 2009 was classified last.

Table 8: Percent of land exhibiting change in land-cover change classes. (Adapted from Bergen et al. 2008, with 2010 added)

Change Category	1976-1989	1989-1998/1999	1998/1999-2009
No Change	80.46	82.61	83.11
Logged	0.48	0.09	0.21
Burned	0.00	0.00	0.00
Regeneration I	2.01	2.03	3.44
Regeneration II	1.22	2.66	3.29
Forest Succession	5.13	3.38	3.42
Development	5.01	3.02	2.73
Noise Error	5.70	6.21	3.80

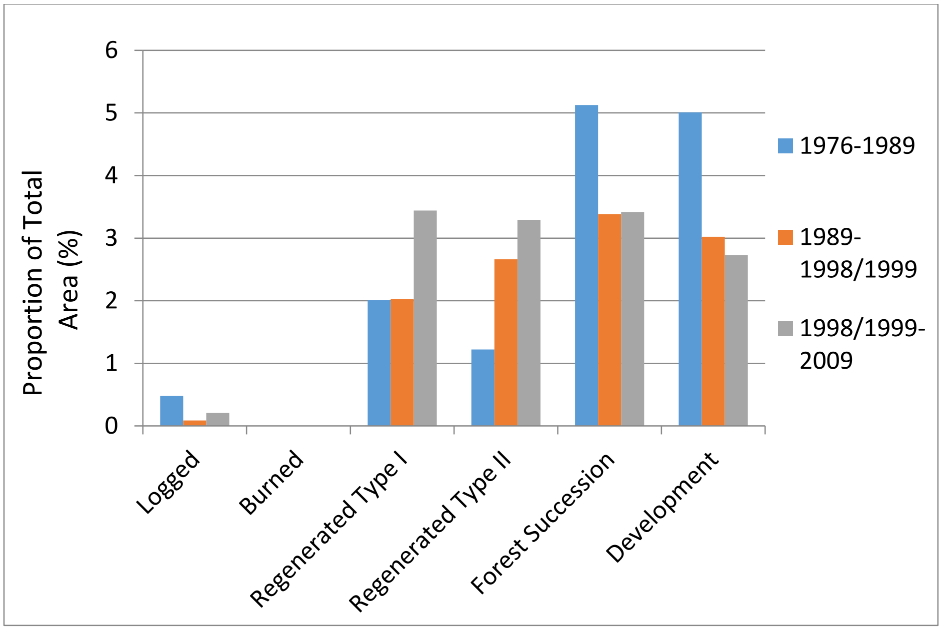


Figure 13: Percent of land exhibiting change in land-cover change classes. No Change and Noise/Error are excluded (Adapted from Bergen et al. 2008, with 2010 added)

3.4 Summary

Four separate Landsat images were classified for the same Primorsky region. Maps, land-cover statistics, accuracy assessment, and change detection were all generated from the classification procedure. Overall accuracy of classification was high but some classes had lower producer's accuracy than others. Mostly the forest types had issues due to shadowing effects causing separate forest types to be spectrally similar. These errors show up in the Noise/error change category and the next section describes steps taken to improve (reduce error) in the classification and change analysis.

4. Change Direction Improvement using Logic Rules

4.1 Introduction

Spectral classifiers must assign pixels which represent a range of variability of any given land-cover class on the ground to a small set of discrete classes. This can sometimes pose challenges. For example some pixels may have spectral patterns that are borderline between two closely related classes (e.g. the three forest classes). In these cases a pixel might be classed into class A at one date and class B at the subsequent date, but in fact did not actually change class if observed on the ground. Multi-date classifications offer a potential way to improve individual date classifications by analyzing the change trajectories of pixels and considering them either logical or non-logical and then potentially re-classing a pixel at one or more dates. For example a logical change might be Young regeneration at date 1 and at date 2 and Deciduous at date 3. A non-logical change might be Deciduous at date 1, Conifer at date 2 and Deciduous at date 3. In this case we suspect that the middle date classed as Conifer is probably classification error and would most logically be Deciduous.

Based on user knowledge of direction and pace of forest transition as well as land-use practices it is possible to group most from-to change directions into logical and illogical categories. In Table 8, the logical categories of change are listed and the illogical categories are listed as other/noise. Illogical categories include both changes that do not make sense and also changes deemed insignificant. Non-significant changes would be dependent on the objective of the classification. An example is Wetland which may fluctuate from year to year in some places between other classes.

Most of the logic is based on what would be expected in natural forest transition dynamics for the southern Primorsky region. Southern Primorsky

Krai typically regenerates in this order starting with a disturbance: Young to Deciduous, Deciduous to Mixed. Most maturing or mature forest in the Primorsky site are Mixed and would stay in this category on maturation, however forests do eventually succeed to more pure Conifer forest (in this region mostly due to elevation and aspect). Using this logic, multi-date images can be compared and illogical changes can be noted.

4.2 Methods

Illogical changes were corrected on a pixel by pixel basis using a scripted modeling approach in ERDAS IMAGINE. ERDAS models used are provided in Appendix H. Depending on the multi-date changes taken place, slightly different methodologies were used to correct for illogical changes. It is not enough to warrant a reclassification when a change between only two dates is illogical since the error could simply be that one of the two dates was classified incorrectly and we don't necessarily know which the incorrect one is. In order to alter a pixels classification type, typically at least three dates were viewed to see what the category should be. For example, if 1998/1999 is classified as Mixed and the other three dates (1975, 1990 and 2010) are Conifer, then it is likely that the pixel in 1998/1999 should be reclassified as Conifer (Table 9, statement 31). Table 9 shows all of the statements used for these changes. We were conservative in developing and applying logic-based change.

Table 9: Logical statements used to reclassify classification results. Y1=1976, Y2=1989, Y3=1998/1999m and Y4=2009.

1. If (Y1=Wetland) and (Y2 and Y3 and Y4=Coniferous) Then Y1=Coniferous
2. If (Y1=Wetland) and (Y2 and Y3 and Y4=Mixed) Then Y1=Mixed
3. If (Y1=Wetland) and (Y2 and Y3 and Y4=Deciduous) Then Y1=Deciduous
4. If (Y1=Wetland) and (Y2 and Y3 and Y4=Young) Then Y1=Young

5. If (Y2=Wetland) and (Y1 and Y3 and Y4=Coniferous) Then Y2= Coniferous
6. If (Y2=Wetland) and (Y1 and Y3 and Y4=Mixed) Then Y2=Mixed
7. If (Y2=Wetland) and (Y1 and Y3 and Y4=Deciduous) Then Y2=Deciduous
8. If (Y2=Wetland) and (Y1 and Y3 and Y4=Young) Then Y2=Young
9. If (Y3=Wetland) and (Y1 and Y2 and Y4=Mixed) Then Y3=Coniferous
10. If (Y3=Wetland) and (Y1 and Y2 and Y4=Mixed) Then Y3=Mixed
11. If (Y3=Wetland) and (Y1 and Y2 and Y4=Deciduous) Then Y3=Deciduous
12. If (Y3=Wetland) and (Y1 and Y2 and Y4=Young) Then Y3=Young
13. If (Y4=Wetland) and (Y1 and Y2 and Y3=Coniferous) Then Y4=Coniferous
14. If (Y4=Wetland) and (Y1 and Y2 and Y3=Mixed) Then Y4=Mixed
15. If (Y4=Wetland) and (Y1 and Y2 and Y3=Deciduous) Then Y4=Deciduous
16. If (Y4=Wetland) and (Y1 and Y2 and Y3=Young) Then Y4=Young
17. If (Y1=Coniferous or Mixed or Deciduous or Young or Cut) and (Y2 and Y3 and Y4=Wetland) Then Y1=Wetland
18. If (Y2=Coniferous or Mixed or Deciduous or Young or Cut) and (Y1 and Y3 and Y4=Wetland) Then Y2=Wetland
19. If (Y3=Coniferous or Mixed or Deciduous or Young or Cut) and (Y1 and Y2 and Y4=Wetland) Then Y3=Wetland
20. If (Y4=Coniferous or Mixed or Deciduous or Young or Cut) and (Y1 and Y2 and Y3=Wetland) Then Y4=Wetland
21. If (Y2=Coniferous or Mixed) and (Y1 and Y3 and Y4=Agriculture) Then Y2= Agriculture
22. If (Y3=Coniferous or Mixed) and (Y1 and Y2 and Y4=Agriculture) Then Y3= Agriculture
23. If (Y1=Coniferous) and (Y2 and Y3 and Y4=Mixed) Then Y1=Mixed
24. If (Y2=Coniferous) and (Y1 and Y3 and Y4=Mixed) Then Y2=Mixed
25. If (Y3=Coniferous) and (Y1 and Y2 and Y4=Mixed) Then Y3=Mixed
26. If (Y1=Deciduous) and (Y2=Coniferous) and (Y3 and Y4=Deciduous) Then Y2=Deciduous
27. If (Y1 and Y2=Deciduous) and (Y3=Coniferous) and (Y4=Deciduous) Then Y3= Deciduous
28. If (Y1=Coniferous) and (Y2=Deciduous or Agriculture) and (Y3 and Y4= Coniferous) Then Y2= Coniferous
29. If (Y1 and Y2=Coniferous) and (Y3=Deciduous or Agriculture) and (Y4= Coniferous) Then Y3=Coniferous
30. If (Y2=Mixed) and (Y1 and Y3 and Y4=Coniferous) Then Y2=Coniferous
31. If (Y3=Mixed) and (Y1 and Y2 and Y4=Coniferous) Then Y3=Coniferous

There were generally four basic principles that were used to reclassify pixels: 1) majority based logic was used where three years of the same land cover were used to reclassify the other year. The reasoning was that if three years are the same and the other is not then there is more confidence that the other non-similar year has been classified incorrectly; 2) year one (1976) and year four (2009) are considered carefully since it is difficult to tell if 2009 is accurate or not without seeing the time after. 1976 is MSS data which is less accurate and similarly it is difficult to know what occurred previously; 3) most of the logical statements are concerned with land-cover types that are classified the least correctly. This can be determined by the number of pixels in each land-cover type and the producer's accuracy results in Table 7. Most of the error was with Mixed, Deciduous, and Coniferous forests; and 4) each logical statement of change is undertaken one at a time and the original land cover maps created in Section 3 are updated before the next statement is conducted. A full list of the logical statements with the amount of pixels changed for each statement is located in Appendix F.

The wetland classification was difficult for this area; a common wetland extent was made to make changes easier to interpret and to separate significant change from non-significant change. Significant change includes changes from Wetland to Agriculture, Urban, Cut, or Burned areas. Non-significant change, which is not of interest in this study, is change from Wetland to forest class between years, although a more permanent change from Wetland to forest or vice versa is of importance. Pixels of Wetland in all three different dates but a forest class in the other date were recoded to Wetland (except for 2009, since it is possible that an actual reforestation was occurring and we do not have a subsequent date to confirm this). The opposite also was done where pixels of the same forest type for three dates but wetland for the other were recoded to forest (see Table 9, 1-20).

4.3 Results and Discussion

4.31 Image Reclassification

After the logical statements were used, the results from Section 3 for each date were recoded and new results were analyzed. The total number of 30m pixels and percent of each date changed is located in Table 10. Most of the change occurred with the first three dates, with 2009 having much less change. Even though less of the logical statements applied to 1976, a relatively large amount of the pixels changed in 1976 most likely due to less accurate classification of the coarser 60m MSS imagery. 2009 may have had fewer changes due to both less logic statements used (we were more conservative in considering change of the last date in the multi-date sequence since we do not have a later date to compare with) and less of a noise error since it was classified last.

Table 10: Total amount of pixels changed by logic statements

	Total Pixels	**Percent Changed**
1976	546174	2.11%
1989	618294	2.39%
1998/1999	501615	1.94%
2009	94228	0.36%

A lot of the pixels that were reclassified appear to have occurred with coniferous, mixed, and deciduous for each date. Table 11 shows the new percentage amounts of each land cover and Figure 13 compares this with the previously classed amounts. Coniferous and Deciduous land-cover proportions decreased in each date. The proportion of mixed forest increased for each year except for 2009. Also of note is Wetland which increases in 1976 and 1998/1999 yet decreases in 1989 and stays approximately the same in 2009. These land-cover types changed the most because most of the logical statements involved reclassifying these classes.

Table 11: Total amount of each land cover class in the site after logic statements

	Class	1976	1989	1998/ 1999	2009
Forest Type, Successional State, Disturbance Class (%)	Conifer	1.53	1.92	1.56	2.86
	Mixed	56.03	55.92	57.65	52.96
	Deciduous	6.02	2.52	4.25	6.00
	Young	0.06	0.80	0.82	0.79
	Cut	0.46	0.57	0.12	0.26
	Burn	0.01	0.00	0.00	0.00
	Insect	0.00	0.00	0.00	0.00
	Total Forest	***64.12***	***61.73***	***64.40***	***62.86***
Other Land Cover (%)	Wetland	15.73	14.81	12.33	14.82
	Bare	0.00	0.00	0.00	0.00
	Urban	1.68	1.87	1.74	1.78
	Agriculture	18.47	21.59	21.53	20.54
	Total	***100.00***	***100.00***	***100.00***	***100.00***

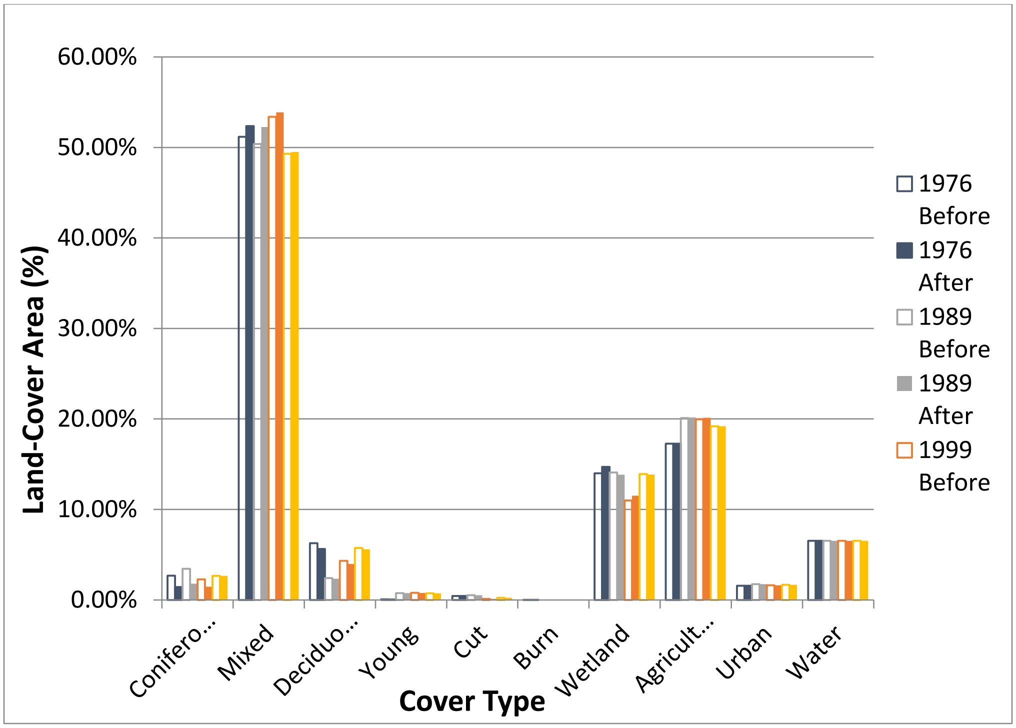


Figure 14: Land cover type proportions for each of the four dates; 1976, 1989, 1998/1999, and 2009 in the Primorsky Krai Landsat study site. Before and after logic statements are shown. Figure includes water.

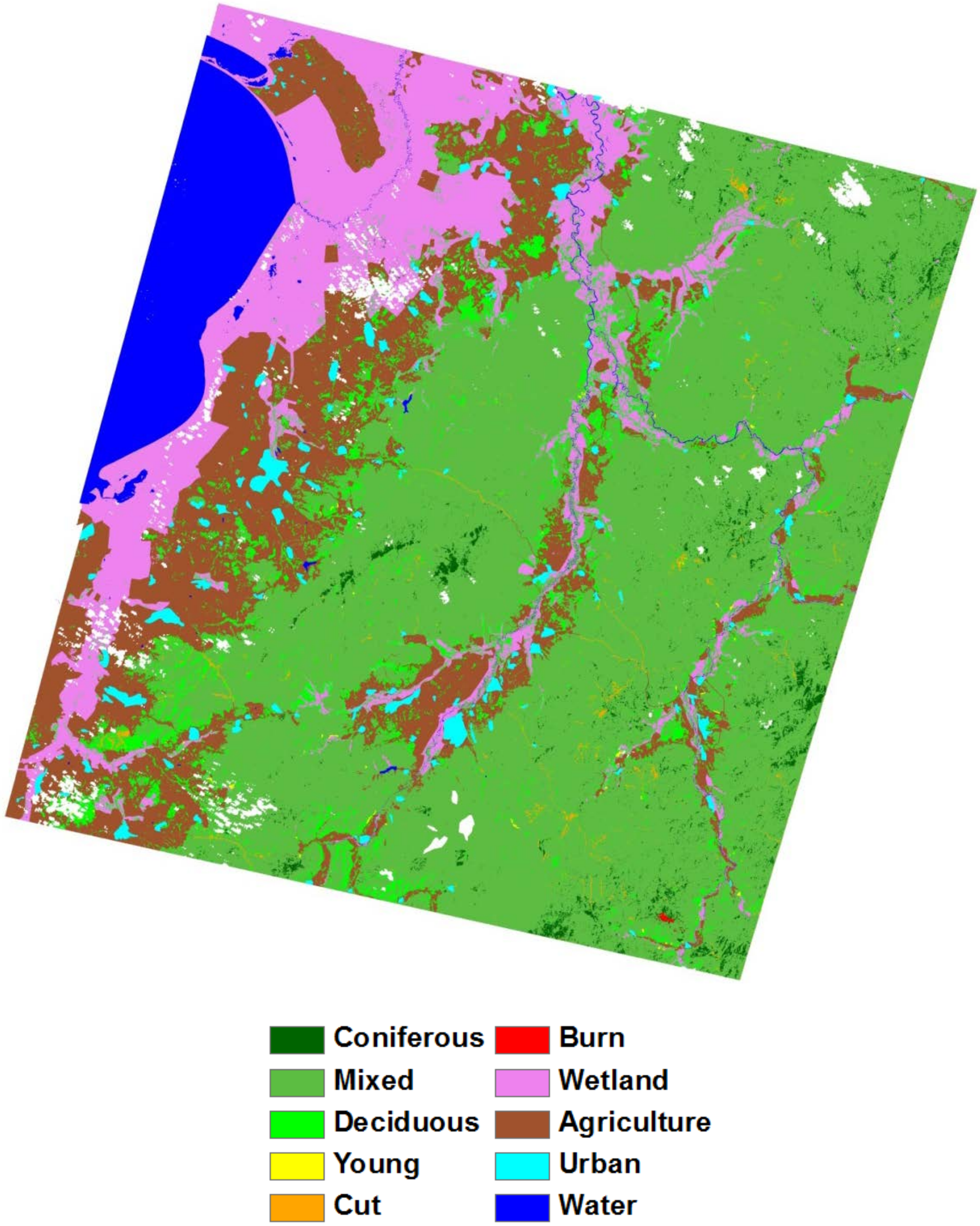


Figure 15: Landsat MSS land-cover classification results from June 30, 1976 (p122r29, WRS-1) after logic statements.

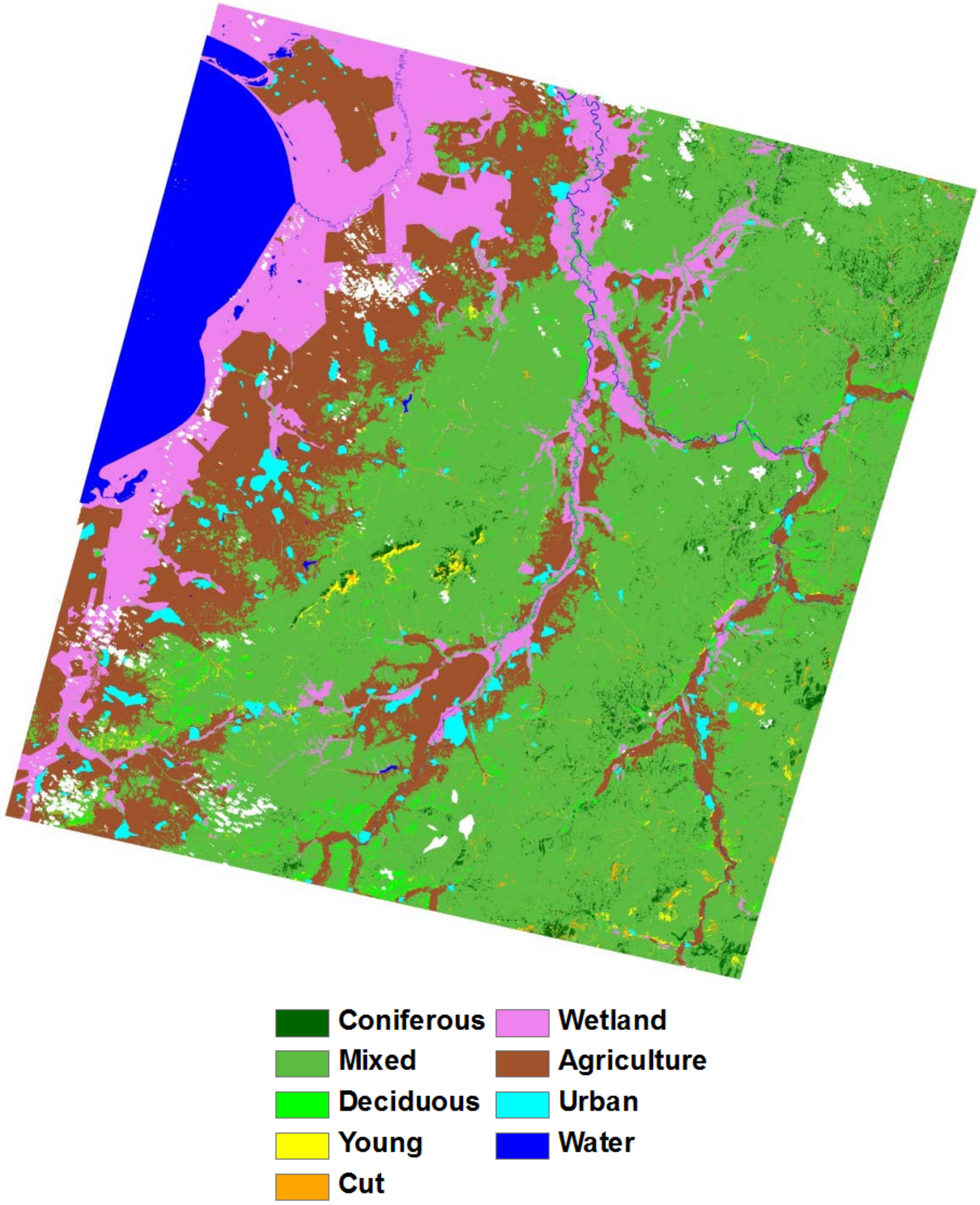


Figure 16: Landsat TM land-cover classification results from May 29, 1998 and September 21, 1999 (p113r29, WRS-2) after logical statements. Dates were classified separately and later combined.

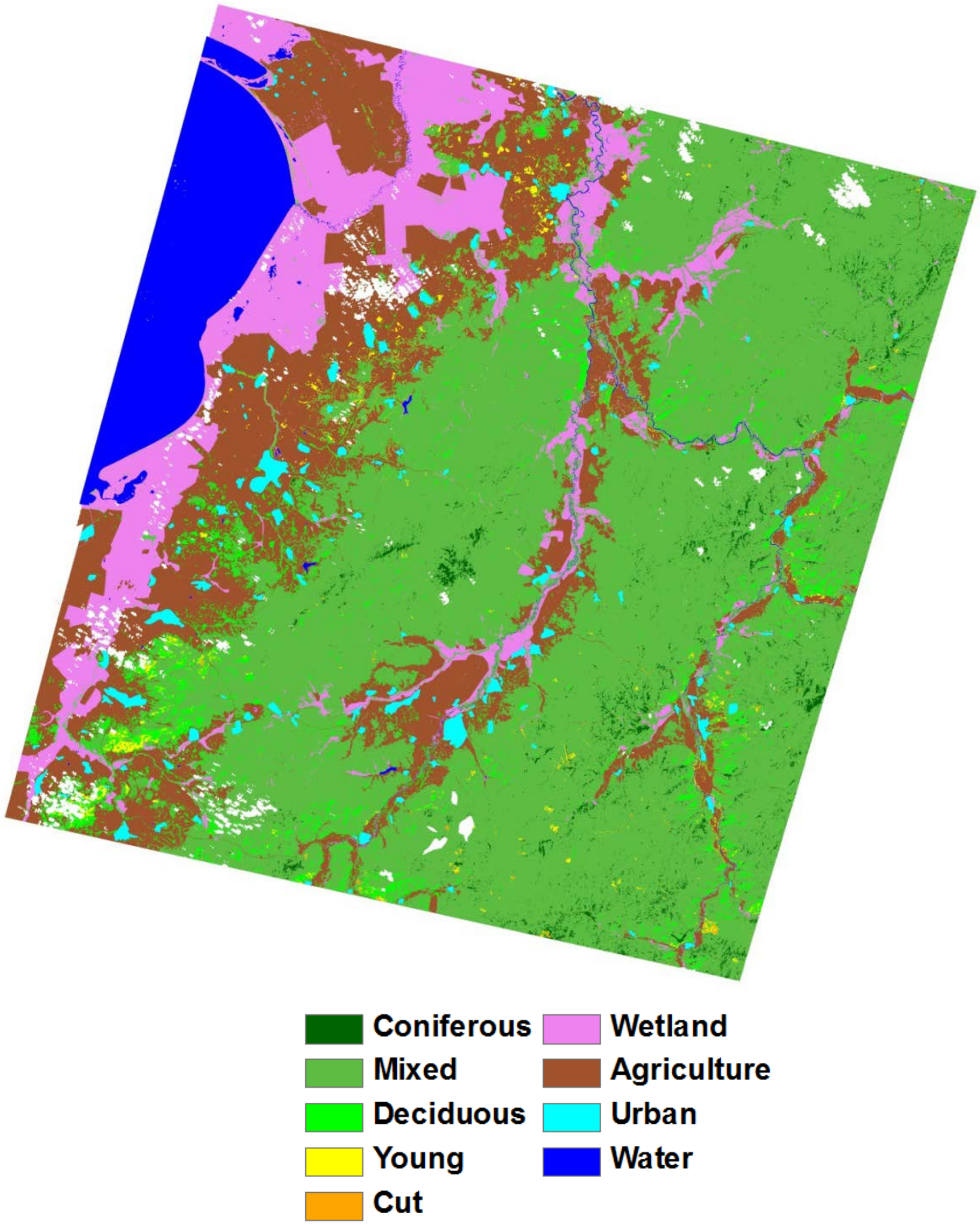


Figure 17: Landsat TM land-cover classification from 1998 and 1999 after logical statements

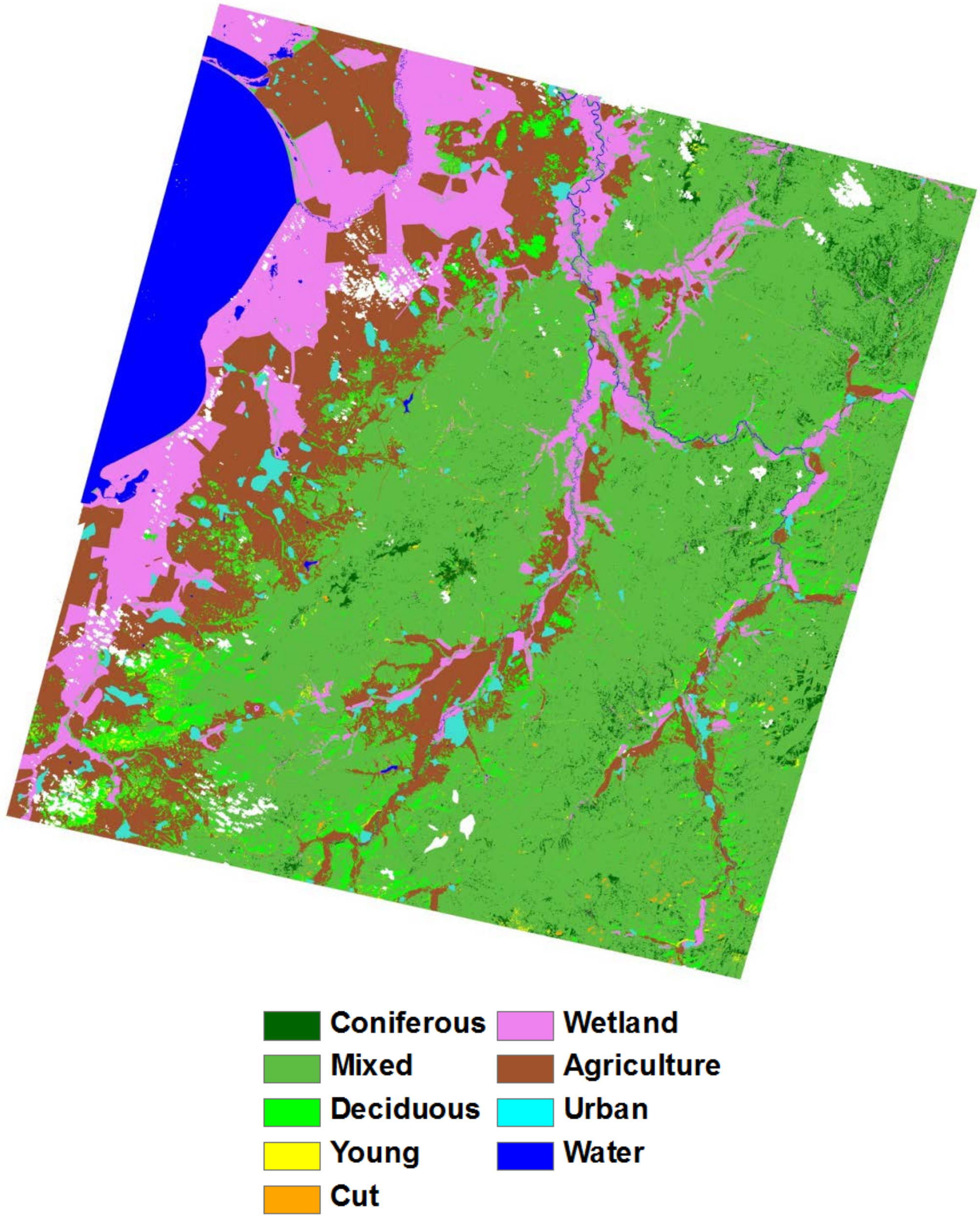


Figure 18: Landsat TM land-cover classification results from August 31, 2009 (p113r29, WRS-2) after logical statements.

4.32 Accuracy Assessment Before and After

When compared again with the accuracy testing pixels, the single-date accuracy results remained mostly similar after the logical statements were used to reclassify selected pixels. Overall accuracy remained the same for 1998/1999 and 2009 but changed slightly for the other two dates (Table 12, changes shown in parenthesis). The overall accuracy in 1976 decreased slightly from 89.3 to 89.0 due to a decrease in producer's accuracy in the coniferous land cover category. This may have been due to the difficulty identifying proper coniferous testing sites in 1976 given the coarser resolution data. Another issue could be that the reclassification procedure simply exacerbated an already existing misclassification of coniferous or mixed areas. The overall accuracy in 1989 however much more notably increased from 92.3 to 93.1. Mixed, Wetland, and Agriculture all increased in producer's accuracy with the largest increase in Agriculture. There may have been some confusion between active agriculture and deciduous in 1989 which the logical statements helped to correct. 1989 was a year where extensive flooding had taken place and many forests were spectrally similar to wetlands given the temporary flooding. This issue may also have been corrected for slightly with the logical statements.

Overall little of the accuracy was altered which was expected given the total percent of Landsat image reclassified was less than 2.5% for each date (Table 10). Given that 1989 had the most pixels reclassified at 2.39%, it is reasonable that more of the accuracy assessment results changed compared to other dates, especially 2009 which just had 0.36% of the image reclassified. This technique could prove much more useful in increasing accuracy in areas where on the ground data is readily available and more certain logical statements of reclassification can be used. Full accuracy tables are located in Appendix J.

Table 12: Producer's accuracy for all land cover classes after logic statements. Shown with number of testing sites and changes shown in parenthesis.

Class	N	1976	N	1989	N	1998/ 1999	N	2009
Conifer	25	72.0 (-4)	25	80.0	25	80.0	25	76.0

Mixed	100	99.0	100	100.0 (+1)	98	100.0	100	93.9
Deciduous	50	83.3	50	75.0	50	83.3	50	91.7
Young	25	84.0	25	100.0	25	100.0	24	91.3
Cut	25	79.2	24	91.7	25	69.6	22	95.2
Burn	5	100.0	n/a	n/a	n/a	n/a	n/a	n/a
Insect	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Wetland	30	86.7	30	90.0 (+3.3)	30	83.3	31	93.5
Agriculture	50	85.7	49	95.8 (+6.2)	50	95.9	49	93.8
Urban	25	100.0	25	100.0	25	100.0	25	96.0
Bare	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Water	23	87.0	25	100.0	25	96.0	25	92.0
Overall		***89.0 (-0.3)***		***93.1 (+0.8)***		***91.9***		***92.2***
KHAT		***0.87***		***0.92***		***0.90***		***0.91***

4.33 Comparison of Land-Cover Change Results before and after Use of Logic Rules

The logical statements resulted in greatly reducing the Noise/error category in land-cover change classes between years. Approximately a 50% improvement took place between all years with the greatest improvement between 1989 and 1998/1999 (Table 13). Most of this improvement came from an increase in the No Change and Forest Succession categories and from minor changes in Development as well. The small changes in Development were most likely due to the logical statements improving the wetland and forest extents, thus decreasing the amount of conversion from these land-covers to Agriculture. The decrease in the Forest Succession category, mostly from the time periods 1976-1989 and 1989-1998/1999 were most likely caused by the statements that reclassified a forest type into another forest type based on majority logic (Table 9 numbers 23-31).

Table 13: Percent of classified area exhibiting change in land-cover change classes after logic statements. Difference between before and after logical statements is written in parenthesis

Change Category	1976-1989	1989-1998/1999	1998/1999-2009
No Change	84.96 (+4.50)	86.94 (+4.33)	85.41 (+2.30)
Logged	0.48	0.09	0.21
Burned	0.00	0.00	0.00
Regeneration I	2.01	2.03	3.44
Regeneration II	1.22	2.66	3.29
Forest Succession	3.40 (-1.73)	2.31 (-1.07)	3.24 (-0.18)
Development	5.01	2.91 (-0.11)	2.55 (-0.18)
Noise Error	2.92 (-2.78)	3.06 (-3.15)	1.85 (-1.95)

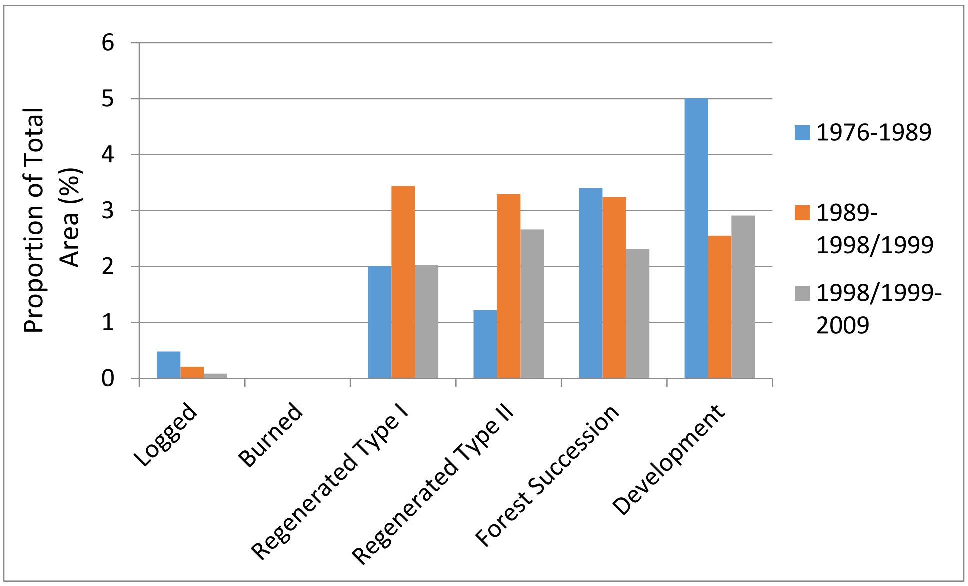


Figure 19: Percent of land exhibiting change in land-cover change classes. No Change and Noise/Error are excluded. Shown after logic statements. (Adapted from Bergen et al. 2008, with 2010 added)

4.4 Summary

Coniferous, Mixed, Deciduous, Wetland, and Agriculture were all specifically targeted to improve the change detection Noise/error. Original change detection results that mistakenly identified areas as Forest Succession change were replaced with no change, improving results. Overall accuracy assessment (besides 1976) and change detection noise improved from doing a reclassification based on logical statements. This is a promising technique to greatly improve classification error.

5. Conclusions and Discussion

The results showed overall less fire and logging disturbance than hypothesized. Low logging disturbance may be due to the resolution of Landsat imagery and smaller scale selective harvesting that may have taken place. Only one burned area was identified in 1976, although some small fires most likely occurred between image dates. In contrast to forests, agricultural change was fairly large. Significant land-cover change was analyzed for overlap with protected areas and forest management boundaries. Figures 18-20 show areas of change in the Primorsky site for the final classification results from Section 4. Between most years the forest succession taking place appears to be nearby the river valley areas, besides some areas of past disturbance further upland. These areas may have been historically disturbed since they are easy to access. Regenerated Type 1 areas had a disturbance and underwent succession between periods. There appears to be a correlation between many of these areas of change and shadowing. Areas once classified as mixed or coniferous and later classified as deciduous fall into the Regenerated Type 1 category although these areas could simply be two different sun angles of an unaltered forest giving two separate spectral signatures which has been a drawback of classifying this area.

There are two main regions however that do not appear to have this potential error which are important to note. One of these regions is in the period from 1976-1989 in the central portion of the study area (shown in black in Figure 18). This area does not have any protection associated with it and it falls under the Arsenevskii Leskhoz and Spasskii Leskhoz. This region also has cuts areas within it and forest succession occurring outside of it indicating that additional disturbance occurred between these periods.

The other notable area of Regenerated Type 1 is located in the southwestern portion of the study area in the Chernigovskii Leskhoz between both the periods 1989-1998/1999 and 1998/1999-2009 (shown in brown in

Figures 19 and 20). This region is also interspersed with areas of forest succession and small cuts. This region has the most disturbance near the year 2000, although significant disturbance in both 1989 and 2009 as well. Forests in this area are situated on more topographically flat land and closer to settlements making them ideal areas to log. Logged areas as a whole are the greatest during the period from 1976-1989. These are areas that were classified as cut in 1989. The cuts in the period from 1989-1998/1999 are much more selective. Cuts from the period 1998/1999-2009 are about half the amount of the period between 1976 and1989. The only burned area occurs in 1976 in the Chuguevskii region of in the southeastern region of the study site.

Development was the largest disturbance category of the study site. Development, mostly taking the form of agriculture expansion, is greatest in the period from 1976-1989. 1976-1989 marks a period of growth in population and infrastructure expansion in the Primorsky Krai region (Newell, 2004). The other two periods have a little over half of the amount that 1976-1989 does. These areas of development are mostly lowland areas in river valleys and on the western portion of the study area near Lake Khanka. The aggregated development areas near Lake Khanka are much less pronounced in the period between 1998/1999 and 2009. Between all three periods at least a small amount of agricultural development occurs in the Xingkaihu and Khankaiskii protected areas (shown in blue and red outlines in Figures 18-20). Khankaiskii was first designated protected in 1997 and Xingkaihu in 2007, thus the greatest period of agricultural expansion from 1976-1989 was previous to regulation. Both the periods from 1989-1998/1999 and from 1998/1999-2009 also show agricultural growth in these protected areas though.

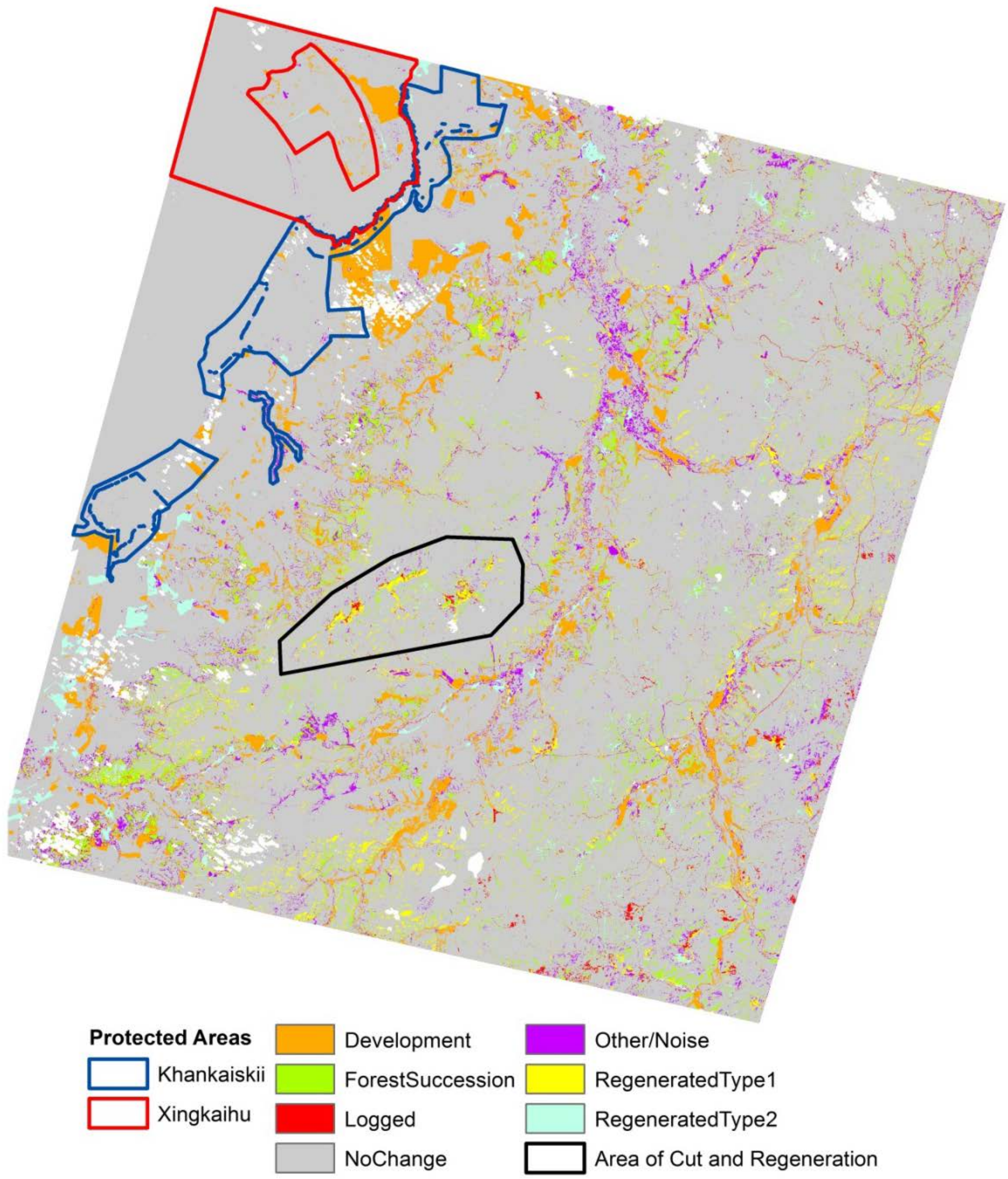


Figure 20: Change Detection results from 1976-1989 after logical statements, shown with important areas discussed in Section 5. Derived from Peterson et al, 2009.

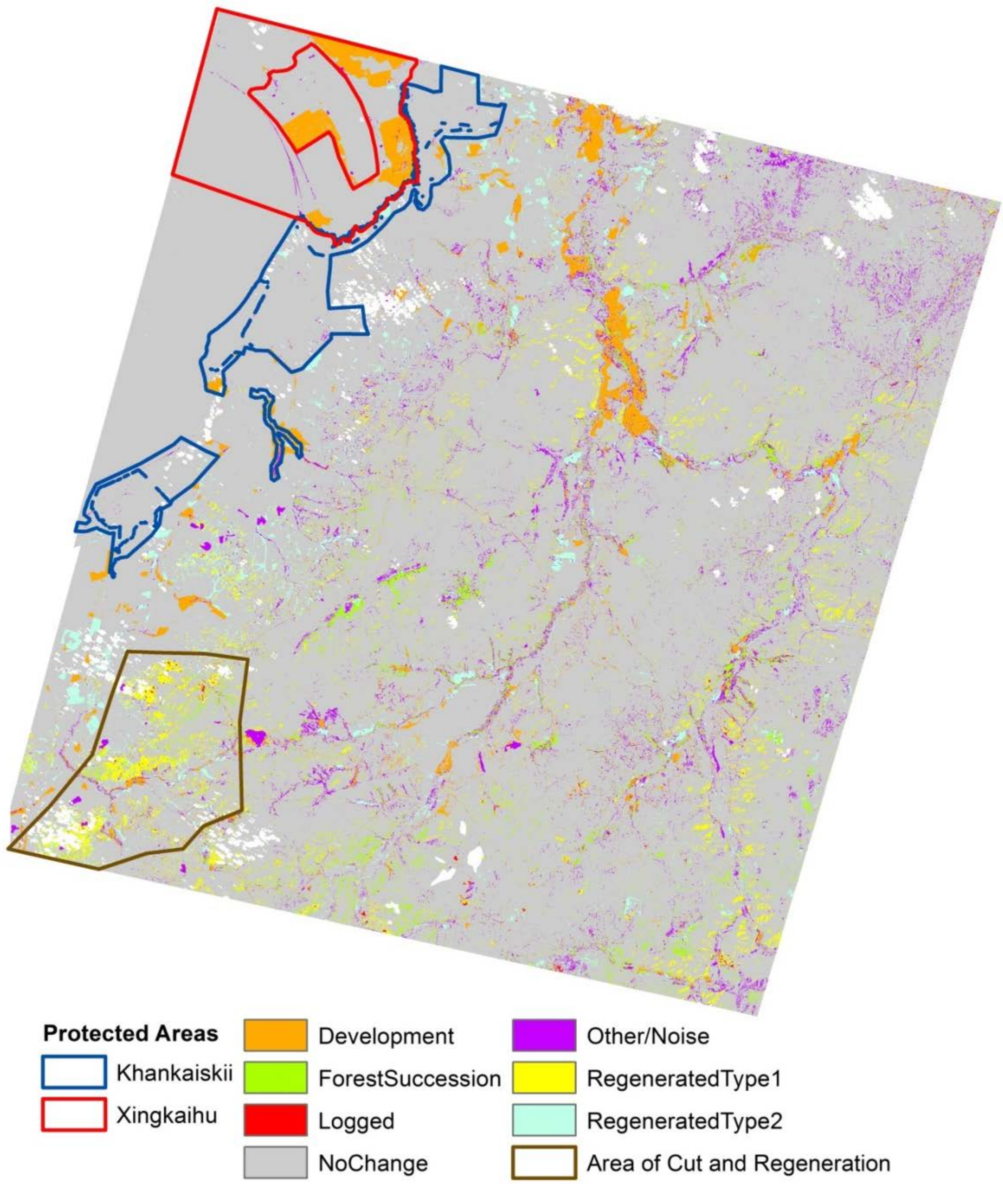


Figure 21: Change Detection results from1989-1998/1999 after logical statements, shown with important areas discussed in Section 5. Derived from Peterson et al, 2009.

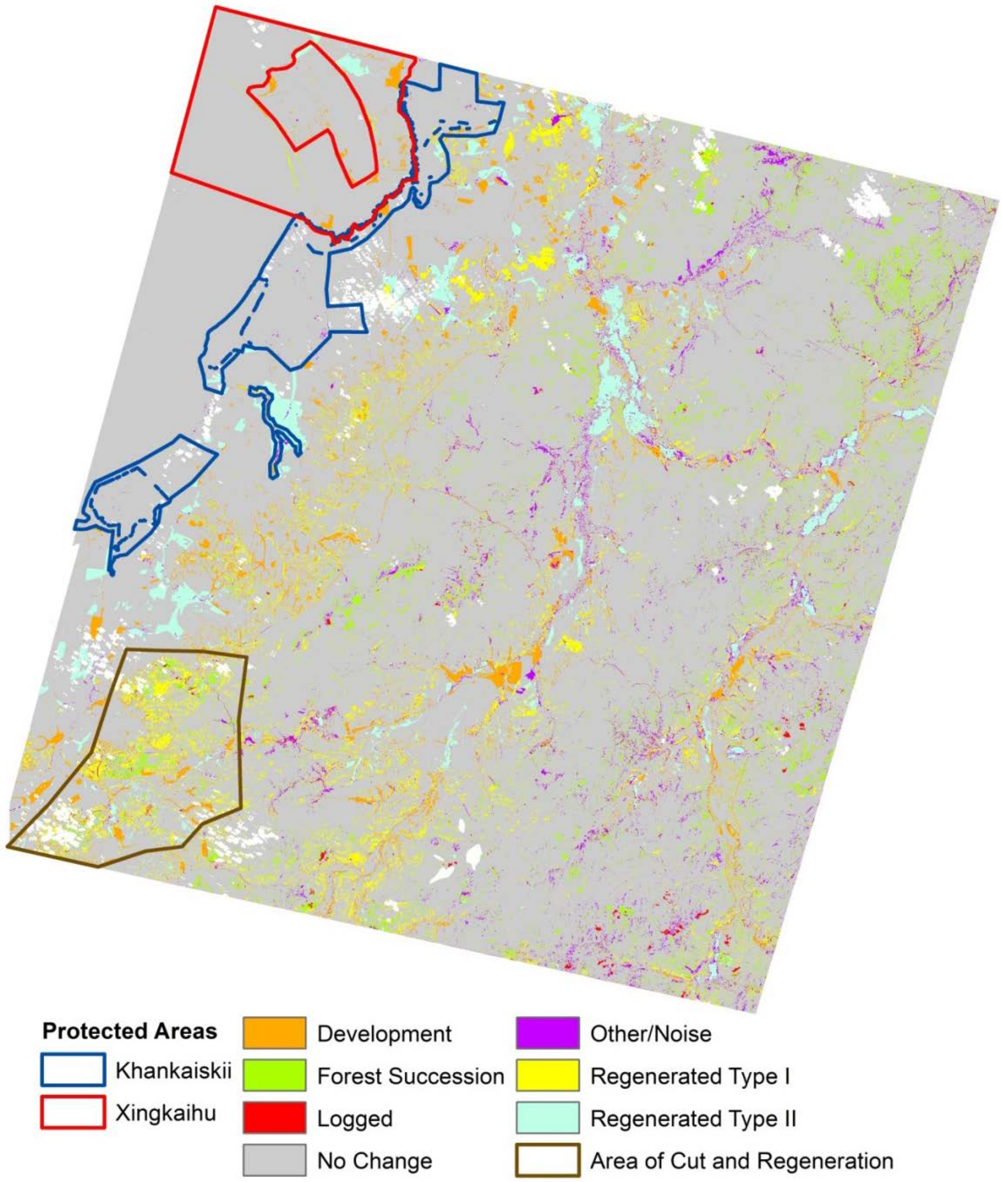


Figure 22: Change Detection results from1998/1999-2009 after logical statements, shown with important areas discussed in Section 5. Derived from Peterson et al, 2009.

Although some agricultural areas are given permission in the Khankaiskii and Xingkaihu region, a significant area of agricultural growth is occurring and should be investigated further in light of regulation to protect these important wildlife regions. Figure 23 shows the classification results for the Xingkaihu protected region from 1976-2009. Figure 24 quantifies this change as a percentage of total land cover. Exact percentages and number of pixels changed can be found in Appendix M. Agriculture mostly expands in the northeastern portion of the protected region. Wetland decreases from 53.97% to 36.40% of the total land cover area in Xingkaihu from 1976-2009. Agriculture increases from 4.09% to 20.27% in Xingkaihu from 1976-2009. The Xingkaihu protected region was established in 2007 so most of the agricultural expansion occurred previous to establishment. Agriculture changes slightly but is proportionally nearly the same in 1998/1999 and 2009 which could be due to the new protected status. Much growth occurred before establishment of the protected region. Agriculture areas shown in the 2009 classified image should be monitored.

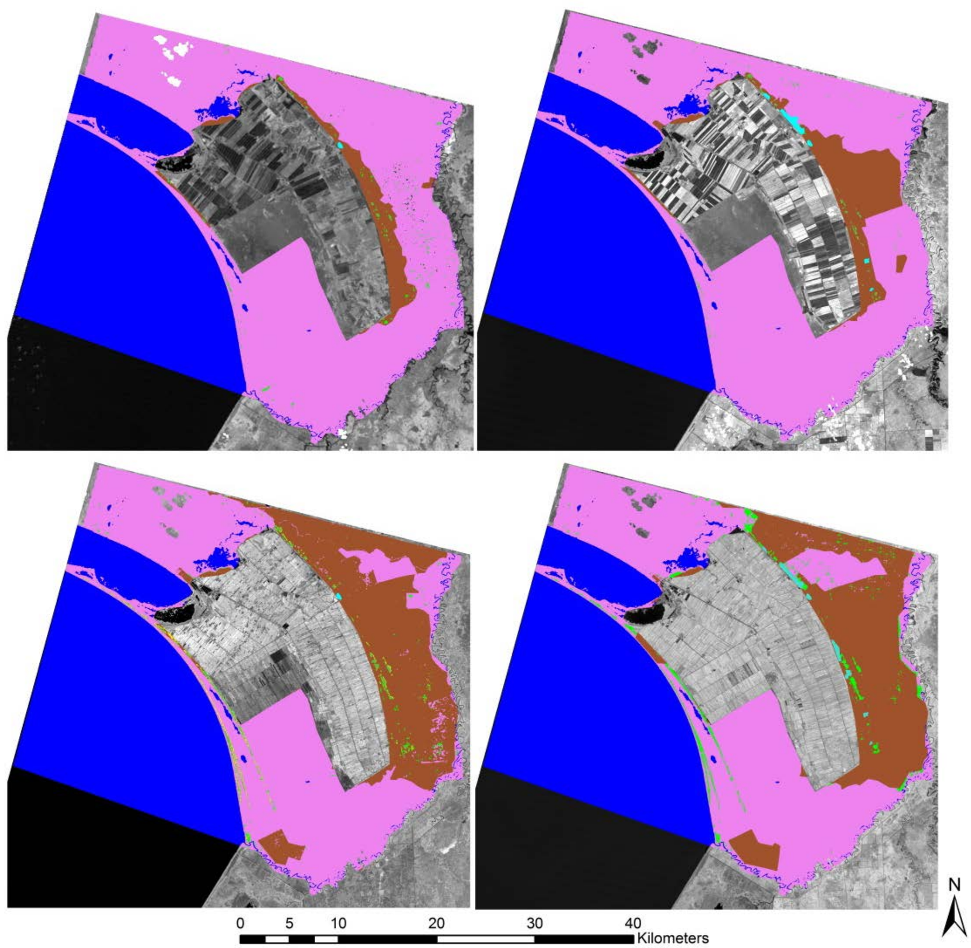


Figure 23: Classification results after logic statements for the Xingkaihu protected region for each date. 1976, shown in upper left corner, 1989, shown in upper right corner, 1998/1999, shown in lower left corner, and 2009, shown in lower right corner. All shown overlaid on Landsat band 4.

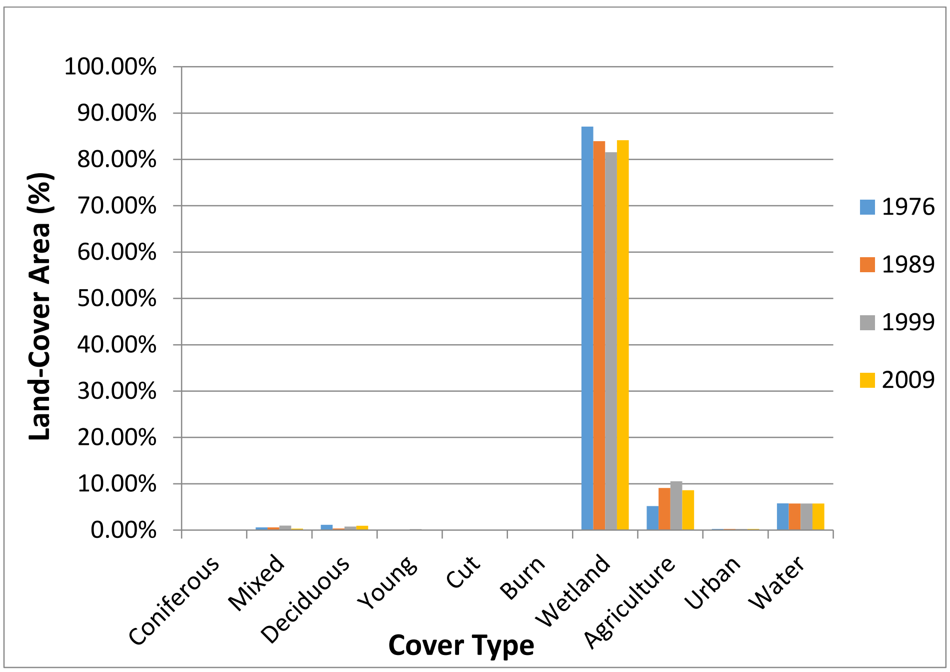


Figure 24: Land cover type proportions for each of the four dates; 1976, 1989, 1998/1999, and 2009 in the Xingkaihu protected region. Shown after logic statements.

Figure 25 shows the classification results for the Khankaiskii protected region from 1976-2009. Figure 26 quantifies this change as a percentage of total land cover. Exact percentages and number of pixels changed can be found in Appendix N. Agriculture expands mostly near the borders of the protected region from 1976-1998/1999. Wetland decreases from 87.10% to 81.55% of the total land cover area in Khankaiskii from 1976-1998/1999.

Agriculture increases from 5.19% to 10.53% in Khankaiskii from 1976-1998/1999. From 1998/1999-2009 Agriculture decreases from 10.53% to 8.60%, bringing the total proportion of Agriculture in the protected region to less than that in 1989. The Khankaiskii protected region was established in 1997 and seems to have had a positive effect at increasing wetland areas.

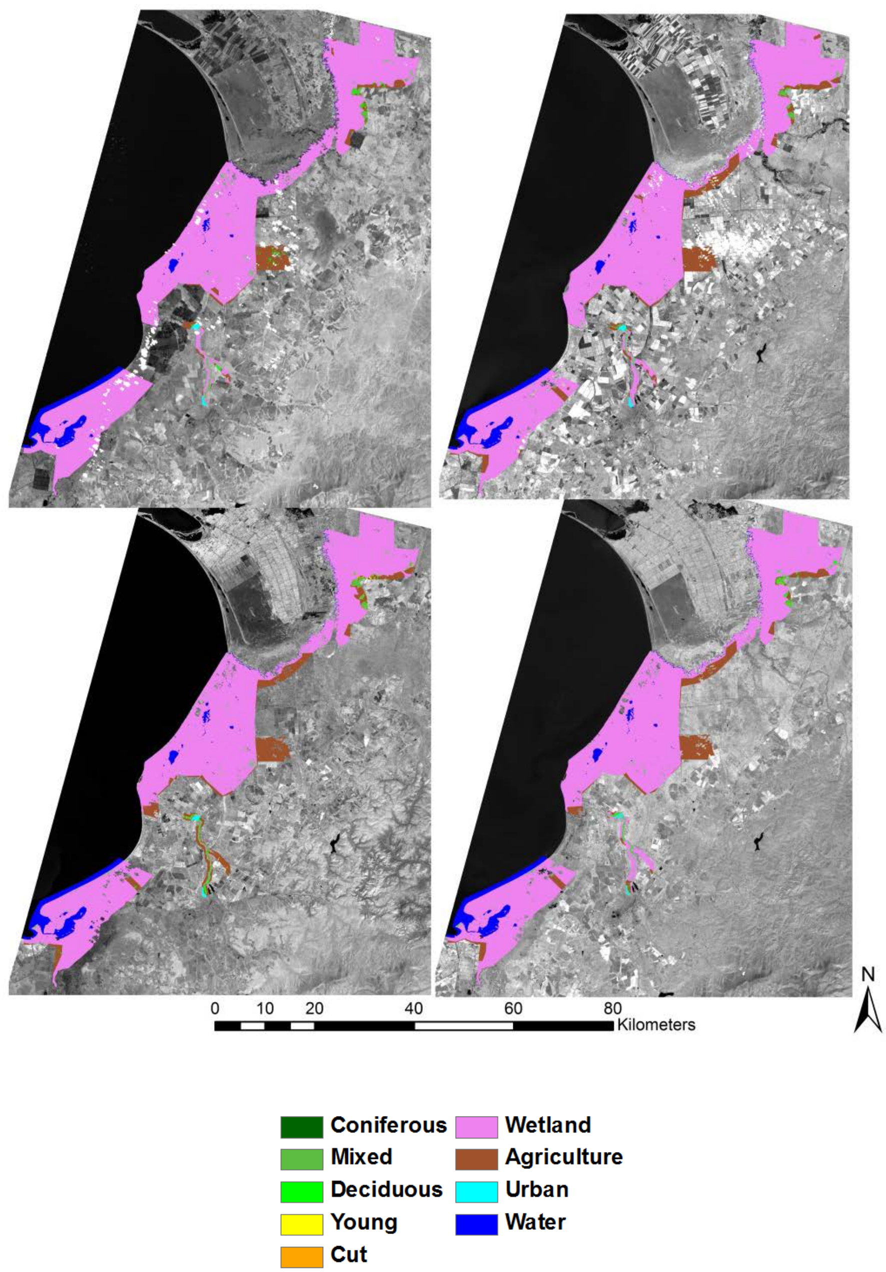


Figure 25: Classification results after logic statements for the Khankaiskii protected region for each date. 1976, shown in upper left corner, 1989, shown in upper right corner, 1998/1999, shown in lower left corner, and 2009, shown in lower right corner. All shown overlaid on Landsat band 4.

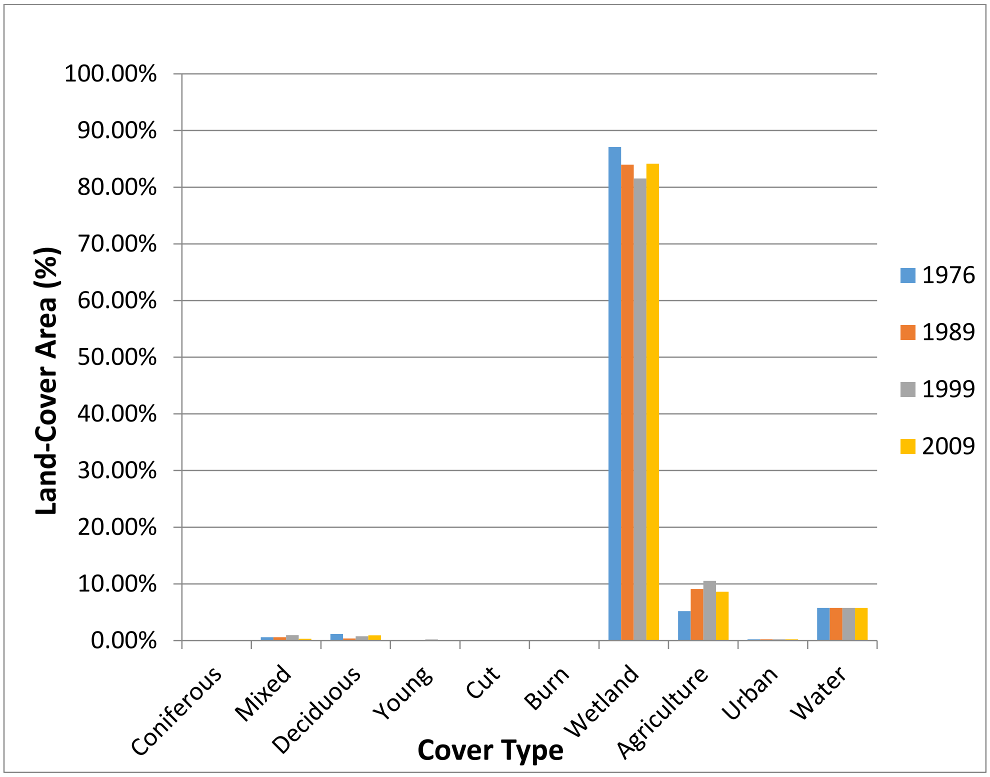


Figure 26: Land cover type proportions for each of the four dates; 1976, 1989, 1998/1999, and 2009 in the Khankaiskii protected region. Shown after logic statements.

As stated previously, the goal of this study was to most accurately classify four separate dates of Landsat data for the southern Primorsky Krai area and to quantify land-cover change between dates. Relatively accurate classification maps were made of the study site. In Section 4 the change detection results were improved upon using logical statements of change. Areas of agricultural development are the most notable land-use changes in this region along with selected harvesting of timber. The data from this research can be expanded upon further and used in many ways. Detailed land cover for this region is not easily available. These findings can help management efforts for the Leshkoz and the protected regions to continue to provide a vital habitat area for important flora and fauna in the surrounding region.

Appendix A: Land-Cover and Land-Use Classification Codes for Settlements and Transportation

I. Urban/Built-up/Industrial*

11 Cities, towns, settlements (defined on Russian topo maps)

111 Large cities (population: 50,000 to 100,000)

112 Small cities (population: 2,000 to 10,000)

113 Towns (population: ~ 2,000)*

114 Villages/rural settlements (population: <100 to ~1000)*

12 Industrial

121 Factories

1211 Primary wood processing

13 Transportation

131 Air transportation

132 Rail transportation

1321 Multi-track (i.e. two or more tracks)

1322 One-track

1323 Narrow gauge railroad (includes dismantled railroad beds)

1324 Railroad under construction

1329 Railroad connector

133 Water transportation

1331 Lock and dam

1332 Canal

134 Road transportation

1341 Paved roads (includes all highways, roads with "highly improved surfaces" and other major thoroughfares with finished surfaces, i.e. asphalt, cement, and also those under construction)*

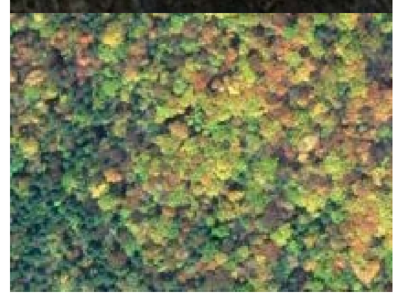
1342 Dirt/gravel roads (includes improved [graded] dirt roads, improved [graded] dirt roads with difficult sections, and improved [graded] dirt roads under construction)*

1343 Forest roads (includes field roads and winter roads)*

1349 Road connector

*Indicates features present in the Primorsky study site.

Appendix B: Land-Cover and Land-Use Classification Codes with Examples

Class ID	Class Description	Example
1	**Conifer -** Spruce/fir forest, Siberian pine forests, Korean pine, Larch	
2	**Mixed -** Mixed pine-broadleaved forest	 
3	**Deciduous -** Deciduous forests (birch-aspen), Oak, willow, poplar, elm, ash	
4	**Young -** Post-cut or post-fire with deciduous (birch-aspen) or conifer regeneration, Regeneration from agriculture	

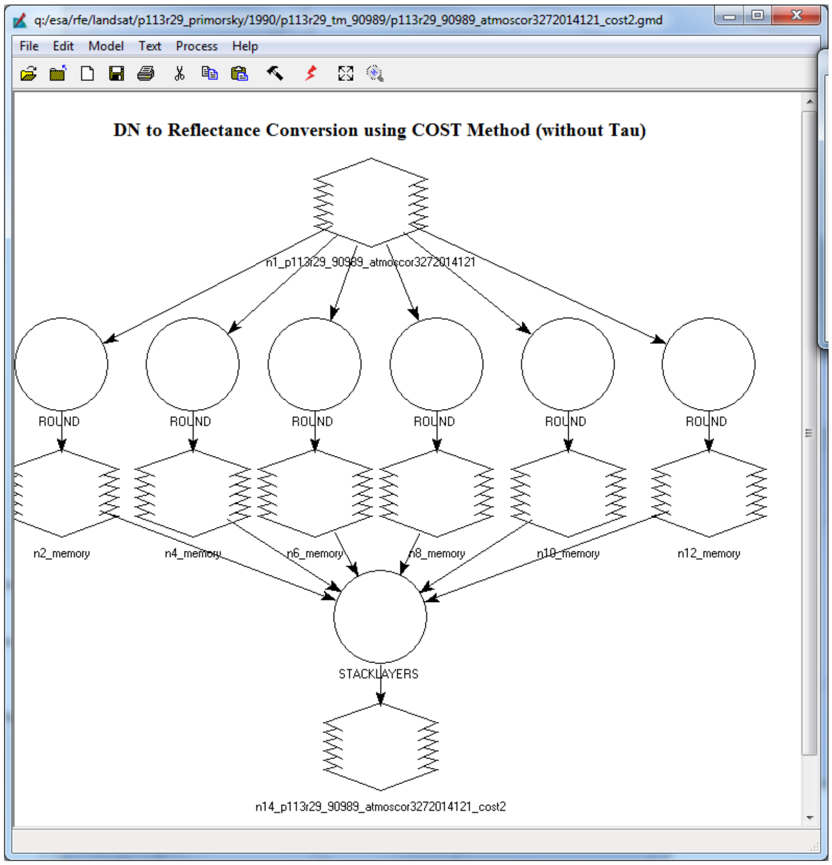
5 **Cut -** Fresh cuts

6 **Burn -** Fresh fire scars

8	**Wetland -** Wetlands, flood-lands, Bog	
9	**Agriculture -** Agriculture (crops, hay, pasture, meadow)	
10	**Urban -** Built-up areas	
12	**Water -** Water	

Appendix C: COST without Tau (Dark Object Subtraction) Normalization and Atmospheric correction Method for 1989, 1998, 1999, and 2009

1989



Displayed from left to right

ROUND (((3.1415926 * (($n1_p113r29_90989_atmoscor3272014121(1) * 0.671338583 + -1.52) - (48 * 0.671338583 + -1.52)) * 1.00721242978 * 1.00721242978) / (1969 * (COS ((90 - 44.33633164) * 3.1415926 / 180)))) * 400)

ROUND (((3.1415926 * (($n1_p113r29_90989_atmoscor3272014121(2) * 1.322204724 + -2.84) - (18 * 1.322204724 + -2.84)) * 1.00721242978 * 1.00721242978) / (1840 * (COS ((90 - 44.33633164) * 3.1415926 / 180)))) *400)

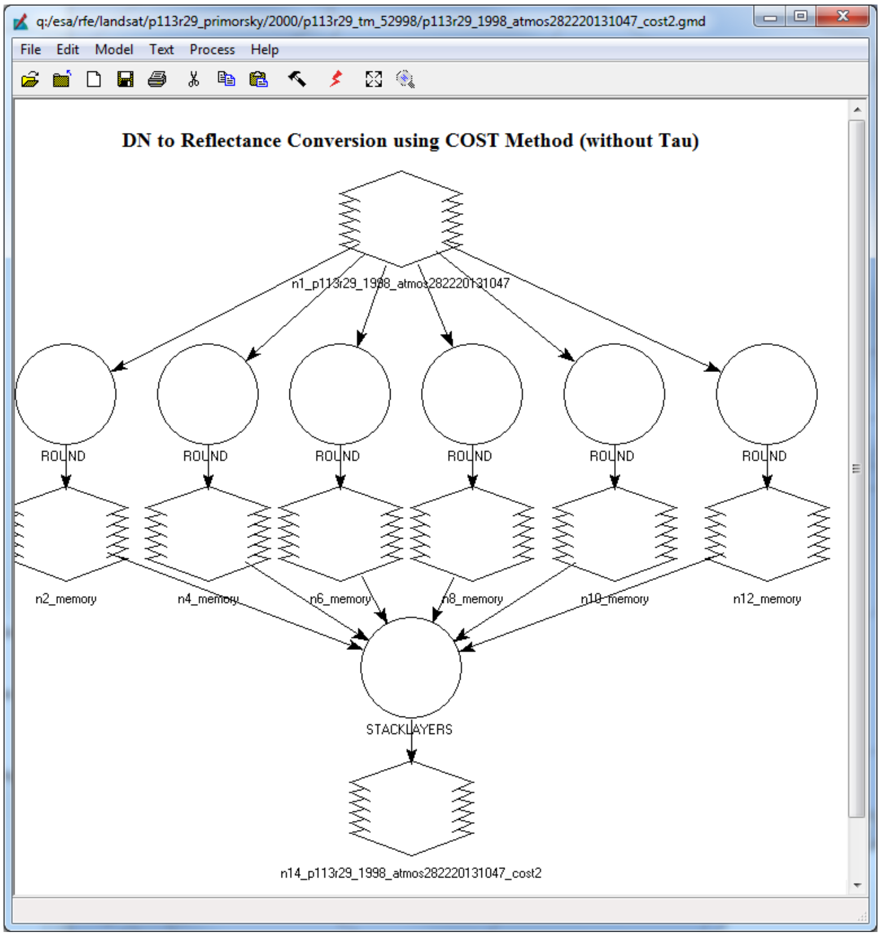
ROUND (((3.1415926 * (($n1_p113r29_90989_atmoscor3272014121(3) * 1.043976378 + -1.17) - (12 * 1.043976378 + -1.17)) * 1.00721242978 * 1.00721242978) / (1551 * (COS ((90 - 44.33633164) * 3.1415926 / 180)))) * 400)

ROUND (((3.1415926 * (($n1_p113r29_90989_atmoscor3272014121(4) * 0.876023622 + -1.51) - (9 * 0.876023622 + -1.51)) * 1.00721242978 * 1.00721242978) / (1044 * (COS ((90 - 44.33633164) * 3.1415926 / 180)))) * 400)

ROUND (((3.1415926 * (($n1_p113r29_90989_atmoscor3272014121(5) * 0.120354331 + -0.37) - (3 * 0.120354331 + -0.37)) * 1.00721242978 * 1.00721242978) / (225.7 * (COS ((90 - 44.33633164) * 3.1415926 / 180)))) *400)

ROUND (((3.1415926 * (($n1_p113r29_90989_atmoscor3272014121(6) * 0.065551181 + -0.15) - (1 * 0.065551181 + -0.15))* 1.00721242978 * 1.00721242978) / (82.07 * (COS ((90 - 44.33633164) * 3.1415926 / 180)))) *400)

1998



Displayed from left to right

ROUND (((3.1415926 * (($n1_p113r29_1998_atmos282220131047(1) * 0.765826772 + -1.52) - (49 * 0.765826772 + -1.52)) * 1.01334815672 * 1.01334815672) / (1957 * (COS ((90 - 59.821) * 3.1415926 / 180)))) * 400)

ROUND (((3.1415926 * (($n1_p113r29_1998_atmos282220131047(2) * 1.448188976 + -2.84) - (19 * 1.448188976 + -2.84)) * 1.01334815672 * 1.01334815672) / (1829 * (COS ((90 - 59.821) * 3.1415926 / 180)))) *400)

ROUND (((3.1415926 * (($n1_p113r29_1998_atmos282220131047(3) * 1.043976378 + -1.17) - (16 * 1.043976378 + -1.17)) * 1.01334815672 * 1.01334815672) / (1557 * (COS ((90 - 59.821) * 3.1415926 / 180)))) * 400)

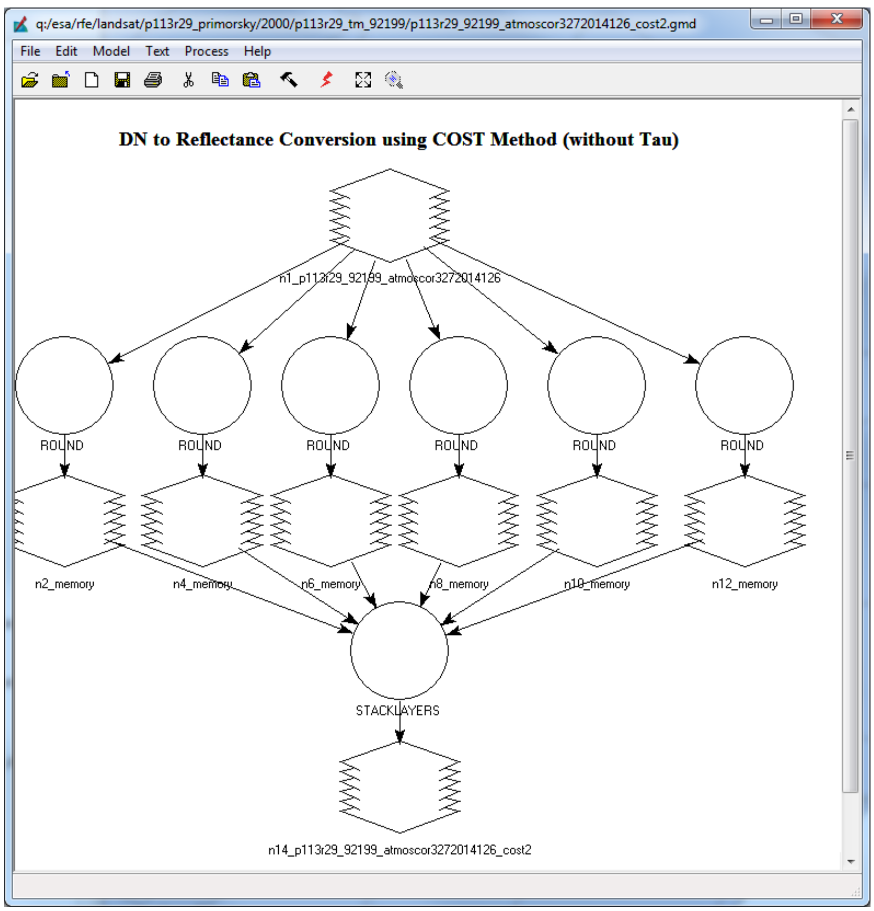
ROUND (((3.1415926 * (($n1_p113r29_1998_atmos282220131047(4) * 0.876023622 + -1.51) - (12 * 0.876023622 + -1.51)) * 1.01334815672 * 1.01334815672) / (1047 * (COS ((90 - 59.821) * 3.1415926 / 180)))) * 400)

ROUND (((3.1415926 * (($n1_p113r29_1998_atmos282220131047(5) * 0.120354331 + -0.37) - (11 * 0.120354331 + -0.37)) * 1.01334815672 * 1.01334815672) / (219.3 * (COS ((90 - 59.821) * 3.1415926 / 180)))) *400)

ROUND (((3.1415926 * (($n1_p113r29_1998_atmos282220131047(6) * 0.065551181 + -0.15) - (13 * 0.065551181 + -0.15))* 1.01334815672 * 1.01334815672) / (74.52 * (COS ((90 - 59.821) * 3.1415926 / 180)))) *400)

STACKLAYERS ($n2_memory, $n4_memory, $n6_memory, $n8_memory, $n10_memory, $n12_memory)

1999



Displayed from left to right

ROUND (((3.1415926 * (($n1_p113r29_92199_atmoscor3272014126(1) * 0.765826772 + -1.52) - (41 * 0.765826772 + -1.52)) * 1.00396512131 * 1.00396512131) / (1969 * (COS ((90 - 41.81966529) * 3.1415926 / 180)))) * 400)

ROUND (((3.1415926 * (($n1_p113r29_92199_atmoscor3272014126(2) * 1.448188976 + -2.84) - (15 * 1.448188976 + -2.84)) * 1.00396512131 * 1.00396512131) / (1840 * (COS ((90 - 41.81966529) * 3.1415926 / 180)))) *400)

ROUND (((3.1415926 * (($n1_p113r29_92199_atmoscor3272014126(3) * 1.043976378 + -1.17) - (11 * 1.043976378 + -1.17)) * 1.00396512131 * 1.00396512131) / (1551 * (COS ((90 - 41.81966529) * 3.1415926 / 180)))) * 400)

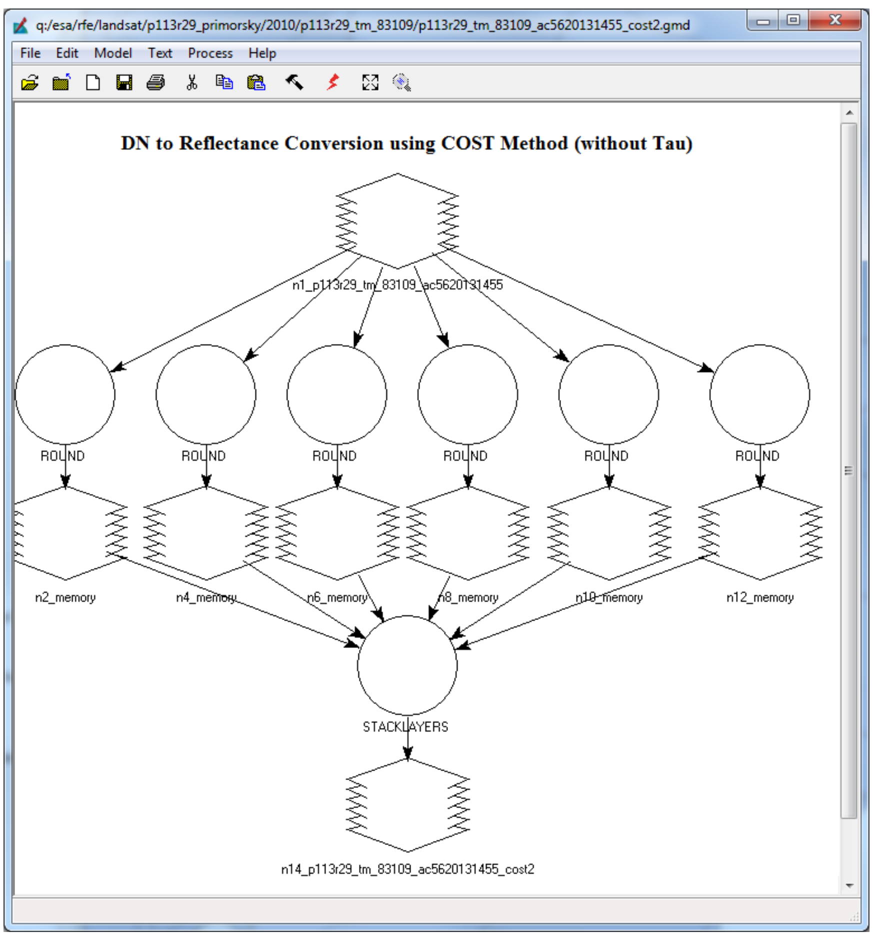
ROUND (((3.1415926 * (($n1_p113r29_92199_atmoscor3272014126(4) * 0.876023622 + -1.51) - (8 * 0.876023622 + -1.51)) * 1.00396512131 * 1.00396512131) / (1044 * (COS ((90 - 41.81966529) * 3.1415926 / 180)))) * 400)

ROUND (((3.1415926 * (($n1_p113r29_92199_atmoscor3272014126(5) * 0.120354331 + -0.37) - (2 * 0.120354331 + -0.37)) * 1.00396512131 * 1.00396512131) / (225.7 * (COS ((90 - 41.81966529) * 3.1415926 / 180)))) *400)

ROUND (((3.1415926 * (($n1_p113r29_92199_atmoscor3272014126(6) * 0.065551181 + -0.15) - (1 * 0.065551181 + -0.15))* 1.00396512131 * 1.00396512131) / (82.07 * (COS ((90 - 41.81966529) * 3.1415926 / 180)))) *400)

STACKLAYERS ($n2_memory, $n4_memory, $n6_memory, $n8_memory, $n10_memory, $n12_memory)

2009



Displayed from left to right

ROUND (((3.1415926 * (($n1_p113r29_tm_83109_ac5620131455(1) * 0.765826772 + -1.52) - (43 * 0.765826772 + -1.52)) * 1.00945399659 * 1.00945399659) / (1957 * (COS ((90 - 49.4983116) * 3.1415926 / 180)))) * 400)

ROUND (((3.1415926 * (($n1_p113r29_tm_83109_ac5620131455(2) * 1.448188976 + -2.84) - (16 * 1.448188976 + -2.84)) * 1.00945399659 * 1.00945399659) / (1829 * (COS ((90 - 49.4983116) * 3.1415926 / 180)))) *400)

ROUND (((3.1415926 * (($n1_p113r29_tm_83109_ac5620131455(3) * 1.043976378 + -1.17) - (11 * 1.043976378 + -1.17)) * 1.00945399659 * 1.00945399659) / (1557 * (COS ((90 - 49.4983116) * 3.1415926 / 180)))) * 400)

ROUND (((3.1415926 * (($n1_p113r29_tm_83109_ac5620131455(4) * 0.876023622 + -1.51) - (10 * 0.876023622 + -1.51)) * 1.00945399659 * 1.00945399659) / (1047 * (COS ((90 - 49.4983116) * 3.1415926 / 180)))) * 400)

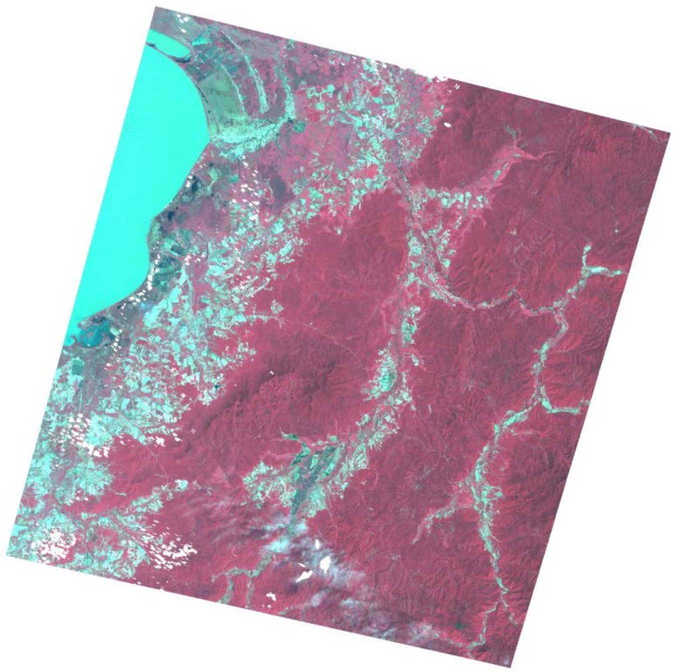
ROUND (((3.1415926 * (($n1_p113r29_tm_83109_ac5620131455(5) * 0.120354331 + -0.37) - (2 * 0.120354331 + -0.37)) * 1.00945399659 * 1.00945399659) / (219.3 * (COS ((90 - 49.4983116) * 3.1415926 / 180)))) *400)

ROUND (((3.1415926 * (($n1_p113r29_tm_83109_ac5620131455(6) * 0.065551181 + -0.15) - (1 * 0.065551181 + -0.15))* 1.00945399659 * 1.00945399659) / (74.52 * (COS ((90 - 49.4983116) * 3.1415926 / 180)))) *400)

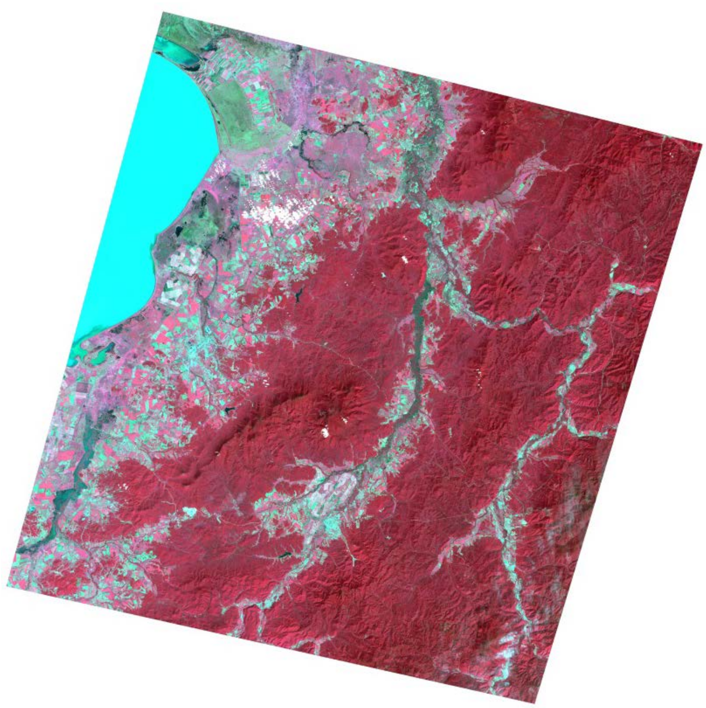
STACKLAYERS ($n2_memory, $n4_memory, $n6_memory, $n8_memory, $n10_memory, $n12_memory)

Appendix D: Atmospheric and Radiometric Corrected Landsat Imagery for 1976, 1989, 1998, 1999, and 2009. Shown in Near Infrared Image Composite

June 30, 1976

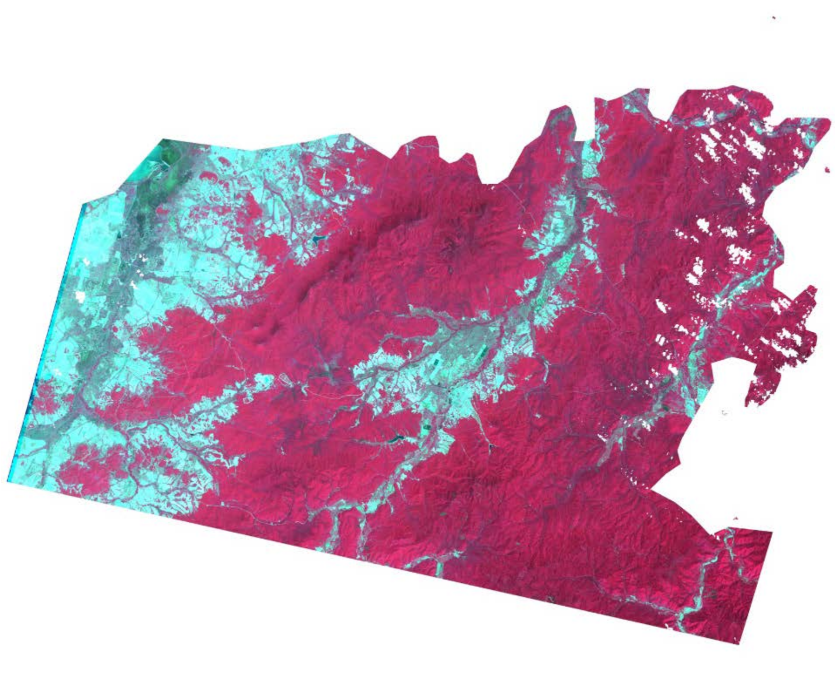


September 09, 1989

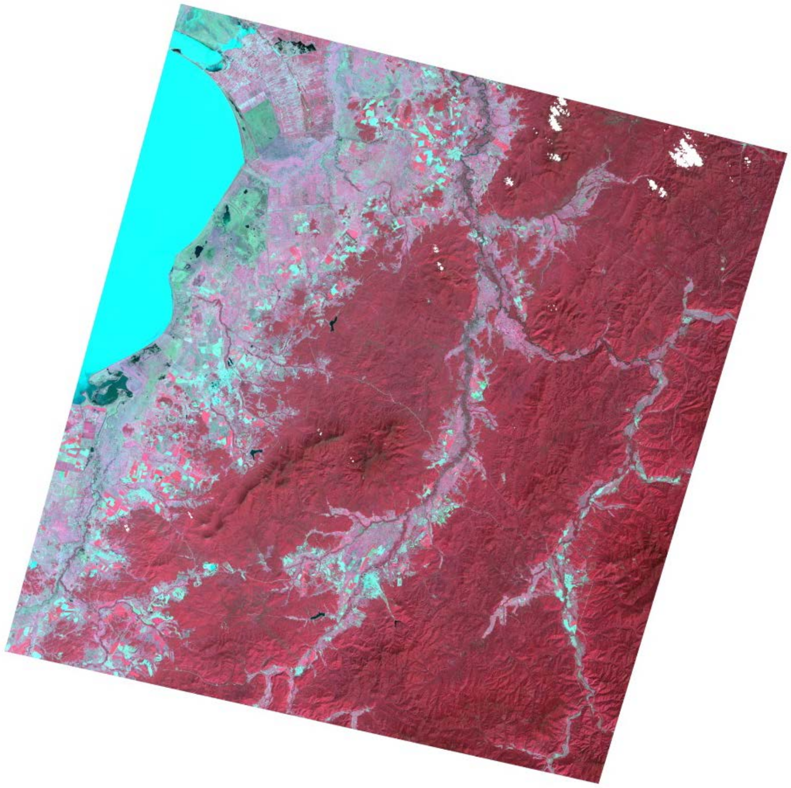


September 21, 1999

May 29, 1998



August 31, 2009



Appendix E: Number of Pixels Assigned By Class for Each Year with Percent Land Cover before Logic Statements

1976			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	691292	2.67%
2	Mixed	13236219	51.18%
3	Deciduous	1621974	6.27%
4	Young	14579	0.06%
5	Cut	112302	0.43%
6	Burn	3240	0.01%
8	Wetland	3619777	14.00%
9	Agriculture	4466199	17.27%
10	Urban	405126	1.57%
12	Water	1691836	6.54%
Sum:		25862544	100.00%

1989			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	888453	3.43%
2	Mixed	13034973	50.39%
3	Deciduous	625483	2.42%
4	Young	195975	0.76%
5	Cut	137832	0.53%
8	Wetland	3644335	14.09%
9	Agriculture	5197130	20.09%
10	Urban	452967	1.75%
12	Water	1691836	6.54%
Sum:		25868984	100.00%

1998/1999			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	589933	2.28%
2	Mixed	13812012	53.39%
3	Deciduous	1117089	4.32%
4	Young	206498	0.80%
5	Cut	28456	0.11%
8	Wetland	2842522	10.99%
9	Agriculture	5160286	19.95%
10	Urban	420767	1.63%
12	Water	1691836	6.54%
Sum:		25869399	100.00%

2009			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	689022	2.66%
2	Mixed	12755181	49.31%
3	Deciduous	1485392	5.74%
4	Young	192062	0.74%
5	Cut	63023	0.24%
8	Wetland	3597060	13.90%
9	Agriculture	4964622	19.19%
10	Urban	431199	1.67%
12	Water	1691836	6.54%
Sum:		25869397	100.00%

Appendix F: Accuracy Assessments for Each Year before Logic Statements

1976 (MSS) Accuracy assessment Matrix													
Land-Cover: Reference Map													
Land-Cover: Classified Map	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**9**	**10**	**12**	**Total**	**User's Accuracy (%)**	**Commission Error (%)**
1: Conifer	**19**	0	0	0	0	0	0	0	0	0	19	100.00	0.00
2: Mixed	6	**99**	7	1	2	0	1	0	0	0	116	85.34	14.66
3: Deciduous	0	1	**40**	3	1	0	0	2	0	0	47	85.11	14.89
4: Young	0	0	0	**21**	0	0	0	0	0	0	21	100.00	0.00
5: Cut	0	0	0	0	**19**	0	0	0	0	0	19	100.00	0.00
6: Burn	0	0	0	0	0	**5**	0	0	0	0	5	100.00	0.00
8: Wetland	0	0	0	0	0	0	**26**	5	0	3	34	76.47	23.53
9: Agriculture	0	0	1	0	2	0	1	**42**	0	0	46	91.30	8.70
10: Urban	0	0	0	0	0	0	0	0	**25**	0	25	100.00	0.00
12: Water	0	0	0	0	0	0	2	0	0	**20**	22	90.91	9.09
Column Total	25	100	48	25	24	5	30	49	25	23	354		
Producers Accuracy (%)	76.00	99.00	83.33	84.00	79.17	100.00	86.67	85.71	100.00	86.96			Overall Accuracy
Omission Error (%)	24.00	1.00	16.67	16.00	20.83	0.00	13.33	14.29	0.00	13.04			89.27%

1976 (MSS) accuracy assessment matrix. KHAT = 0.87

1989 (TM) Accuracy Assessment Matrix												
Land-Cover: Reference Map												
Land-Cover: Classified Map:	**1**	**2**	**3**	**4**	**5**	**8**	**9**	**10**	**12**	**Total**	**Users Accuracy (%)**	**Commission Error (%)**
1: Conifer	**20**	0	0	0	0	0	0	0	0	20	100.00	0.00
2: Mixed	5	**99**	11	0	1	1	1	0	0	118	83.90	16.10
3: Deciduous	0	0	**36**	0	0	0	1	0	0	37	97.30	2.70
4: Young	0	0	1	**25**	1	0	0	0	0	27	92.59	7.41
5: Cut	0	0	0	0	**22**	0	0	0	0	22	100.00	0.00
8: Wetland	0	0	0	0	0	**27**	0	0	0	27	100.00	0.00
9: Agriculture	0	0	0	0	0	1	**46**	0	0	47	97.87	2.13
10: Urban	0	0	0	0	0	0	0	**25**	0	25	100.00	0.00
12: Water	0	0	0	0	0	1	0	0	**25**	26	96.15	3.85
Column Total	25	99	48	25	24	30	48	25	25	349		
Producers Accuracy (%)	80.00	100.00	75.00	100.00	91.67	90.00	95.83	100.00	100.00			Overall Accuracy
Omission Error (%)	20.00	0.00	25.00	0.00	8.33	10.00	4.17	0.00	0.00			93.12%

1989 (TM) accuracy assessment matrix. KHAT = 0.92

1998/1999 (TM) Accuracy Assessment Matrix												
Land-Cover: Reference Map												
Land-Cover Classified Map:	**1**	**2**	**3**	**4**	**5**	**8**	**9**	**10**	**12**	**Total**	**Users Accuracy (%)**	**Commission Error (%)**
1: Conifer	**20**	0	0	0	0	0	0	0	0	20	100.00	0.00
2: Mixed	5	**97**	5	0	6	0	0	0	0	113	85.84	14.16
3: Deciduous	0	0	**40**	0	0	1	1	0	0	42	95.24	4.76
4: Young	0	0	1	**25**	1	0	0	0	0	27	92.59	7.41
5: Cut	0	0	0	0	**16**	0	0	0	0	16	100.00	0.00
8: Wetland	0	0	0	0	0	**25**	1	0	1	27	92.59	7.41
9: Agriculture	0	0	0	0	0	3	**47**	0	0	50	94.00	6.00
10: Urban	0	0	2	0	0	0	0	**25**	0	27	92.59	7.41
12: Water	0	0	0	0	0	1	0	0	**24**	25	96.00	4.00
Column Total	25	97	48	25	23	30	49	25	25	347		
Producers Accuracy (%)	80.00	100.00	83.33	100.00	69.57	83.33	95.92	100.00	96.00			Overall Accuracy
Omission Error (%)	20.00	0.00	16.67	0.00	30.43	16.67	4.08	0.00	4.00			91.93%

1998/1999 (TM) accuracy assessment matrix. KHAT = 0.90

2009 (TM) Accuracy Assessment Matrix												
Land-Cover: Reference Map												
Land-Cover Classified Map:	**1**	**2**	**3**	**4**	**5**	**8**	**9**	**10**	**12**	**Total**	**Users Accuracy (%)**	**Commission Error (%)**
1: Conifer	**19**	1	0	0	0	0	0	0	0	20	95.00	5.00
2: Mixed	6	**93**	1	1	1	1	0	0	0	103	90.29	9.71
3: Deciduous	0	5	**44**	1	0	0	3	0	0	53	83.02	16.98
4: Young	0	0	2	**21**	0	0	0	0	0	23	91.30	8.70
5: Cut	0	0	0	0	**20**	0	0	0	0	20	100.00	0.00
8: Wetland	0	0	0	0	0	**29**	0	1	2	32	90.63	9.38
9: Agriculture	0	0	0	0	0	1	**45**	0	0	46	97.83	2.17
10: Urban	0	0	1	0	0	0	0	**24**	0	25	96.00	4.00
12: Water	0	0	0	0	0	0	0	0	**23**	23	100.00	0.00
Column Total	25	99	48	23	21	31	48	25	25	345		
Producers Accuracy (%)	76.00	93.94	91.67	91.30	95.24	93.55	93.75	96.00	92.00			Overall Accuracy
Omission Error (%)	24.00	6.06	8.33	8.70	4.76	6.45	6.25	4.00	8.00			92.17%

2009 (TM) accuracy assessment matrix. KHAT = 0.91

Appendix G: From-To Change Matrices Showing Total Pixel Amount before Logic Statements

1976-1989 Change Matrix										
1976:	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**9**	**10**	**12**
1: Conifer	180617	463283	3448	7159	16256	0	16418	3899	202	0
2: Mixed	695054	11552028	351649	112009	96748	0	222493	195961	10231	0
3: Deciduous	4381	619714	182500	46042	10488	0	353474	403181	2153	0
4: Young	16	4117	1707	1913	350	0	3143	3333	0	0
5: Cut	5609	79953	2656	7135	7527	0	4398	3914	1110	0
6: Burn	0	1466	4	1751	3	0	16	0	0	0
8: Wetland	1819	66333	68098	6133	1961	0	2847374	626085	1636	0
9: Agriculture	840	243877	15143	13331	3860	0	194434	3942112	43126	0
10: Urban	23	1457	54	432	413	0	637	7637	394466	0
12: Water	0	0	0	0	0	0	0	0	0	1691836

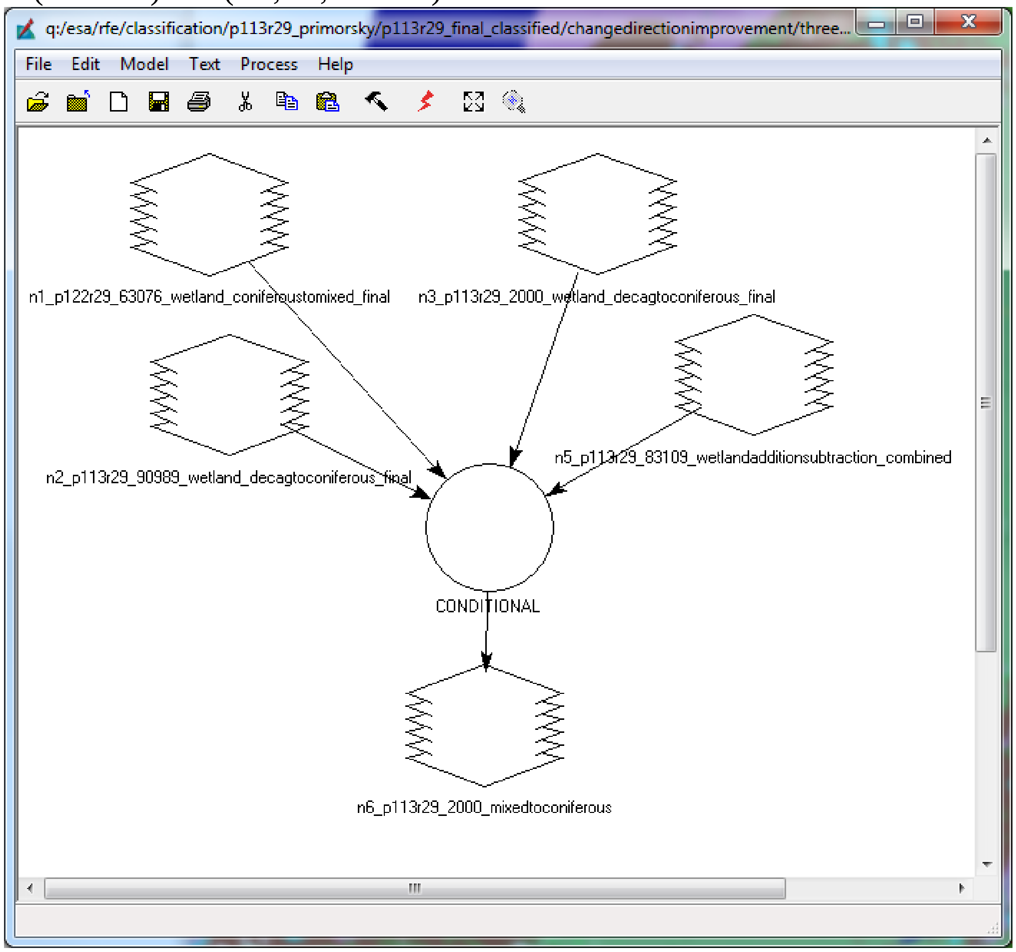
1989-1998/1999 Change Matrix									
1989:	**1**	**2**	**3**	**4**	**5**	**8**	**9**	**10**	**12**
1: Conifer	174988	707301	1101	1302	2293	815	629	17	0
2: Mixed	392015	11967511	434411	75056	17351	27229	119028	2321	0
3: Deciduous	2975	317570	231055	12963	1005	43760	16069	84	0
4: Young	3018	137469	25284	11437	1774	5999	10784	209	0
5: Cut	5101	104512	8924	7448	4206	2982	4540	119	0
8: Wetland	6514	315548	151542	25224	785	2526632	616823	850	0
9: Agriculture	5191	257457	260865	72621	976	233852	4346989	10164	0
10: Urban	128	4590	3763	446	66	1054	35924	406996	0
12: Water	0	0	0	0	0	0	0	0	1691836

1998/1999-2009 Change Matrix									
1998/1999:	**1**	**2**	**3**	**4**	**5**	**8**	**9**	**10**	**12**
1: Conifer	152852	403152	4318	1268	5615	18185	4473	68	0
2: Mixed	532430	11986805	735750	107965	38543	247785	158792	3851	0
3: Deciduous	765	254345	462970	40189	5636	138502	211883	2663	0
4: Young	646	35205	61293	19722	4125	25375	59844	288	0
5: Cut	866	16888	3094	2638	2858	1044	1047	21	0
8: Wetland	749	22932	61280	6458	2170	2504931	243647	355	0
9: Agriculture	690	33809	155540	13749	3107	659626	4265390	19125	0
10: Urban	13	1996	1129	73	969	1480	10279	404828	0

12: Water	0	0	0	0	0	0	0	0	1691836

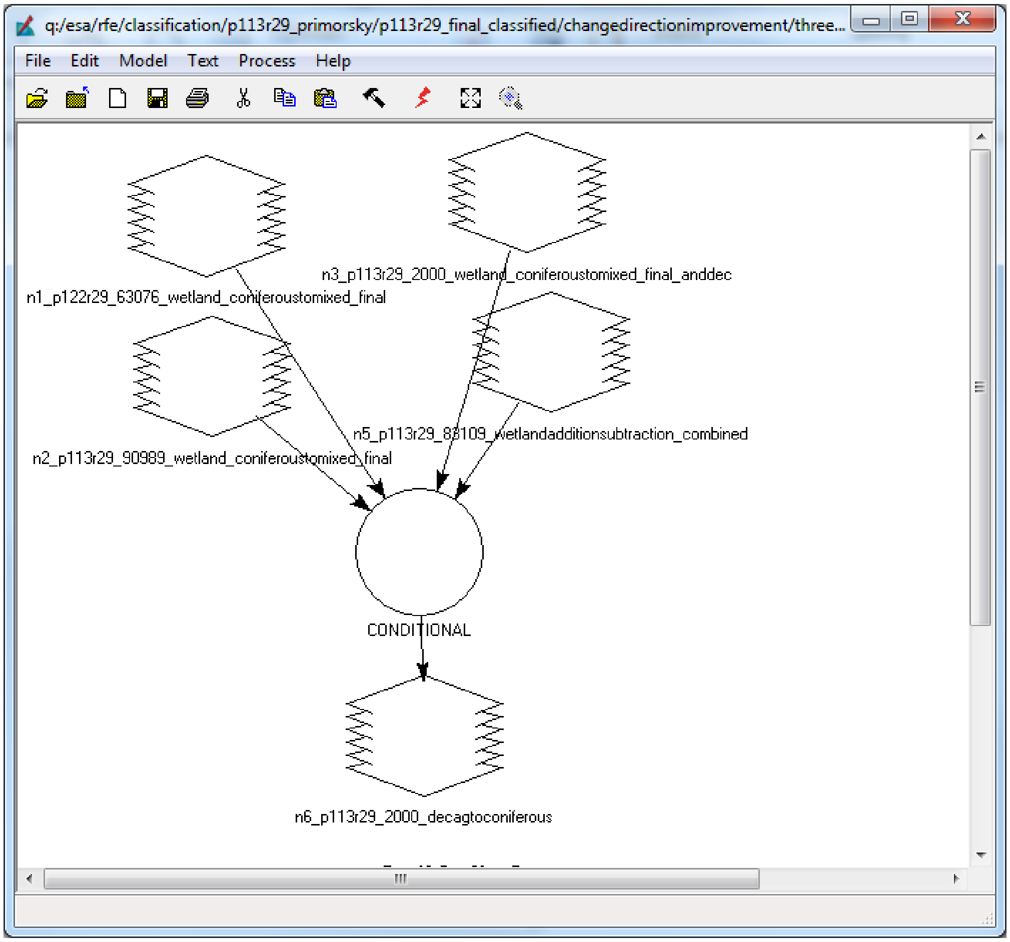
Appendix H: ERDAS Imagine Models for Classification Improvement

If (Y2=mix) and (Y1,Y3,Y4=con) Then Y2=con
If (Y3=mix) and (Y1,Y2,Y4=con) Then Y3=con



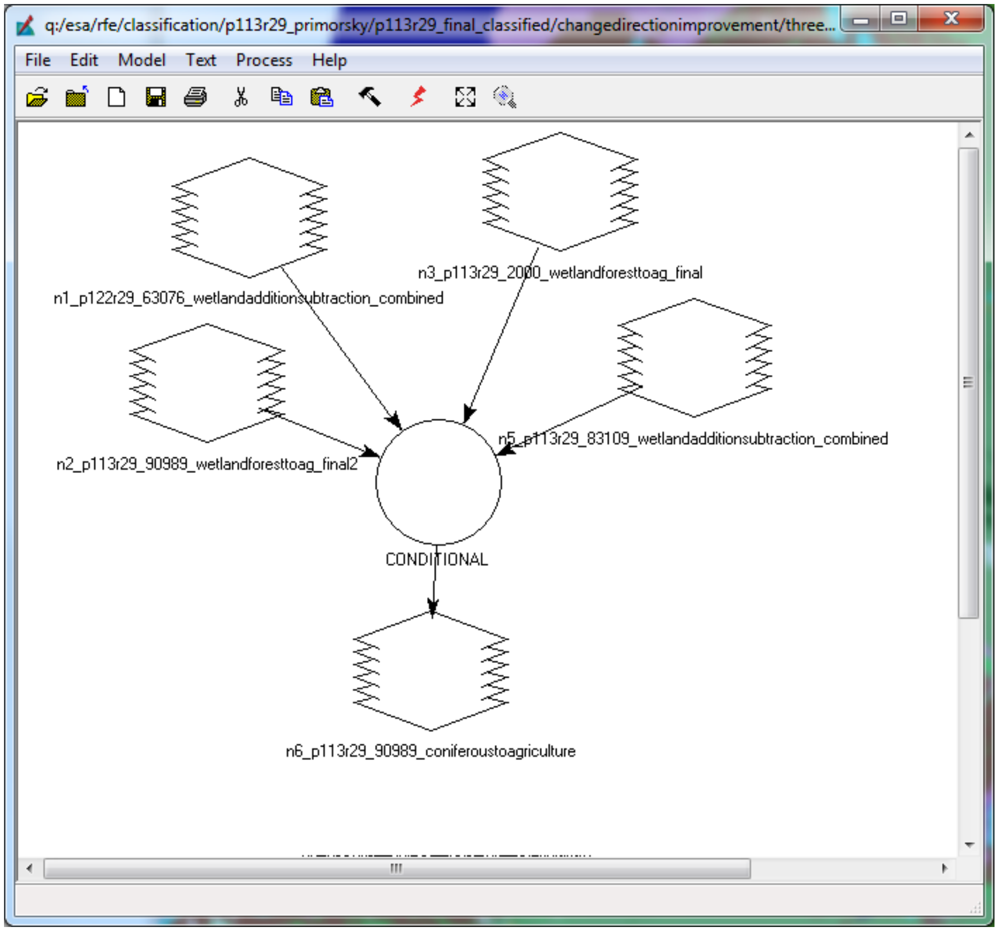
CONDITIONAL { (($n3_p113r29_2000_wetland_decagtoconiferous_final == 2) AND ($n1_p122r29_63076_wetland_coniferoustomixed_final == 1) AND ($n2_p113r29_90989_wetland_decagtoconiferous_final == 1) AND ($n5_p113r29_83109_wetlandadditionsubtraction_combined == 1)) 1 }

If (Y1=con) and (Y2 =dec, ag) and (Y3, Y4=con) Then Y2=con
If (Y1, Y2=con) and (Y3 =dec, ag) and (Y4=con) Then Y3=con



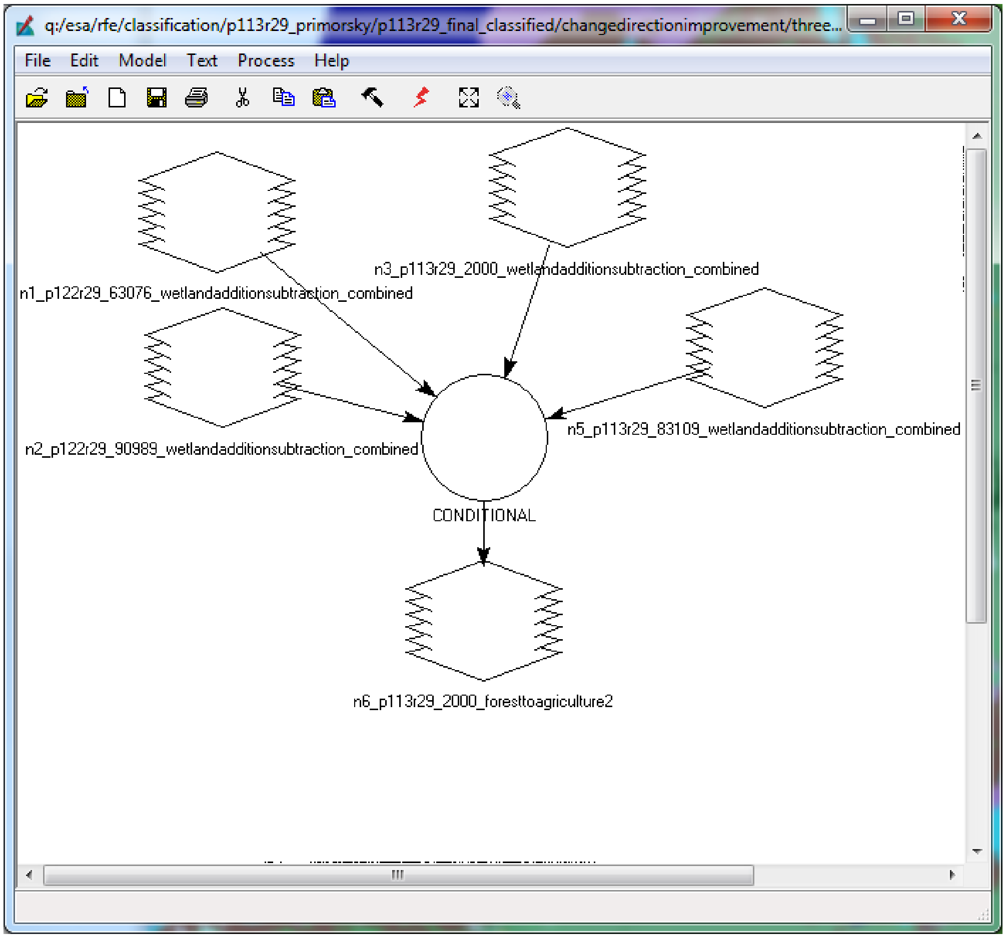
CONDITIONAL { ((($n3_p113r29_2000_wetland_coniferoustomixed_final_anddec == 3) OR ($n3_p113r29_2000_wetland_coniferoustomixed_final_anddec == 9)) AND ($n1_p122r29_63076_wetland_coniferoustomixed_final == 1) AND ($n2_p113r29_90989_wetland_coniferoustomixed_final == 1) AND ($n5_p113r29_83109_wetlandadditionsubtraction_combined == 1)) 1 }

If (Y1=con) and (Y2,Y3,Y4=mix) Then Y1=mix
If (Y2=con) and (Y1,Y3,Y4=mix) Then Y2=mix
If (Y3=con) and (Y1,Y2,Y4=mix) Then Y3=mix
If (Y1=dec) and (Y2 =con) and (Y3, Y4 =dec) Then Y2=dec
If (Y1, Y2=dec) and (Y3 =con) and (Y4 =dec) Then Y3=dec



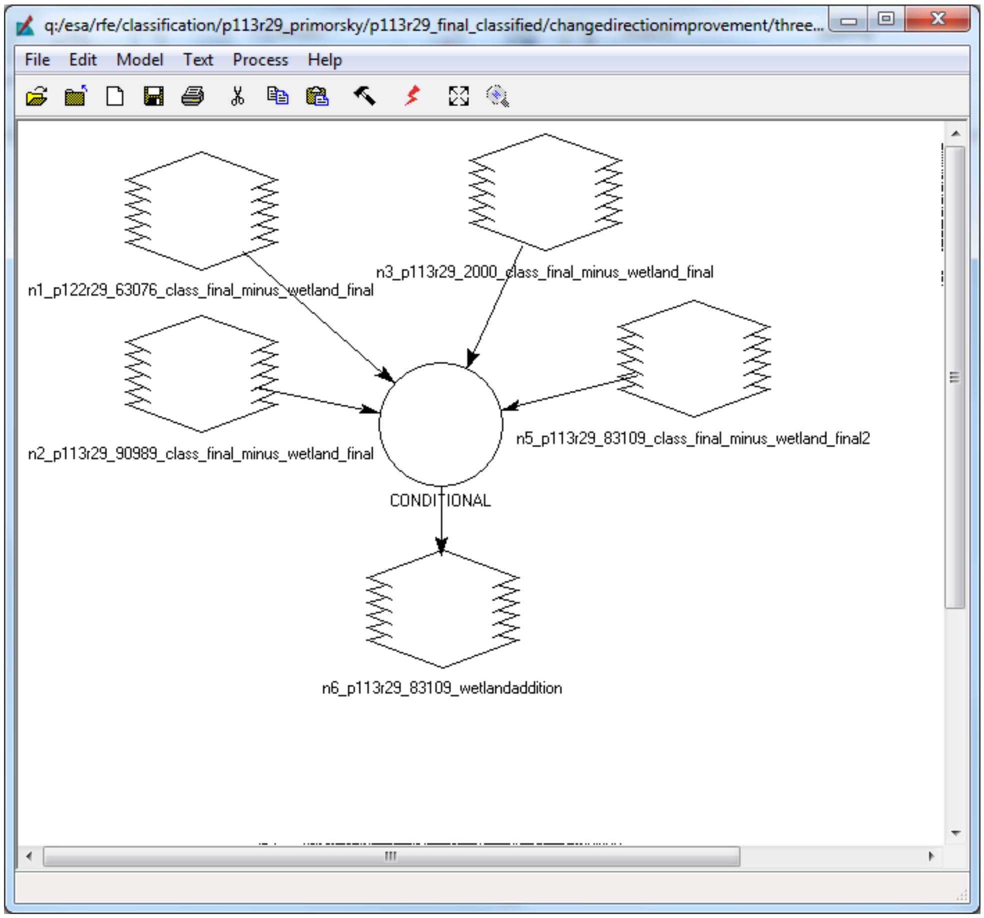
CONDITIONAL { (($n2_p113r29_90989_wetlandforesttoag_final2 == 1) AND ($n1_p122r29_63076_wetlandadditionsubtraction_combined == 2) AND ($n3_p113r29_2000_wetlandforesttoag_final == 2) AND ($n5_p113r29_83109_wetlandadditionsubtraction_combined == 2)) 2 }

If (Y3=con/mixed) and (Y1,Y2,Y4=ag) Then Y3=ag
If (Y2=con/mixed) and (Y1,Y3,Y4=ag) Then Y2=ag



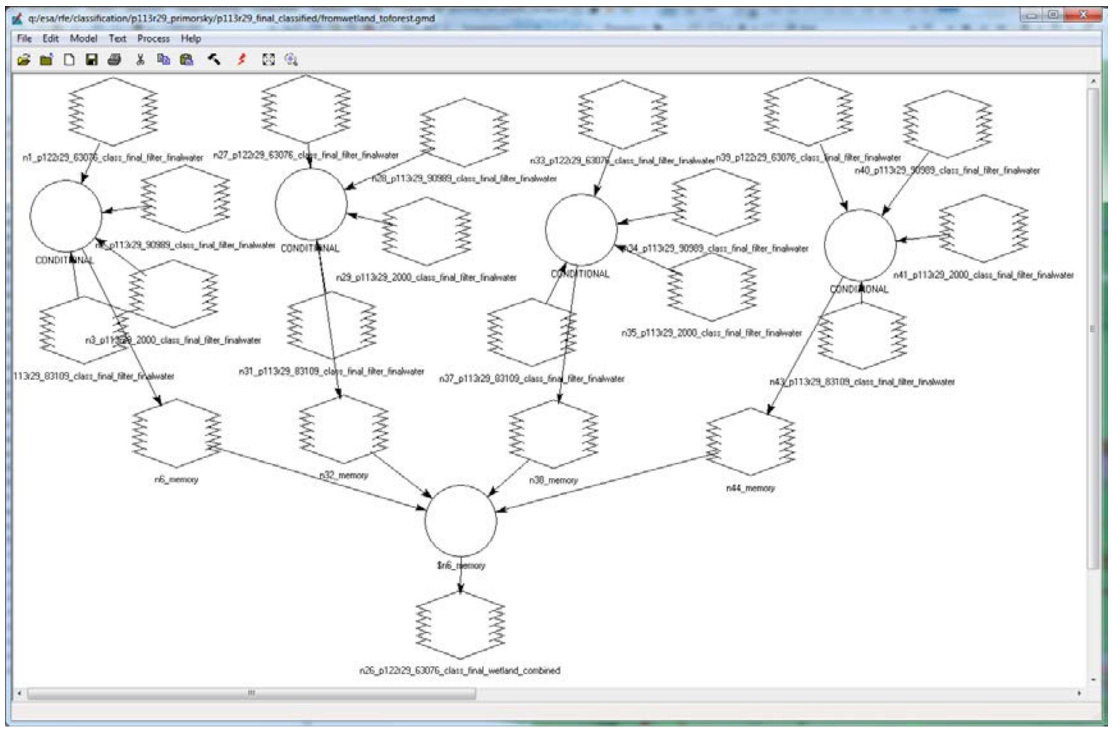
CONDITIONAL { ((($n3_p113r29_2000_wetlandadditionsubtraction_combined == 1) OR ($n3_p113r29_2000_wetlandadditionsubtraction_combined == 2)) AND($n1_p122r29_63076_wetlandadditionsubtraction_combined == 9) AND ($n2_p122r29_90989_wetlandadditionsubtraction_combined == 9) AND ($n5_p113r29_83109_wetlandadditionsubtraction_combined == 9)) 9 }

If (Y1=con/mix/dec/young/cut) and (Y2,Y3,Y4=wetland) Then Y1=wetland
If (Y2=con/mix/dec/young/cut) and (Y1,Y3,Y4=wetland) Then Y2=wetland
If (Y3=con/mix/dec/young/cut) and (Y1,Y2,Y4=wetland) Then Y3=wetland
If (Y4=con/mix/dec/young/cut) and (Y1,Y2,Y3=wetland) Then Y4=wetland



CONDITIONAL { (($n5_p113r29_83109_class_final_minus_wetland_final2== 1 OR
$n5_p113r29_83109_class_final_minus_wetland_final2 == 2 OR
$n5_p113r29_83109_class_final_minus_wetland_final2 == 3 OR
$n5_p113r29_83109_class_final_minus_wetland_final2 == 4 OR
$n5_p113r29_83109_class_final_minus_wetland_final2 == 5) AND
($n2_p113r29_90989_class_final_minus_wetland_final == 8) AND
($n1_p122r29_63076_class_final_minus_wetland_final == 8) AND
($n3_p113r29_2000_class_final_minus_wetland_final == 8)) 8 }

If (Y1=wetland) and (Y2,Y3,Y4=con) Then Y1=con, If (Y1=wetland) and (Y2,Y3,Y4=mix) Then Y1=mix, If (Y1=wetland) and (Y2,Y3,Y4=dec) Then Y1=dec, If (Y1=wetland) and (Y2,Y3,Y4=young) Then Y1=young, If (Y2=wetland) and (Y1,Y3,Y4=con) Then Y2=con, If (Y2=wetland) and (Y1,Y3,Y4=mix) Then Y2=mix, If (Y2=wetland) and (Y1,Y3,Y4=dec) Then Y2=dec, If (Y2=wetland) and (Y1,Y3,Y4=young) Then Y2=young, If (Y3=wetland) and (Y1,Y2,Y4=mix) Then Y3=con, If (Y3=wetland) and (Y1,Y2,Y4=mix) Then Y3=mix, If (Y3=wetland) and (Y1,Y2,Y4=dec) Then Y3=dec, If (Y3=wetland) and (Y1,Y2,Y4=young) Then Y3=young, If (Y4=wetland) and (Y1,Y2,Y3=con) Then Y4=con, If (Y4=wetland) and (Y1,Y2,Y3=mix) Then Y4=mix, If (Y4=wetland) and (Y1,Y2,Y3=dec) Then Y4=dec, If (Y4=wetland) and (Y1,Y2,Y3=young) Then Y4=young



EQ 1: CONDITIONAL { (($n1_p122r29_63076_class_final_filter_finalwater == 8) AND ($n3_p113r29_2000_class_final_filter_finalwater == 1) AND ($n2_p113r29_90989_class_final_filter_finalwater == 1) AND ($n5_p113r29_83109_class_final_filter_finalwater == 1)) 1 }

EQ 2: CONDITIONAL { (($n27_p122r29_63076_class_final_filter_finalwater == 8) AND ($n29_p113r29_2000_class_final_filter_finalwater == 2) AND ($n28_p113r29_90989_class_final_filter_finalwater == 2) AND ($n31_p113r29_83109_class_final_filter_finalwater == 2)) 2 }

EQ 3: CONDITIONAL { (($n33_p122r29_63076_class_final_filter_finalwater == 8) AND ($n35_p113r29_2000_class_final_filter_finalwater == 3) AND ($n34_p113r29_90989_class_final_filter_finalwater == 3) AND ($n37_p113r29_83109_class_final_filter_finalwater == 3)) 3 }

EQ 4: CONDITIONAL { (($n39_p122r29_63076_class_final_filter_finalwater == 8) AND ($n41_p113r29_2000_class_final_filter_finalwater == 4) AND ($n40_p113r29_90989_class_final_filter_finalwater == 4) AND ($n43_p113r29_83109_class_final_filter_finalwater == 4)) 4 }

EQ 5: $n6_memory + $n32_memory + $n38_memory + $n44_memory

Appendix I: Number of Pixels Assigned By Class for Each Year with Percent Land Cover after Logic Statements

1976			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	369222	1.43%
2	Mixed	13543784	52.37%
3	Deciduous	1455647	5.63%
4	Young	13923	0.05%
5	Cut	112063	0.43%
6	Burn	3240	0.01%
8	Wetland	3801504	14.70%
9	Agriculture	4466199	17.27%
10	Urban	405126	1.57%
12	Water	1691836	6.54%
Sum:		25862544	100.00%

1989			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	464953	1.80%
2	Mixed	13513957	52.26%
3	Deciduous	608143	2.35%
4	Young	193966	0.75%
5	Cut	137643	0.53%
8	Wetland	3579240	13.84%
9	Agriculture	5217279	20.18%
10	Urban	452967	1.75%
12	Water	1691836	6.54%
Sum:		25859984	100.00%

1998/1999			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	377249	1.46%
2	Mixed	13939294	53.88%
3	Deciduous	1027406	3.97%
4	Young	197628	0.76%
5	Cut	28414	0.11%
8	Wetland	2979910	11.52%
9	Agriculture	5206895	20.13%
10	Urban	420767	1.63%
12	Water	1691836	6.54%
Sum:		25869399	100.00%

2009			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	691154	2.67%
2	Mixed	12803458	49.49%
3	Deciduous	1450451	5.61%
4	Young	190999	0.74%
5	Cut	62928	0.24%
8	Wetland	3582750	13.85%
9	Agriculture	4964622	19.19%
10	Urban	431199	1.67%
12	Water	1691836	6.54%
Sum:		25869397	100.00%

Appendix J: Accuracy Assessments for Each Year after Logic Statements

1976 (MSS) Accuracy assessment Matrix													
Land-Cover: Reference Map													
Land-Cover: Classified Map	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**9**	**10**	**12**	**Total**	**User's Accuracy (%)**	**Commission Error (%)**
1: Conifer	**18**	0	0	0	0	0	0	0	0	0	18	100.00	0.00
2: Mixed	7	**99**	7	1	2	0	1	0	0	0	116	84.62	15.38
3: Deciduous	0	1	**40**	3	1	0	0	2	0	0	47	85.11	14.89
4: Young	0	0	0	**21**	0	0	0	0	0	0	21	100.00	0.00
5: Cut	0	0	0	0	**19**	0	0	0	0	0	19	100.00	0.00
6: Burn	0	0	0	0	0	**5**	0	0	0	0	5	100.00	0.00
8: Wetland	0	0	0	0	0	0	**26**	5	0	3	34	76.47	23.53
9: Agriculture	0	0	1	0	2	0	1	**42**	0	0	46	91.30	8.70
10: Urban	0	0	0	0	0	0	0	0	**25**	0	25	100.00	0.00
12: Water	0	0	0	0	0	0	2	0	0	**20**	22	90.91	9.09
Column Total	25	100	48	25	24	5	30	49	25	23	354		
Producers Accuracy (%)	72.00	99.00	83.33	84.00	79.17	100.00	86.67	85.71	100.00	86.96			Overall Accuracy
Omission Error (%)	28.00	1.00	16.67	16.00	20.83	0.00	13.33	14.29	0.00	13.04			88.98%

1976 (MSS) accuracy assessment matrix. KHAT = 0.87

1989 (TM) Accuracy Assessment Matrix												
Land-Cover: Reference Map												
Land-Cover: Classified Map:	**1**	**2**	**3**	**4**	**5**	**8**	**9**	**10**	**12**	**Total**	**Users Accuracy (%)**	**Commission Error (%)**
1: Conifer	**20**	1	0	0	0	0	0	0	0	21	95.24	4.76
2: Mixed	5	**98**	11	0	1	0	4	0	0	119	82.35	17.65
3: Deciduous	0	0	**36**	0	0	0	1	0	0	37	97.30	2.70
4: Young	0	0	1	**25**	1	0	0	0	0	27	92.59	7.41
5: Cut	0	0	0	0	**22**	0	0	0	0	22	100.00	0.00
8: Wetland	0	0	0	0	0	**28**	0	0	0	28	100.00	0.00
9: Agriculture	0	0	0	0	0	1	**43**	0	0	44	97.73	2.27
10: Urban	0	0	0	0	0	0	0	**25**	0	25	100.00	0.00
12: Water	0	0	0	0	0	1	0	0	**25**	26	96.15	3.85
Column Total	25	99	48	25	24	30	48	25	25	349		
Producers Accuracy (%)	80.00	98.99	75.00	100.00	91.67	93.33	89.58	100.00	100.00			Overall Accuracy
Omission Error (%)	20.00	1.01	25.00	0.00	8.33	6.67	10.41	0.00	0.00			92.26%

1989 (TM) accuracy assessment matrix. KHAT = 0.91

1998/1999 (TM) Accuracy Assessment Matrix												
Land-Cover: Reference Map												
Land-Cover Classified Map:	**1**	**2**	**3**	**4**	**5**	**8**	**9**	**10**	**12**	**Total**	**Users Accuracy (%)**	**Commission Error (%)**
1: Conifer	**20**	0	0	0	0	0	0	0	0	20	100.00	0.00
2: Mixed	5	**97**	5	0	6	0	0	0	0	113	85.84	14.16
3: Deciduous	0	0	**40**	0	0	1	1	0	0	42	95.24	4.76
4: Young	0	0	0	**25**	1	0	0	0	0	26	96.15	3.85
5: Cut	0	0	0	0	**16**	0	0	0	0	16	100.00	0.00
8: Wetland	0	0	1	0	0	**25**	1	0	1	28	89.29	10.71
9: Agriculture	0	0	0	0	0	3	**47**	0	0	50	94.00	6.00
10: Urban	0	0	2	0	0	0	0	**25**	0	27	92.59	7.41
12: Water	0	0	0	0	0	1	0	0	**24**	25	96.00	4.00
Column Total	25	97	48	25	23	30	49	25	25	347		
Producers Accuracy (%)	80.00	100.00	83.33	100.00	69.57	83.33	95.92	100.00	96.00			Overall Accuracy
Omission Error (%)	20.00	0.00	16.67	0.00	30.43	16.67	4.08	0.00	4.00			91.93%

1998/1999 (TM) accuracy assessment matrix. KHAT = 0.90

2009 (TM) Accuracy Assessment Matrix												
Land-Cover: Reference Map												
Land-Cover Classified Map:	**1**	**2**	**3**	**4**	**5**	**8**	**9**	**10**	**12**	**Total**	**Users Accuracy (%)**	**Commission Error (%)**
1: Conifer	**19**	1	0	0	0	0	0	0	0	20	95.00	5.00
2: Mixed	6	**93**	1	1	1	1	0	0	0	103	90.29	9.71
3: Deciduous	0	5	**44**	1	0	0	3	0	0	53	83.02	16.98
4: Young	0	0	2	**21**	0	0	0	0	0	23	91.30	8.70
5: Cut	0	0	0	0	**20**	0	0	0	0	20	100.00	0.00
8: Wetland	0	0	0	0	0	**29**	0	1	2	32	90.63	9.38
9: Agriculture	0	0	0	0	0	1	**45**	0	0	46	97.83	2.17
10: Urban	0	0	1	0	0	0	0	**24**	0	25	96.00	4.00
12: Water	0	0	0	0	0	0	0	0	**23**	23	100.00	0.00
Column Total	25	99	48	23	21	31	48	25	25	345		
Producers Accuracy (%)	76.00	93.94	91.67	91.30	95.24	93.55	93.75	96.00	92.00			Overall Accuracy
Omission Error (%)	24.00	6.06	8.33	8.70	4.76	6.45	6.25	4.00	8.00			92.17%

2009 (TM) accuracy assessment matrix. KHAT = 0.91

Appendix K: From-To Change Matrices Showing Total Pixel Amount after Logic Statements

1976-1989 Change Matrix										
1976:	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**9**	**10**	**12**
1: Conifer	203178	127795	3212	7159	16256	0	7514	3896	202	0
2: Mixed	249385	12423189	351649	112009	96748	0	104566	195961	10231	0
3: Deciduous	4381	619714	188800	46042	10488	0	180847	403181	2153	0
4: Young	16	4117	1707	1929	350	0	2471	3333	0	0
5: Cut	5609	79953	2656	7135	7527	0	4159	3914	1110	0
6: Burn	0	1466	4	1751	3	0	16	0	0	0
8: Wetland	1431	38792	44694	4108	1772	0	3082648	626085	1636	0
9: Agriculture	836	214729	15143	13331	3860	0	194434	3971264	43126	0
10: Urban	23	1457	54	432	413	0	637	7637	394466	0
12: Water	0	0	0	0	0	0	0	0	0	169183 6

1989-1998/1999 Change Matrix									
1989:	**1**	**2**	**3**	**4**	**5**	**8**	**9**	**10**	**12**
1: Conifer	243114	215779	1080	1302	2293	748	613	17	0
2: Mixed	115097	12764565	434411	75056	17351	15225	89880	2321	0
3: Deciduous	2656	317570	236152	12963	1005	21642	16069	84	0
4: Young	3018	137469	25284	11477	1774	3950	10784	209	0
5: Cut	5101	104512	8924	7448	4206	2793	4540	119	0
8: Wetland	4024	182839	56783	16314	743	2700447	616823	850	0
9: Agriculture	4108	211916	260865	72621	976	233852	4422762	10164	0
10: Urban	128	4590	3763	446	66	1054	35924	406996	0
12: Water	0	0	0	0	0	0	0	0	1691836

1998/1999-2009 Change Matrix									
1998/1999:	**1**	**2**	**3**	**4**	**5**	**8**	**9**	**10**	**12**
1: Conifer	200996	148095	4235	1268	5615	13577	3393	68	0
2: Mixed	486577	12299070	735750	107965	38543	154196	113251	3851	0
3: Deciduous	744	254345	465999	40189	5636	45811	211883	2663	0
4: Young	646	35205	61293	19869	4125	16358	59844	288	0
5: Cut	866	16888	3094	2638	2858	1002	1047	21	0
8: Wetland	623	14001	23393	5248	2075	2690568	243647	355	0
9: Agriculture	678	33809	155540	13749	3107	659626	4312011	19125	0

10: Urban	13	1996	1129	73	969	1480	10279	404828	0
12: Water	0	0	0	0	0	0	0	0	1691836

Appendix L: Total Pixels Changed for Each Logic Statement

Rule	Date	From	To	Number of Pixels
If (Y1=wetland) and (Y2,Y3,Y4=con) Then Y1=con	1976	8	1	342
If (Y1=wetland) and (Y2,Y3,Y4=mix) Then Y1=mix	1976	8	2	22331
If (Y1=wetland) and (Y2,Y3,Y4=dec) Then Y1=dec	1976	8	3	2721
If (Y1=wetland) and (Y2,Y3,Y4=young) Then Y1=young	1976	8	4	16
If (Y2=wetland) and (Y1,Y3,Y4=con) Then Y2=con	1989	8	1	119
If (Y2=wetland) and (Y1,Y3,Y4=mix) Then Y2=mix	1989	8	2	89534
If (Y2=wetland) and (Y1,Y3,Y4=dec) Then Y2=dec	1989	8	3	3579
If (Y2=wetland) and (Y1,Y3,Y4=young) Then Y2=young	1989	8	4	0
If (Y3=wetland) and (Y1,Y2,Y4=mix) Then Y3=con	1998/1999	8	1	21
If (Y3=wetland) and (Y1,Y2,Y4=mix) Then Y3=mix	1998/1999	8	2	6794
If (Y3=wetland) and (Y1,Y2,Y4=dec) Then Y3=dec	1998/1999	8	3	1435
If (Y3=wetland) and (Y1,Y2,Y4=young) Then Y3=young	1998/1999	8	4	40
If (Y4=wetland) and (Y1,Y2,Y3=con) Then Y4=con	2009	8	1	2237
If (Y4=wetland) and (Y1,Y2,Y3=mix) Then Y4=mix	2009	8	2	50414
If (Y4=wetland) and (Y1,Y2,Y3=dec) Then Y4=dec	2009	8	3	1511
If (Y4=wetland) and (Y1,Y2,Y3=young) Then Y4=young	2009	8	4	107
If (Y1=con/mix/dec/young/cut) and (Y2,Y3,Y4=wetland) Then Y1=wetland	1976	1,2,3,4,5	8	207137
If (Y2=con/mix/dec/young/cut) and (Y1,Y3,Y4=wetland) Then Y2=wetland	1989	1,2,3,4,5	8	28137
If (Y3=con/mix/dec/young/cut) and (Y1,Y2,Y4=wetland) Then Y3=wetland	1998/1999	1,2,3,4,5	8	145678
If (Y4=con/mix/dec/young/cut) and (Y1,Y2,Y3=wetland) Then Y4=wetland	2009	1,2,3,4,5	8	39959
If (Y2=con/mix) and (Y1,Y3,Y4=ag) Then Y2=ag	1989	1,2	9	29152

If (Y3=con/mix) and (Y1,Y2,Y4=ag) Then Y3=ag	1998/1999	1,2	9	46621
If (Y1=con) and (Y2,Y3,Y4=mix) Then Y1=mix	1976	1	2	313627
If (Y2=con) and (Y1,Y3,Y4=mix) Then Y2=mix	1989	1	2	445669
If (Y3=con) and (Y1,Y2,Y4=mix) Then Y3=mix	1998/1999	1	2	255057
If (Y1=dec) and (Y2 =con) and (Y3, Y4 =dec) Then Y2=dec	1989	1	3	4
If (Y1, Y2=dec) and (Y3 =con) and (Y4 =dec) Then Y3=dec	1998/1999	1	3	83
If (Y1=con) and (Y2 =dec, ag) and (Y3, Y4=con) Then Y2=con	1989	3,9	1	239
If (Y1, Y2=con) and (Y3 =dec, ag) and (Y4=con) Then Y3=con	1998/1999	3,9	1	33
If (Y2=mix) and (Y1,Y3,Y4=con) Then Y2=con	1989	2	1	21861
If (Y3=mix) and (Y1,Y2,Y4=con) Then Y3=con	1998/1999	2	1	45853

Appendix M: Number of Pixels Assigned By Class for Each Year with Percent Land Cover after Logic Statements for the Xingkaihu Protected Region

1976			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	718	0.06%
2	Mixed	1131	0.10%
3	Deciduous	3274	0.28%
4	Young	0	0.00%
5	Cut	0	0.00%
6	Burn	0	0.00%
8	Wetland	627256	53.97%
9	Agriculture	47497	4.09%
10	Urban	273	0.02%
12	Water	482003	41.48%
Sum:		1162152	100.00%

1989			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	0	0.00%
2	Mixed	1870	0.16%
3	Deciduous	1032	0.09%
4	Young	79	0.01%
5	Cut	3	0.00%
8	Wetland	586102	50.43%
9	Agriculture	88288	7.60%
10	Urban	2929	0.25%
12	Water	482003	41.47%
Sum:		1162306	100.00%

1998/1999			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	39	0.00%
2	Mixed	5735	0.49%
3	Deciduous	4659	0.40%
4	Young	3907	0.34%
5	Cut	0	0.00%
8	Wetland	428370	36.86%
9	Agriculture	237315	20.42%
10	Urban	279	0.02%
12	Water	482003	41.47%
Sum:		1162307	100.00%

2009			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	17	0.00%
2	Mixed	1	0.00%
3	Deciduous	17838	1.53%
4	Young	151	0.01%
5	Cut	6	0.00%
8	Wetland	423079	36.40%
9	Agriculture	235605	20.27%
10	Urban	3608	0.31%
12	Water	482003	41.47%
Sum:		1162308	100.00%

Appendix N: Number of Pixels Assigned By Class for Each Year with Percent Land Cover after Logic Statements for the Khankaiskii Protected Region

1976			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	104	0.01%
2	Mixed	6294	0.58%
3	Deciduous	12504	1.15%
4	Young	0	0.00%
5	Cut	0	0.00%
6	Burn	0	0.00%
8	Wetland	950361	87.10%
9	Agriculture	56595	5.19%
10	Urban	2509	0.23%
12	Water	62775	5.75%
Sum:		1091142	100.00%

1989			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	0	0.00%
2	Mixed	6294	0.58%
3	Deciduous	3917	0.36%
4	Young	359	0.03%
5	Cut	23	0.00%
8	Wetland	916451	83.96%
9	Agriculture	99188	9.09%
10	Urban	2547	0.23%
12	Water	62775	5.75%
Sum:		1091554	100.00%

1998/1999			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	46	0.00%
2	Mixed	10498	0.96%
3	Deciduous	8377	0.77%
4	Young	2224	0.20%
5	Cut	0	0.00%
8	Wetland	890256	81.55%
9	Agriculture	114970	10.53%
10	Urban	2512	0.23%
12	Water	62775	5.75%
Sum:		1091658	100.00%

2009			
Code	**Class Name**	**Count**	**Percent Land Cover**
1	Coniferous	0	0.00%
2	Mixed	3374	0.31%
3	Deciduous	10091	0.92%
4	Young	462	0.04%
5	Cut	4	0.00%
8	Wetland	918574	84.14%
9	Agriculture	93843	8.60%
10	Urban	2537	0.23%
12	Water	62775	5.75%
Sum:		1091660	100.00%

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