

5-3-2008

## A 17-year assesment of changes in biomass in the south of Chile, using Landsat satellite images

Fredy A. Bernales

Follow this and additional works at: <https://scholarsjunction.msstate.edu/td>

---

### Recommended Citation

Bernales, Fredy A., "A 17-year assesment of changes in biomass in the south of Chile, using Landsat satellite images" (2008). *Theses and Dissertations*. 18.  
<https://scholarsjunction.msstate.edu/td/18>

This Graduate Thesis - Open Access is brought to you for free and open access by the Theses and Dissertations at Scholars Junction. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of Scholars Junction. For more information, please contact [scholcomm@msstate.libanswers.com](mailto:scholcomm@msstate.libanswers.com).

A 17-YEAR ASSESMENT OF CHANGES IN BIOMASS IN THE SOUTH OF CHILE,  
USING LANDSAT SATELLITE IMAGES

By

Fredy A. Bernales

A Thesis Submitted to the Faculty of  
Mississippi State University  
in Partial Fulfillment of the Requirements  
for the Degree of Master of Science  
in Geosciences  
in the Department of Geosciences

Mississippi State, Mississippi

May 2008

A 17-YEAR ASSESMENT OF CHANGES IN BIOMASS IN THE SOUTH OF CHILE,  
USING LANDSAT SATELLITE IMAGES

By

Fredy A. Bernales

Approved:

---

William Cooke III  
Assistant Professor of GIS  
(Director of Thesis)

---

Jinmu Choi  
Assistant Professor of GIS  
(Committee Member)

---

Jamie Dyer  
Assistant Professor of Meteorology  
(Committee Member)

---

Christopher P. Dewey  
Associate Professor of Geology  
Graduate Coordinator of the  
Department of Geosciences

---

Gary Myers  
Professor and Interim Dean of the  
College of Arts and Sciences

Name: Fredy A. Bernales

Date of Degree: May 3, 2008

Institution: Mississippi State University

Major Field: Geosciences

Major Professor: Dr. William Cooke

Title of the Study: A 17-YEARS ASSESMENT OF CHANGES IN BIOMASS IN  
THE SOUTH OF CHILE, USING LANDSAT SATELLITE  
IMAGES

Pages in the Study: 98

Candidate for Degree of Master of Science

Southern Chile is recognized by different international organizations such as UNESCO, and Conservational International as an ecologically sensitive area. The country of Chile is home to one third of the earth's remaining temperate forests. The lack of multi-temporal studies that evaluate changes in land cover biomass make this study an important one for increasing awareness of how the evolution of the landscape affects environmental planning and development of legal precedents aimed at protecting this rich ecological habitat. In the study area, 40% of areas that traditionally supported row crops and pasture hay were replaced by forestry plantations and herbaceous successional vegetation. This replacement has impacted the Chilean people and their agricultural way of life. The results obtained depict the usefulness of Change Vector Analysis (CVA) as a technique to analyze changes in biomass over time.

## DEDICATION

This study is dedicated to everybody who collaborated in its process and got involved along the way. Specially, to my committee members who believed in its purpose. Also, this is dedicated to the local people from the area of study in Chile that provided me with important information regarding different aspects of the current issues in the region.

## AKNOWLEDGEMENTS

I cannot leave behind the support of my wife, mother, father and sister who followed the progress of this research. I deeply appreciate all their help in good and bad times. Also, I want to thank the professors in the department of geosciences who showed the highest level of professionalism giving me the opportunity to grow as an individual and a professional. Specially, I appreciate my family's patience in times when distance kept us apart.

## TABLE OF CONTENTS

DEDICATION .....	ii
ACKNOWLEDGEMENTS .....	iii
LIST OF TABLES .....	vii
LIST OF FIGURES .....	viii
CHAPTER	
I. INTRODUCTION .....	1
II. RESEARCH OBJECTIVES .....	4
III. BACKGROUND INFORMATION AND LITERATURE REVIEW .....	6
3.1 Land Use and Land Cover .....	6
3.2 Change Detection Methodology in Remote Sensing .....	7
3.2.1 Radiometric Normalization Techniques .....	8
3.2.1.1 Simple Regression .....	8
3.2.1.2 Histogram Matching .....	9
3.2.1.3 Pseudo-Invariant Features .....	9
3.2.1.4 Dark Bright Method .....	9
3.2.1.5 No Change Set Method .....	10
3.2.2 Change Detection Using Image Enhancement Techniques .....	10
3.2.2.1 Image Differencing .....	10
3.2.2.2 The Normalization Vegetation Index .....	12
3.2.2.3 Principal component Analysis .....	14
3.2.2.4 Change Vector Analysis .....	16
3.2.3 Change Detection With Classification .....	18

3.2.3.1	Multi-date Data Classification .....	18
3.2.3.2	Post Classification Comparison .....	19
3.2.4	Choosing the Best Technique .....	21
3.3	Land-Cover Changes as an Important Measure of Biodiversity .....	24
3.4	Land-use (economy) and Land Cover (ecology) in the Area of Study .....	25
3.4.1	The Economy .....	25
3.4.2	The Ecology .....	32
3.5	Classification Scheme and Classes for the Area of Study .....	33
IV.	MATERIALS AND METHODS .....	35
4.1	Study Area .....	35
4.2	Data Acquisition .....	35
4.3	Image Rectification and Relative Radiometric Normalization .....	38
4.3.1	Image Statistics and Scattergrams .....	42
4.3.2	Identifying Water and Surface Cluster .....	43
4.3.3	Half Vertical Width and Half Perpendicular Width .....	43
4.3.4	NC Pixels Using AOI .....	44
4.3.5	Normalization .....	45
4.4	Change Vector Analysis and Change Detection .....	45
4.4.1	Model Maker and Change in Magnitude .....	49
4.4.2	Determining the Threshold From CM .....	49
4.4.3	Change in Direction .....	50
4.4.4	Understanding the Changes .....	51
V.	RESULTS AND DISSCUSSION .....	53
5.1	Relative Radiometric Normalization .....	53
5.1.1	Composite image and statistics .....	53
5.1.2	Scattergrams to extract NC data .....	54
5.1.3	HVW and HVP Calculations .....	56
5.1.4	Extracting Areas of No-Change .....	56
5.1.5	Regression Model .....	59
5.2	Change Vector Analysis .....	61
5.2.1	Change in Magnitude .....	62
5.2.2	Direction Change .....	65
5.3	Changes in Eco-Regions .....	73
5.3.1	Andes Mountains .....	73
5.3.2	Central Valley .....	76
5.3.3	Coastal Belt .....	79
5.4	Accuracy Assessment .....	82
5.5	Discussion .....	84
5.5.1	CVA and Change Detection .....	84
5.5.2	Landsat and Land Cover/Land Use Changes .....	85



5.5.3 Change Producers .....	84
5.5.4 Technique for Multispectral Study in Developing Countries .....	87
VI. CONCLUSION .....	89
LITERATURE CITED .....	93

## LIST OF TABLES

### TABLES

1-1 Total of forest products exports in Chile from 1997 to 2005 in US \$ .....	2
3-1 Main destinations for wood products exports .....	28
3-2 Forest products and sub-products produced in Chile .....	29
3-3 Main companies with native forest holdings .....	30
3-4 Forestry plantations in Chile by region and by size of individual landowners .....	31
3-5 Forest cover in the South of Chile .....	34
4-1 Landsat Bands Applications .....	37
4-2 Composite Image for CVA .....	46
5-1 Chile.img Image info statistics in ERDAS IMAGINE .....	54
5-2 Coordinates statistics from scattergrams for identifying water and surface cluster .....	54
5-3 Half vertical width for bands 3 and 4 .....	56
5-4 Final statistics of the normalized CVA image .....	60
5-5 Percentage of change in the area of study .....	66
5-6 Categories of changes in biomass .....	67
5-7 Accuracy assessment results for the area of study .....	83
5-8 Population migration in the area of study .....	86

## LIST OF FIGURES

### FIGURES

1. Map of the country of Chile and the area of study .....	40
2. Images from the study area in the South of Chile .....	41
3. Flow chart for biomass calculation using change vector analysis .....	48
4. Change in direction using Change Vector Analysis .....	52
5. Scattergrams from bands 3_7 and 4_8 corresponding to bands 3 and 4 from image 1986 and 2003 .....	55
6. Model for extracting areas no change for radiometric normalization .....	57
7. No change pixels represented in an image .....	58
8. Regression model for Radiometric Normalization .....	59
9. Regression of pixels from date 1 and 2 after the normalization process .....	61
10. Model for calculating the Euclidean distance between bands green, red, NIR infrared and Mid infrared from image from date 1 and 2 .....	63
11. Total biomass change in the area of study .....	64
12. Pixel spectral response and threshold selection .....	65
13. Total changes in square miles in the area of study .....	69
14. Biomass loss in the area of study .....	70
15. Specific land cover/land use changes detected with CVA .....	71
16. Biomass growth in the area of study .....	72

17. The Andes Mountains covered by native species known as frontier forest .....	74
18. Direction of the changes in The Andes Mountains .....	75
19. Central valley in the VIII region Chile .....	77
20. Changes in biomass in the central valley .....	78
21. Image of the Coastal Mountain Belt in Chile .....	80
22. Direction of the changes in the Coastal Belt in the VIII region Chile .....	81
23. Percentage of changes in biomass .....	88
24. Area of study in the country of Chile .....	92

## CHAPTER I

### INTRODUCTION

Human societies have struggled in history to develop a lifestyle that goes along with the environment. In modern times rapid population growth accelerates the use of natural resources. The intensity and extent of the use of bio-resources on the earth have increased rapidly to satisfy needs such as fuel, food, fodder and timber. As a consequence, there is great interest in quantifying the amount of biomass which corresponds to the quantity or weight of all living matter in a given area or biological community (Markham and baker, 1987). The trends that modern societies have followed to continue functioning affect the landscape, and as a consequence there are species loss and an overall effect in the ecological functions; therefore, changes in land cover and land use can also directly affect the sustainability of a region (Mittermeier and Myers, 2000).

Appropriate planning is necessary to maintain biodiversity and when this is disrupted there are direct and indirect mechanisms associated with it that reflect the consequences. Direct mechanisms include food, fuel, timber and indirect mechanisms which include water quality, soil fertility and erosion among others, in addition to cultural values that surround certain landscapes. Assessing changes in the landscape helps to minimize the consequences of industrial activities and to develop appropriate planning

(Myers et al, 2000). The area of study in the South of Chile is characterized by activities such as timber production and agriculture. Assessing the changes in biomass can help to improve planning and management of these bioresources.

Chile is located in southwestern coast of South America and it has an approximate area of 292,260 sq. mi., Chile is 2,653 miles long and 221 miles at its widest point with an average width of 109 miles wide. From North to South Chile changes its landscape going from a dry climate to a dense temperate forest present along some areas of the Andes Mountains belt. Many of the ecological components of the study area are unique to the region, therefore protecting these areas is fundamental for preserving this rich habitat.

Exports in this country have grown steadily since the mid 80's (table 1-1) and many of these products are coming from bio-resources such as timber and its sub-products. In Chile biomass continues to be a major source of energy and fuel, just like in most developing countries.

Table 1-1 Total of forest products exports in Chile from 1997 to 2005 in US \$.

YEAR	1997	1998	1999	2000	2001	2002	2003	2004	2005
Total forest Products	1,829	1,660	1,970	2,365	2,205	2,301	2,254	3,396	3,495

Since traditional methods for researching the conditions of the landscape in large areas are time consuming and expensive, remote sensing can be used to obtain

information regarding past and current conditions of certain locations by carrying out inventorying of resources over spatial and temporal scales (Singh, 1989).

The global changes can be divided into two types: systematic and cumulative (Elredge, 1998). Systemic corresponds to changes that affect the bio-chemical flows that sustain the biosphere. For example, fossil fuel consumption increases the concentration of carbon dioxide in the atmosphere. This type of change is mostly connected to industrialization and the use of inappropriate technology. Cumulative change is connected to those activities that human societies have used since antiquity such as those produced in settlements areas such as agriculture and overall changes in land cover. These changes in small scale do not produce global consequences unless these are repeated over and over. Systematic and cumulative changes can be uncovered by the use of satellite images and remote sensing techniques.

The basic components of satellite images are multi-spectral scanners which record the surface reflectance of electromagnetic (EM) radiation from the sun in seven discrete bands. The images are divided into pixels arranged in columns and rows. Bands are associated to layers, and an image is composed by a set of layers. Using remote sensing is possible to analyze satellite images that carry specific and important characteristics of the landscape (Singh, 1989).

This study utilizes a change detection technique known as change vector analysis, which uses spectral reflectance and a pixel by pixel analysis to extract changes in the landscape. A field trip and the use of aerial photography helped to identify the land cover/land use classes present in the area of study.

## CHAPTER II

### RESEARCH OBJECTIVES

The objective of this research is to determine cumulative changes in biomass. Specifically, in an area of intensive economical activities in the South of Chile using images from the years 1986 and 2003. Due to the lack of multi-temporal studies not only in the country of Chile, but in the South American region, it is fundamental to establish which methodologies represent a good choice for measuring changes in large areas. Even though the use of remote sensing is becoming more common in developing countries, there are still a limited number of studies to understand the evolution of the landscape. In this context the use of change vector analysis with the support of aerial photography and limited field survey is a valuable technique for this type of studies.

The objectives of this research are:

1. Quantify the total change in biomass that occurred between the years 1986 and 2003 in part of the region VIII and IX in the South of Chile. This is going to provide important variables to use in ecological and environmental application, for example; regional ecosystem models.



2. Compare the amount of biomass growth and loss in the area of study. By determining the difference between loss of biomass and re-growth it is possible to establish the current conditions compared to those 17 years ago. This is key to understanding the consequences of the activities that lead to cumulative changes in the near future in this area.
3. Evaluate the changes in biomass between 1986 and 2003 in three main eco-regions in the area of study. These eco-regions correspond to the Andes Mountains, Central Valley and Coastal Belt. Each eco-region is characterized by specific land cover types that dominate each area. As a consequence, the results can be used separately to further analyze changes related to the different components of each eco-region.

## CHAPTER III

### BACKGROUND INFORMATION AND LITERAURE REVIEW

Often human societies fail to look at what's occurring around them. We get caught with the rhythm of our lifestyle undermining all consequences of our actions. Understanding how different parts of the earth are interconnected is fundamental to create consciousness about the importance of individual and social responsibility.

“Today there are more than five billion of us. We consume directly (By eating, feeding, livestock, clearing, forest for lumber and fuel wood) and indirectly (through biomass burning to prepare agricultural fields, crop wastage, landscape conversion) as much as 40% of global terrestrial net primary production.” (Vitousek, et al. 1986).

#### 3.1 Land Use and Land Cover

Land use and land cover are terms that are often misused when describing products that are derived from remotely sensed data. While these two concepts in remote sensing are distinct, they are at the same time linked to each other. Land use corresponds to the manner in which humans employ the land and its resources, such as: agriculture, urban development, grazing, logging, and mining. Land cover describes the physical state

of the land surface and it includes categories such as: cropland, forest, pasture, urban areas, roads and wetlands (Meyer, 1994)

The study of the consequences of land use on the land cover is an important subject for developing appropriate management for natural resources (Lubchenco and Hobson, 1997). Activities driven by humans are usually the reason for changes in the landscape (Wilkie and Finn, 1996), such as shifting land-use patterns, which can be a consequence of a variety of social and economical causes. These processes can result in land cover or land use changes that affect water and radiation budgets, biodiversity and other processes that, consequently, can affect climate and the biosphere (Showalter et. al 1993.). Monitoring changes in land cover and land use over large geographic areas is key to understanding changes in the landscape in many environmentally sensitive locations and this can be accomplish with the use of remote sensing methods.

### 3.2 Change Detection Methodology in Remote Sensing

In order to successfully interpret remote sensing imagery it is common to use visual characterization of features within the landscape. Therefore, a fundamental step of digital image processing is to understand the visual cues that facilitate feature identification for its interpretation (Wilkie and Finn, 1996). This is possible by using remote sensing images containing one or more wavelengths of reflected light. An important part of this process corresponds to the radiometric normalization that is necessary to reduce radiometric noise, which is a consequence of changes in solar illumination, sensor calibration or atmospheric conditions (Yuan and Elvidge, 1995). Common change

detection techniques can be divided into three broad types: image enhancing, multi-date classification and post classification comparison. For image enhancement techniques, radiometric normalization is critical. (Tso and Mather, 2001).

### 3.2.1 Radiometric Normalization Techniques

Radiometric normalization techniques have two main steps in common: choosing the normalization target and establishing the normalization coefficients (Elvidge, 1995). When choosing the normalization target there are some basic guidelines used by all the methods and these are (Eckhardt, 1990):

1. The target should be located at a constant elevation
2. A minimal amount of vegetation must cover those targets
3. The ideal area should be flat
4. The target should not change over time

The most widely know methodologies for determining the coefficients of no change areas are: Simple Regression (SR), Histogram Matching method (HM), Pseudo Invariant Feature Set method (PIF), Dark Bright method (DB) and No Change set method.

#### 3.2.1.1 *Simple Regression*

Simple regression consists of using the least-square equation for deriving normalization coefficient from y-intercept and slope parameters (Jensen, 1983). This method uses all pixels from the reference and subject image for the normalization process. The regression equation is the following:

$$U_k = A * X_k + B_k \quad (3-1)$$

X represents represent the k band of the subject image; U is the k band of the reference image, A and B are the gain offset of the normalization (Elvidge, 1997).

### 3.2.1.2 *Histogram matching*

Histogram matching corresponds to a processing method for image normalization in which the image histogram is used to modify the subject image histogram distribution (Yang and Lo, 2000). The basic technique attempts to resemble the histogram of an image from one date to that of another.

### 3.2.1.3 *Pseudo Invariant-Features*

Pseudo invariant features methodology uses the reflection distribution of elements which have a statistical invariance, such as roads, or any surface that remains without significant changes along time. The gray level distribution is considered fundamental to perform normalization (Schott, 1988).

### 3.2.1.4 *Dark Bright Method*

The dark bright method consists of using the average of a set of dark and bright pixels. These are extracted from the subject and reference image using Kauth-Thomas greenness brightness transformation to derive the normalization coefficient. In this method it is assumed that images from two different dates always have pixels with the same average surface reflectance (Hall, 1991).

#### 3.2.1.5 *No Change Set Method*

This radiometric normalization process consists of determining a set of pixels that represent no change areas by the use of scattergrams. The Near Infrared bands from the subject and reference image are used to create a spectral feature space image that is a two axes frequency image showing the occurrence frequencies by the intensity (ERDAS, 1999). The near infrared bands are the best option because the water and surface clusters are easily distinguished. Those pixels falling into the no change areas are used to normalize the coefficient of all bands, instead of using all the image pixels as in other methods (Yuan and Elvidge, 1996).

### 3.2.2 Change Detection Using Image Enhancement Techniques

Image enhancement corresponds to the use of mathematical combinations using images from different dates, such as image differencing, the normalized vegetation difference index (NDVI), principal component analysis or change vector analysis. In some cases, thresholds are applied to characterize the image features and to isolate the pixels of “change” from those of “no change” (Singh, 1989).

#### 3.2.2.1 *Image Differencing*

Image differencing consists in subtracting images previously geographically co-registered to each other, to produce an image with an output that represents changes between the two dates. Basically, those pixels that exhibit no change in radiance are located around the mean, while pixels of radiance change are distributed in the tails of the

distribution (Singh, 1986). This technique was used to determine and to produce change maps in the area of Rayong and Chantaburi (Trisirisatayawong and Samchimchom 2003). The objective was to identify those areas of change for environmental, coastal resources, and urban expansion monitoring. A band by band linear regression was used to radiometrically normalize the images in order to correct differences in brightness values produced by external factors. The LANDSAT images corresponded to the years 1988 and 2000 respectively, both acquired around the same season. The main issues surrounding the area of study were a consequence of economical factors such as industrial activities and tourism. These activities drove changes in land use and consequently in land cover. The research was divided into four main stages: (1) image rectification, which corrects and improves image co-registration, (2) radiometric normalization which improves the characteristics in brightness from both images to increase the accuracy of the results, (3) the image differencing process yielded a histogram where the means and tails were analyzed to differentiate areas of change from those of no change, (4) accuracy assessment, which was done by surveying the area, comparing the results, and by the use of aerial photography. The experiment showed that most accurate results can be obtained using band 2 and band 3 with 70 percent accuracy. Band 4 presented less accurate results, decreasing the accuracy to less than 50 percent. More research on determining appropriate spectral bands for different type of changes was recommended.

Other authors suggest that this methodology is useful for coastal zone change detection (Weismiller et al., 1977), monitoring forest change (Vogelmann, 1988), and detecting urban expansion (Jensen and Toll, 1982). While often producing excellent

results, it has been suggested that image differencing alone may be too simple to adequately describe many surface changes (Weismiller et al., 1977; Jensen and Toll, 1982; Sohl, 1999). This type of approach is very useful to discriminating vegetation, soil and water, but results are considered poor when examining how vegetation density changes over time. Comparison of simple ratio images may be made difficult by changes in weather conditions and solar irradiance (Wilkie and Finn 1996).

#### 3.2.2.2 *The Normalized Vegetation Index*

The normalized vegetation index helps normalize radiometric differences in vegetation and is often a better choice for image subtraction particularly if atmospheric conditions (haze) are not similar for the two dates of imagery (Yuan & Elvidge, 1996; Markham and Barker, 1986). Also, NDVI is used to identify the difference existent between two images related to green biomass (Tucker, 1979). The normalized vegetation index is calculated with the following formula:

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})} \quad (3-2)$$

NIR is the near-infrared band response for a given pixel, (MSS band 4) and RED is the red response, (MSS band 3). The vegetation index is calculated for date 1 and date 2 and then subtracted (Nelson 1983, Singh 1986). In a study of land cover change in rural areas of the forest-steppe ecotone of Andean Patagonia, NDVI methodology was used to identify land cover changes (Farias, 2003). Images from 1987 and 2003 were used to identify directional vegetation change drivers in the region, to detect possible vegetation



changes that occurred in the area and to assess the extent and nature of these changes. NDVI was used based on the assumption that there is a relationship between the amount of vegetation cover and the vegetation indices. The following steps were taken to develop a vegetation index differencing study: first, image registration, second atmospheric normalization, third vegetation index differencing (for images from date 1 and 2) and fourth analysis of the changes. After considering different possibilities and reviewing the performance of difference vegetation indices, a slight variation of the classic NDVI was used. This consisted in eliminating the subtraction of the red band radiance, considered irrelevant; therefore, the infrared percentage vegetation index (IPVI) was used. This is considered computationally faster and never negative (Crippen, 1990).

$$IPVI = \frac{NIR}{(NIR + RED)} \quad (3-3)$$

Determining the degree of change throughout a threshold is fundamental to represent the areas of change coming from the vegetation index differencing methodology. Since there are no general criteria to establish a threshold (Singh, 1989; Chuvieco and Salas, 1998) the histogram was used to determine this fundamental part of the land cover change study. The threshold was given by a number of standard deviation from the mean pixel value. Therefore, pixel values located within the standard deviation limits were considered as “no change” pixels, and values outside the standard deviation region were labeled as “change” areas. The quantification of change and no change areas as well as the calculation of proportions were done using GIS. Although, it is suggested that the use of other methodologies should be considered, the image

differencing is considered satisfactory for the scope of this study. The NDVI methodology is widely used because it generally performs better than other methods for measuring positive and negative changes in vegetation (Coppin and Bauer, 1996). However, selecting the appropriate threshold is somewhat subjective and critical for the results and its interpretations (Bateson and Curtis, 1996; Tompkins et al., 1997).

### 3.2.2.3 *Principal Component Analysis*

Principal component analysis is the most commonly used method that creates orthogonal axes from often highly inter-correlated bands within multi-spectral imagery (Nomikos and Macgragor, 1994). The main difference of this approach with similar techniques is that it not only removes the correlation (redundancy) between bands, but it effectively reduces the number of bands within an image without losing or changing overall information content (Wilkie and Finn, 1996). This method uses a variance-covariance matrix. The standardization of the covariance matrix into a correlation matrix by dividing by the appropriate standard deviation reduces all the variables to equal importance as measured by scale (Singh and Harrison, 1985). Substantial improvements have been reported for signal to noise ratios and image enhancement.

Principal component analysis has been effectively used in terrestrial change detection studies (Lodwick, 1979). In Multi-temporal studies, this technique has been used to analyze the relationships between multi-temporal remote sensing datasets (Cooley, 1971). For example, when images corresponding to different dates are compared, there will be a high correlation between them; therefore, areas that show the

absence of correlation are of interest for the research as they would represent areas of change. Images from the southern coast of Hainan, Russia, were analyzed using principal component analysis by The Department of Geography in the University of Waterloo in Ontario, Canada (Piwowar and Milward, 2002). The objective was to discriminate those areas of change from those of no change. Basic standardization of the image was performed to increase the accuracy of the results; this consisted of geometric correction and resampling of the images. Then PCA was used to reduce spectral redundancy. Finally, the factor loadings for each image were analyzed which they showed a tendency for separation of near infrared (NIR) variance, which loaded highly in all PC2 axes. All PC1 axes were coded with their associated image year and saved in a single file. In order to uncover changes across images, visual detection by band overlay was used. Since the image containing PC1 had high variance values originating from the NIR portion of the spectrum, the assumption was made that changes reflected between the components from change analysis would be a consequence to variation in vegetation presence and vigor. In the image containing PC2 that was characterized by variance that originated in the visible portion of the electromagnetic spectrum, it was assumed that changes came from coastal development including roads and buildings. In this study PCA is considered a powerful technique for monitoring changes by transforming spectrally and spatially dissimilar imagery into data that can be compared in a meaningful and efficient fashion. Nevertheless, it is suggested that this technique could be more powerful if used in combination with other methods such as the normalized vegetation index (NDVI).

As in every method there are advantages and disadvantages. In the case of PCA, as in other automatic processes that are not guided, there is a lack of information when wanting to emphasize specific features on the landscape. Although high order PCA will contain less variance than will low order components, the information that low order components contain can nevertheless be useful (Jolliffe, 2002). Before low order components are discarded, they should be examined individually to determine if one or another has relevant information. Also, the brightness values of each component do not reveal information from very specific changes on the earth surface. As a consequence, other types of information such as aerial photography, land use maps or field work are necessary to guide the interpretation (Wilkie and Finn, 1996).

#### 3.2.2.4 *Change Vector Analysis*

When using change vector analysis, change is described by a spectral change vector, which represents the direction and magnitude of change from the first date to the second date or two points in spectral space (Michalek and Wagner, 1993). An empirically derived or modeled threshold is used to determine the minimum magnitude that represents a change occurrence. A study developed by the Department of Geology and Geography at the University of West Virginia had as an objective to understand major changes in connection to land cover and land use in Las Vegas, Nevada (Warner, 2005). These changes specifically included: desert and shrubland to residential and commercial. This reduced the number of classes to identify. Radiometric normalization is necessary as in most techniques that use spectral reflectance to measure changes on the landscape. The

changes were uncovered by using a composite image made by combining green bands from time 1 and time 2 into a single image. Any pixels that were not shaded gray in this case represented changed pixels, and these were manually recoded to 0 to isolate no change pixels. Since areas of change are spatially clumped the process was rapidly completed. Then, a simple linear regression was calculated on a band by band basis to estimate the equation that normalizes the 1972 DN (Digital Number) values to those of the 1992 image, using only pixel locations that are inferred to have unchanged land cover types. A total of 24 separate areas of change and no change were trained and digitized. Also, a probability density function for each training class was exported to a spreadsheet program. The probability density function of a training class corresponded to the observed frequency of each DN value for that class. Then in the spreadsheet program, the change and no change probability density values were summed and transformed to the percentages of the total number of samples per class. Aerial photography was used for the accuracy assessment in combination with a small amount of field samples.

Change vector analysis is particularly beneficial for detecting changes that can be discriminated and it eliminates errors such as those coming from post classification comparison, when two separate classifications are overlaid. These errors are produced by assuming that land cover/land use in a specific area in two different dates correspond to the same classes. (Chen, 2003). This method provides detailed direction and magnitude change information. Also, by the use of CVA it is possible to obtain relevant results when measuring continuous variables such as vegetation patterns along ecological transitions and gradients (Loveland, 1999). However, determining areas of change with change

vector analysis becomes much more complex as the number of bands increases (Wilkie and Finn, 1996).

### 3.2.3 Change Detection with Classification

#### 3.2.3.1 *Multi-date Data Classification*

Multi-date data classification corresponds to a single analysis of a combined dataset of two dates, in order to identify areas of change (Singh, 1986). Target features are extracted and the image is recoded as a binary file representing those features of interest. This method was used to detect changes in land cover in Central Africa by The Center of Tropical Research, and The Department of Biology from The University of San Francisco (Yafit and Shoshani, 2001). The basic objectives were to understand anthropogenic influences in the forest and Savanna due to forest conversion to agriculture, the introduction of exotic species, logging and wildfires. The use of vegetation maps and ground data aided the classification of the images. Previously, the images were radiometrically corrected and haze removal helped to improve the visual cue. A single analysis of a combined dataset of the two dates was developed to identify the areas of change (Singh, 1986). Classes where changes took place are expected to be significantly different to those where change did not occur. The result showed high correlation between ground truth and multi-date data classification. However, they recommended that by using a fusion approach, multi-date data classification can produce

better results. A fusion approach refers to combining the use of methodologies such as the normalized vegetation index or the use of other image enhancement techniques.

### *3.2.3.2 Post Classification Comparison*

Post classification comparison corresponds to a comparative analysis of spectral classification for times t1 and t2 produced independently (Singh, 1989). This is one of the most commonly used techniques for land cover classification studies. In this context it should be noticed that the change map of two images will only be generally as accurate as the product of the accuracies from each individual classification (Stow, 1993). The most commonly used techniques are unsupervised and supervised classification.

Unsupervised Classification consists of the use of statistical clustering techniques to combine pixels into classes due to the degree of similarity of brightness values in each spectral band (Wilkie and Finn, 1996). This technique was used in the study, “An Assessment of Rainforest Change Using Satellite Images for the Bragatina Region of the Amazon River Basin”, by the Department of Geography and Earth Science from Brazil. This research focused on the Amazon basin which covers approximately 3.9 millions Km<sup>2</sup> of the South American region, and it represents one of the most ecologically diverse ecosystems on Earth (Moran, 1993, Tucker et al., 1998). The main issues present in the study area are linked to logging, clearing due to agriculture and urbanization. Throughout satellite images and unsupervised classification, land cover and land use maps were produced.

This process involved automatic grouping of pixels into spectrally defined classes or clusters (ERDAS, 1999). Different cluster tolerances were attempted along the investigation, from which 30 and 40 produced more information than necessary, and it increased the difficulty in distinguishing spectrally similar clusters. A matrix function was used to determine the areas of coincidence for each LCU class (land cover unsupervised), between the two maps (ERDAS, 1999). This method was found to be very useful for developing signature classes in the area of study. However, it is necessary to obtain ground truth to verify the accuracy of the signature classes created by the software. Some of the difficulties of this method have to do with the lack of one to one relationships between land cover and spectral classes, which may encourage the researcher to modify the number of characteristics of land cover classes, or to re-evaluate the type of remote sensing imagery to be used in the study. This method is also useful as a last resort, if supplementary data are insufficient for undertaking supervised classification (Wilkie and Finn, 1996).

Supervised Classification is a type of classification that converts the spectral data contained within remote sensing images directly into thematic land cover information (Jensen, 1996). In the area of Valdivia in the country of Chile, a study was developed to evaluate the distribution and extension of land cover and land use in the year 2003 (Segura, Reinaldo and Trincado 2003). Supervised classification helped to classify the area of study into the following land cover and land use types: mature native forest, new native forest, forest plantations (pine and eucalyptus), shrubland and prairie. Radiometric correction and geo-rectification helped to improve the conditions



of the image in order to produce the best classification possible. The Kappa coefficient derived a percentage which represented the accuracy of the study. In addition, aerial photography from the area of study was used to identify the land cover and land use distinct classes. With an accuracy of 64% the results were satisfactory. Nevertheless, the shrubland and grassland classes generated the greatest error values due to its geographical distribution. Also, more research is needed to be able to distinguish mature and young native forest with a higher degree of accuracy. Some of the disadvantages that exist with the supervised classification methodology have to do with the need to select thematic land cover classifications that are mutually exclusive to each image, because most likely each image will carry its own land cover/use types. Also, other type of ground truth is needed to train the image, for example: aerial photography, field work, photo interpretation or videography. Also, outliers or unrepresentative data must be deleted (Wilkie and Finn, 1996).

#### 3.2.4 Choosing the Best Technique

Selecting an appropriate methodology for measuring changes in the landscape is fundamental for the results of the research. This decision making process must consider all the advantages and disadvantages of each technique. All those factors inherent to each method such as the characteristic of the area of study, the accessibility to the location, the knowledge of the area of study and the quality of the images are important to consider and evaluate (Jensen, 1998).

When enough field data is available, supervised classification is the most appropriate approach since the accuracy can be higher than other techniques as showed in

the case studies in the South of Chile and the Amazon, Brazil (Segura, Reinaldo and Trincado 2003). In both cases, there was enough field data to evaluate the changes on the landscape and to verify those by accessing the area. In addition, the dates chosen for the multi-temporal studies do not go far back in time increasing the confidence on the classifications. Also, this technique works fine when there are plenty of similar studies that can be used as a base for the classification, such as the study in the Amazon, an area that has been the target of many studies. However, when ground truth is limited, other approaches such as image enhancing techniques are a better choice (Singh 1989). In the case of multi-date data classification, the use of a fusion approach is recommended which means that the results do not carry the confidence necessary to support the changes. Therefore, using Multi-date data classification is an option to consider when it is combined with other techniques such as the normalized vegetation index. Disadvantages linked to those techniques such as image differencing, NDVI, PCA, and CVA, are related to choosing a threshold representing change that can be hard to define as experienced in investigations such as those in Patagonia and Malaysia. Nevertheless, both of these projects used either aerial photography and/or field surveys to obtain satisfactory outcomes during the process.

Since there is no perfect approach for classification or detecting changes in a multi-temporal study, the use of change vector analysis with the support of ground truth, such as field work, aerial photography or previous classifications, represents a strong approach for measuring changes in the landscape. This is mainly because the accuracy results will come not only from one source such as ground truth, but spectral reflectance

will play an important role in detecting those changes in land cover and land use. Also, defining the type of changes that are the focus of the research like Warner did in his research in Dallas, Texas (Warner, 2005), can help to narrow the margin of error inherent to this technique. In order to identify changes in land cover or land use different bands combinations can be utilized. Change vector analysis is a relatively new technique that has great potential for detecting those changes in the landscape, specially those that belong to continuous variables; therefore when measuring changes in the landscape with limited access to the area of study, change vector analysis represents the best option. Changes such as reforestation, deforestation, regrowth, biomass loss, increment in water coverage area and burning can be detected by spectral response, and then these changes can be supported with ground truth and other studies that reflect the landscape condition. With change vector analysis, the decision making process for classifying an image is not only a consequence of the researcher capacity to distinguish the land cover/land use classes, but a condition of the spectral response, which is most likely to change at several different wavelengths. This technique can be applied to any number of bands. As a consequence, different parts of the landscape can be studied by choosing those bands that will best reflect the changes that are the focus of an investigation. A technique is better than others only based on the goal and constrains of that research. In this research the goal can be best accomplished by choosing a technique that is not purely based on the researchers' knowledge, especially when field trips cannot be used as part of the classification process.

### 3.3 Land-Cover Changes as an Important Measure of Biodiversity

Edward O. Wilson divided in 1992 the threats to biodiversity into five major categories:

- habitat loss and fragmentation,
- habitat damage (pollution, catastrophic disturbance),
- invasion by non-native species,
- overexploitation, and
- secondary extinctions resulting from the loss of critical (keystone) species.

In general, these are triggered by the pattern and intensity of land use by societies. (Wilkie and Finn, 1996). Remote sensing represents a strong approach in science to measure changes in the landscape that affect biodiversity directly or indirectly. Timber production can have a number of effects including deforestation, which can lead to soil erosion impoverishment, or shifting land use patterns linked to habitat loss, especially in those areas where there are endemic species. Moreover, deforestation can also affect the hydrological cycle through changes in evapo-transpiration and run-off (Mather, 2001).

By understanding changes in biomass it is possible to uncover the consequences or possible trends linked to those major threats of biodiversity defined by Wilson in 1992. In a study carried out by the organization "Global Monitoring for Environmental Security," a basic work line is developed to link measures of historical land cover changes to pressures on biodiversity. This process is divided in two phases: the characterization of land cover change and the analysis of the results to define the type of pressure present such as: intensification, abandonment, afforestation, urbanization or

other biological, environmental and socio-economical factors. By understanding the extent and distribution of changes in an area it is possible to establish trends and pressures over the natural resources and biodiversity.

There are organizations attempting to measure the extent of change at a global level, like the Global Forest Resources Assessment of the U.N Food and Agriculture Organization (FAO). However, there are great limitations to these global approaches linked to specific ecological conditions that exist at different geographical locations; therefore, there is a fundamental need to look deeper into areas that are considered biodiversity hot spots such as the area of study in Chile (Conservation International 2007).

In order to uncover possible changes in biodiversity in the area of study in Chile, modifications produced by land use like the production of timber in the area (non-native species) can be contrasted with the evolution of biomass in different aspects by extracting information such as: biomass past and current condition, difference of biomass re-growth and loss. Also, understanding the direction of the changes can be crucial in finding the main producers behind these changes.

### 3.4 Land-use (economy) and Land Cover (ecology) in the Area of Study

#### 3.4.1 *The Economy*

The timber production represents - for the area of study and the country of Chile - an important sector in terms of exports (Table 3-4). In 1974, this country elaborated a

national management strategy that increased the development of timber production (Chile's Frontier Forest: Conserving a Global Treasure, 2002). Among the measures taken that year was the "Forestry Development Law" (701), which subsidized forestation, administration and management activities, creating the conditions for the growth of this industry (Valenzuela 1984, INFOR 2005). At the same time, the government decreased its involvement in this economic sector by limiting to only controlling legislations affecting this sector, promoting forest related activities and the management of protected areas and other land under the National System of Protected Areas law (Chile's Frontier Forest: Conserving a Global Treasure, 2002). In addition to the subsidies, the government decided to privatize all timber production territories with the country.

There are two main timber companies in the region (Table 3-3) : Forrestal Mininco and Milalemu both owning around 70,000 and 40,000 hectares of native forest, respectively (INFOR, 2005). The wood product industry pursues a plan to double plantation acreage from more than 5 million acres today to more than 10 million acres by the year 2020 (Conservation International, 2007). Also, there are additional subsidies that will push the expansion of these plantations coming from the recently expanded version of public law 701. The destinations of the exports are countries such as: USA, Japan, China, Belgium, Argentina, Republic of Korea, and Italy (Table 3-1). Some of the sub products coming from this industry include (Table 3-2) : chemical pulp, mechanical pulp, newsprint, paper and paper board, chips and particles, sawnwood, particle board, hardboard, medium density fiber board, plywood and veneer sheets (Chile's Frontier Forest: Conserving a Global Treasure, 2002). All these exports account for about 10% of

the national economy. What the numbers reflect is a very active sector of the economy that advance much faster than any regulation attempt to protect the rich ecological habitat of this region. In addition, it is important to mention that the use of GIS in the timber industry as a tool for monitoring is limited to the following area: harvest pacification, road building, and assessing risk of fire occurrence (Remote Sensing and GIS Forestry: Experiences in Chile, 2002). Land cover and land use are connected to each other as consequence of social and cultural activities. In modern times more than ever we depend directly on the natural resources. Specifically, in the area of study there are economical activities such as agriculture and forestry that are changing the landscape continuously. These changes are reflected on the land cover of the area. Even though this is one of the more productive areas on the continent there are no previous studies to measure multi-temporal changes. This research study focuses on the changes produced on the land cover over the period of seventeen years.

Table 3-1. Main destinations for wood products exports

COUNTRY OF (%) DESTINATION	JANUARY-JULY 1999	(%)	COUNTRY OF DESTINATION	JANUARY-JULY 2000
U.S.A 20.6	267	24.0	U.S.A	293
Japan 13.1	150	13.6	Japan	186
China 7.3	78	7.0	Belgium	103
Belgium 7.2	62	5.7	China	102
Argentina 6.1	59	5.4	Italy	86
Republic of Korea 5.5	58	5.2	Taiwan	77
Italy 4.1	56	5.1	Republic of Korea	57
Sub-Total 63.9	730	-	Sub-Total	904
Other Countries 36.1	378	-	Other Countries	514
Total	1,108	100.0		1,418

INFOR



Table 3-2 Forest products and sub-products produced in Chile

PRODUCT	UNITS VOLUME	1997	1998	1999
Chemical Pulp	Metric Tons	1,868	1,980	2,064
Mechanical Pulp	Metric Tons	209	185	135
Newsprint	Metric Tons	184	163	225
Other Paper and Paper				
Board	Metric Tons	430	479	571
Chips and Particles	Cubic Meters	6,032	5,458	5,840
Sawnwood	Cubic Meters	4,661	4,551	5,254
Particle Board	Cubic Meters	424	321	301
Hardboard	Cubic Meters	56	55	75
Medium Density Fiberboard	Cubic Meters	408	362	409
Plywood	Cubic Meters	65	129	166
Veneer Sheets	Cubic Meters	97	104	112

INFOR

Table 3-3 Main companies with native forest holdings

COMPANY REGION	SURFACE AREA (Ha)	ADMINISRTATIVE
Forestal Savia	103,000	XII
Forestal Mininco	70,000	VIII and IX
Forestal Millalemu	40,000	VIII and IX
Soc. Agrícola Alicahue	20,000	-
Forestal Anchile	20,000	X
Forestal Los Lagos	20,000	X
Soc. Agrícola y	-	-
Gananadera San Lucas Ltda.	15,728	XII
Inversiones Emasil	10,000	X
Forestal Taquihue	6,700	X
TOTAL 305,428		INFOR

Table 3-4 Forestry plantations in Chile by region and by size of individual landowners

ADMINISTRATIVE ON REGION TENURE	LARGE AND MEDIUM SIZE LANDOWNERS	SMALL LANDOWNERS	NO INFORMATION ON LAND
IV	1,610	-	58,075
V	34,363	11,518	2,900
VI	59,249	14,403	1,986
VII	178,296	44,462	14,053
VIII	198,150	45,038	29,235
IX	76,622	23,180	3,812
X	46,910	10,029	2,322
XI	5,306	-	-
XII	13	-	-
TOTAL	600,519	148,630	112,383 INFOR

### 3.4.2 *The Ecology*

Chile has a great ecological patrimony, both at a local and global scale (Table 3-5). This is reflected by the organization Conservation International which has designated the temperate native forest present in the area of study as one of the world's top 25 biodiversity hot spots.

The UNESCO (United Nations Educational, Scientific and Cultural Organization), during its last Bureau which took place from 18 to 20 of September of 2007, added the temperate forest in Chile – present in the area of study – as a new biosphere reserve. This creates opportunities for scientific research in the area and governmental involvement to reduce biodiversity loss. All these measures help to develop the overall conditions needed to preserve this rich habitat. Biosphere reserves are also used as experimental sites (UNESCO, 2007).

The great ecological value associated to this area has to do especially with the type of forest present, which has endemic species only found in the country of Chile. There are species that are up to 3,000 years old (Donoso, 1981) and one third of the temperate forest left in the world is located in Chile along the area of study and farther south (Chile's Frontier Forest: Conserving a Global Treasure, 2002). The lack of laws that can protect this world patrimony makes studies such as this of a great scientific value. In relation to this forest there are many other species that belong to this habitat, which are very much in danger when timber companies put an economical value to these lands.

### 3.5 Classification Scheme and Classes for the Area of Study

There exists a limited amount of multi temporal studies in South America. Specifically, there are two previous land cover/use classifications in the area of study, and the classes identified were the following: 1. Urban areas, 2. Cropland, 3. Grassland and Shrubland, 4. Forest, 5. Wetlands, 6. Barren areas, 7. Snow and glaciers, 8. Water bodies and undefined areas. The forest was subdivided into: 4.1 Forestry plantations and 4.2 Native forest. The Global Forest Watch organization developed one of the two studies, in which the classes were identified by the use of aerial photography and intensive field work.

The other land cover/use classification was performed by CONAF (the Chilean forest service) and the land cover/use classes were the following: native forest, plantations, rotational agriculture, prairie, urban building, bared ground, water bodies and snow and glaciers. The differences in classes correspond to the use perused by each classification. The Global Forest Watch was more focused on the frontier forest. On the other side, CONAF was more focused on understanding the landscape for fire prevention. In terms of classification schemes both studies look to produce a classification in level one that takes into consideration general growth patterns. The classification Scheme used in this research corresponds to level one, specifically that used by the USGS (United States Geological Survey) to define the NLCD (National Land Cover Data). These are general land cover classes that can be interpreted from aerial photography: Water, Urban Developed, Barren, Woody Cover, Herbaceous Successional, Row Crop and Pasture Hay.

Table 3-5. Forest cover in the South of Chile

CHILE'S FORESTS	SURFACE AREA (HA)	PERCENT OF TOTAL
NATIVE FOREST		
Mature Forest	5,977,996.3	38.2
Secondary Forest	3,582,427.3	22.9
Mature-Secondary Forest	865,525.3	5.5
Sub-alpine or Timberline Forest	3,017,209.0	19.3
Subtotal	13,443,157.9	85.9
FORESTRY PLANTATIONS	2,118,840.2	13.5
MIXED FOREST	87,744.0	0.6
<b>TOTAL</b>	<b>15,647,742.1</b>	<b>100</b>

Conaf

## CHAPTER IV

### MATERIALS AND METHODS

#### 4.1 Study Area

The area of study is a major producer of timber products, agriculture and cattle (Figure 1). Demographically, it is the second most populated region in Chile with 1,861,562 habitants, second only to the major urban center Santiago (INE, 2003). The general geographical boundaries are to the east Argentina - defined by the Andes Mountains - to the West a coastal mountain belt, to the South region VII known as Maule, and to the North the IX region known as The Araucania. The surface of this area approximately represents 4.9 percent of the total surface of the country. The climate in the region is Mediterranean; however, due to factors linked to the geography, this area is known by its extensive winter rains with a total of 2,400 mm during some seasons and a considerable range of temperatures. The satellite images cover most of the VIII region and a small portion of the IX region. These images carry specific characteristics defined by the type of satellite.

## 4.2 Data Acquisition

The data used in this multi-temporal change study correspond to two Landsat satellite images, one corresponds to Landsat 5 acquired on December 1986 and the other to Landsat 7 acquired on December 2003 (Figure 2). The Landsat 5 satellite was launched in 1984 and Landsat 7 in 1999, respectively. The data file value, range from 0 to 255 for each pixel, with 0 being no return and 255 maximum returns. These values are linked to spectral reflectance, and different features on the landscape have a different response to reflectance. The main characteristics of these satellites are a thematic mapper (TM) and the multispectral scanner. The Thematic Mapper has greater spatial, spectral and radiometric resolution. TM has seven spectral bands with a 30 meters spatial resolution, except for the thermal band with a field of view of 120 meters which is not incorporated in this research. The images are catalogued into scenes of 115 miles (185 Km) wide by 106 miles long (170 Km). With the use of GIS it is possible to display a range of characteristics of the landscape by manipulating the different bands, such as 3, 2 and 1, which create a true color composite (similar to a photograph), 4, 3 and 2 false colors (similar to an infrared photograph), or 5, 4 and 2 pseudo color composite. By using the characteristics of each band in Landsat satellite images (Table 4-1), different characteristics of the landscape can be explored ( Lillesand and Kiefer 1994).

Landsat satellite images are conditioned by different factors that need to be addressed before going into any type of image processing.



Table 4-1 Landsat Bands Applications

<b>Band</b>	<b>Spectral Range</b>	<b>Principal Applications</b>
1	0.45-0.52 um	Coastal Water Mapping Soil Vegetation Differentiation Coniferous Differentiation
2	0.52-0.60 um	Green Reflectance by Healthy Vegetation
3	0.63-0.69 um	Chlorophyll Absorption for Plant specifies Differentiation
4	0.76-0.90 um	Biomass Surveys Water Body Delineation
5	1.55-1.72 um	Vegetation Moisture Measurement Snow
6	10.4-12.5 um	Plant heat Stress Measurement Thermal
7	2.08-2.35 um	Hydrothermal Mapping

### 4.3 Image Rectification and Relative Radiometric Normalization

In order to compare images from the same area acquired at two different times, it is needed to rectify the images to correct distortions coming from factors such as altitude or velocity of the sensor to factors related to atmospheric conditions. The objective of this process is to eliminate the distortions and improve the geometric integrity of the images (Lillesand, 1994).

Most Satellite images, due to atmospheric interference, need radiometric normalization to make any image enhancing technique for change detection, such as change vector analysis to be successful. In order to complete this task it is necessary to process the images captured in 1986 and 2003 by selecting the bands that are going to be used in the research.

The main purpose of radiometric normalization is to match the original statistics of the bands from the subject image corresponding to those of the reference image throughout a method such as a regression. The method chosen in this study was based on the Elvidge's 1995 approach for selecting areas of no change using scattergrams. Due to the presence of deep water in the area of study, this method presents advantages to processing the reference image. Deep water is considered an invariant feature over time which can be used to normalize the image that presents the lowest quality. The basic objective is to delineate areas of no-change (NC) in a composite image (Figure 7), based on the bands NIR1 and NIR2, using the DN (digital numbers) of the pixels in NC to calculate a regression using a model. Then, the regression coefficients are utilized to normalize the DN of one image (subject) based on the other (reference). In this study the

image from 1986 was picked to be the subject and the image from 2003 the reference.

The main steps included in this process are: identifying the water and surface clusters that serves to calculate the Half Perpendicular Width (HPW) and the Half Vertical Width (HVW). HVW corresponds to the half vertical width of no change regions in the scattergrams and HPW is calculated using the water and cluster coordinates. In order to define the areas of no change in the NIR bands, a mask is created by a mathematical function, and then this is transformed into an AOI (Area of Interest) file. This file is finally used to extract the pixel reflectance values for the normalization process.

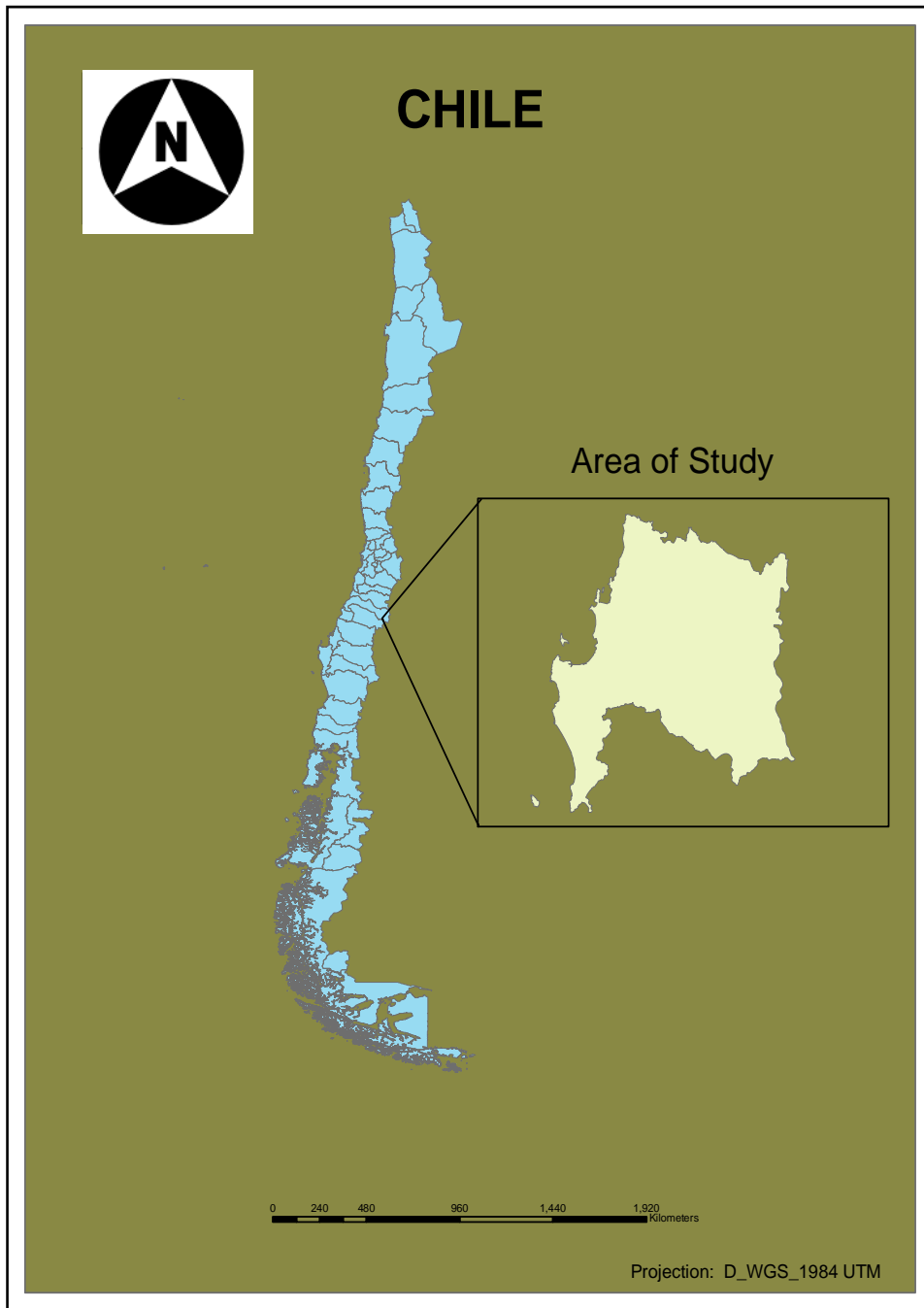


Figure 1. Map of the country of Chile and the area of study

## Landsat Images

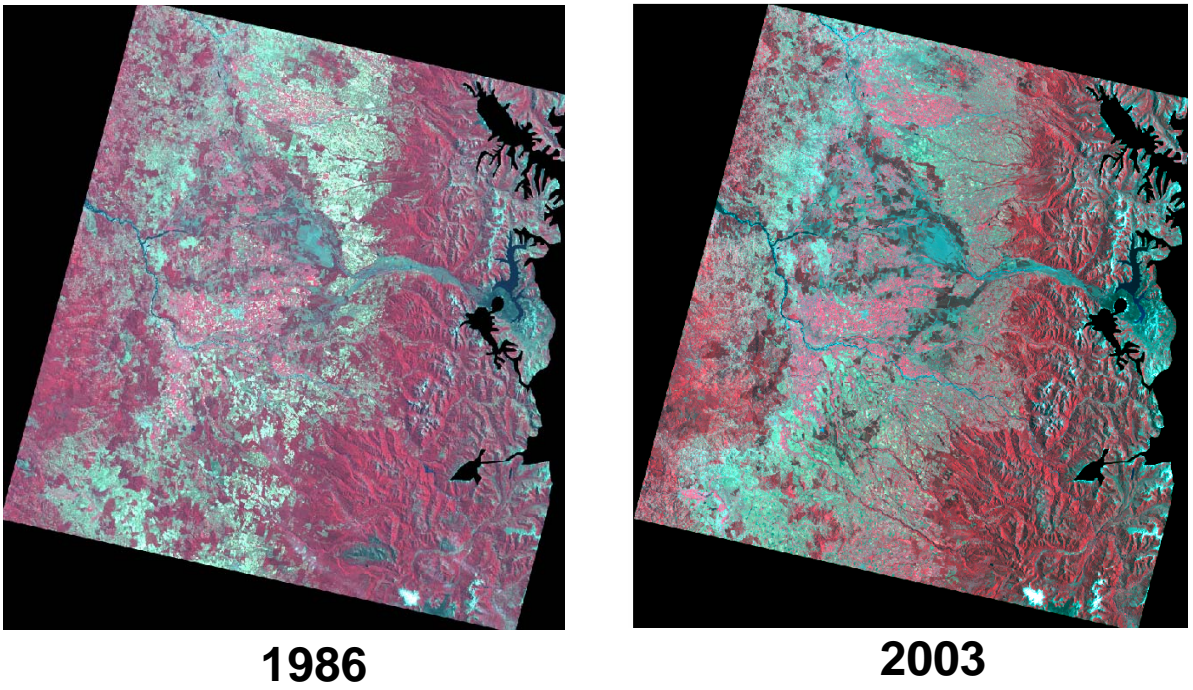


Figure 2. Images from the study area in the South of Chile.

#### 4.3.1 *Image Statistics and Scattergrams*

A composite image was created with the bands coming from the 1986 and 2003 images combined in a single file. The bands used in this process were the following: Green (2), Red (3), NIR1 (4), and NIR2 (5). Therefore, there are a total of eight different bands coming from the images acquired at two different dates. The purpose of the composite image is to facilitate the normalization process during the different stages in order to eventually correct those statistics for the subject image file.

After the composite image is created, it is visually inspected and consequently the image statistics recorded. Then, the values can be compared to those resulting from the radiometric normalization process. Matching the values to fit the regression line can be accomplished by different normalization techniques, therefore in this study the “no change” areas were obtained by the use of feature space images or scattergrams.

The identification of NC areas is based on scattergrams made by manipulating the composite image in the feature space layer panel, then specific combination are selected for example, 3\_7 and 4\_8, generating scatterplots that corresponds to the NIR1 and NIR2 bands from the two images respectively. The reference image (2003) was plotted on the y axis and the image from subject date on the x axis (Figure 5). Next, the feature space images were used to obtain the water and surface cluster coordinates.

#### 4.3.2 Identifying Water and Surface Cluster

By opening both feature space images in different viewers it is possible to identify the local maximum coordinates of the water cluster and the coordinates of the land surface cluster from both scatter plots of infrared channels (3-7 and 4-8 feature space images). This is done by visual identification and selecting those representative areas that can be located by linking the composite image with the scattergrams. Those coordinates are used to calculate “a” and “b” in the following formula:

$$a = \frac{J u \max - J l \max}{i - u \max - i l \max} \quad (4-1)$$

$$b = J l \max - a - i l \max \quad (4-2)$$

The terms  $J u \max$ ,  $J l \max$ ,  $i u \max$  and  $i l \max$  correspond to the center of the surface cluster and water cluster from the images acquired on 1986 and 2003 respectively.

The selection of the cluster can be done by linking the original images to the viewers with the scatterplots. Next, factors a and b are used for calculating the half vertical and half perpendicular width.

#### 4.3.3 Half Vertical Width and Half Perpendicular Width

“a” and “b” in equations 2 and 3 are used to estimate the half vertical width (HVW<sub>nc</sub>) of no-change areas from half perpendicular width (HPW<sub>nc</sub>). A predetermined value of 4 is used in equation 4 to calculate HPW<sub>nc</sub> (Elvidge, 1997). The relationship of HVW<sub>nc</sub> and HPW<sub>nc</sub> is the following:

$$HVW_{NC} = \sqrt{1+a^2} \times HPW_{NC} = \sqrt{1+a^2} \times 4 \quad (4-3)$$

The results obtained from HVW and HPW are used for masking those areas of no change through a mathematical function.

The mathematical definition of NC is: (4-4)

$$NC = (x, y) : |y_3 - b_3 - a_3 \times x_3| \leq HVW_{NC3} \text{ and } |y_4 - b_4 - a_4 \times x_4| \leq HVW_{NC4}$$

In this equation “a” and “b” correspond to the results of the water and surface cluster coordinate calculation. The Y’s are the DN of the reference image (7 and 8) and the X’s are the DN of subject image (band 3 and 4). The main objective of this function is to determine those areas of no change to extract those values for the normalization process.

#### 4.3.4 NC Pixels Using AOI

The model maker helps to process the image through a simple chain of steps. By using the ERDAS IMAGINE software, conditional algorithms such as EITHER – IF – OR – OTHERWISE can be used to identify values indicating no-change areas in the output image. Furthermore, areas of NC can be obtained by masking pixels that fall into a previously defined threshold. This model takes the original image, then isolates the pixels that are going to be used into the regression. The pixels are grouped and transformed into an AOI file.

An AOI file is created representing areas of no change (Figure 7). NC pixel areas included in this file are used to estimate the values for the final regression through an



equation and a model. This process is done for the green, red, NIR1 and NIR2 bands in the model maker where the output correspond to a.sca and b.sca. files. The sca. file is later read to obtain those values that represent pixels of no change areas. Then, these are used to normalize the original image.

#### 4.3.5 Normalization

The following function is inserted into a final model in ERDAS IMAGINE to normalize the subject image. This is accomplished with the coefficients obtained from the model previously built.

$$X_k = A_k \times X_k + B_k \quad (4-5)$$

The images are visually inspected, then the statistics reported in the image info window are recorded and to be compared with those from the original image. Moreover, the subject image bands are ready to be re-stacked with the reference image bands for further processing.

#### 4.4 Change Vector Analysis and Change Detection

Most Change detection methods are sensitive to spectral differences between images that are not necessarily a result of changes in classes. As a consequence, the images were previously radiometrically normalized. Table 4-2 summarizes the bands in the input image for change vector analysis.

Table 4-2 Composite Image for CVA

<b>Bands</b>	<b>Year</b>	<b>Band Type</b>	<b>Wavelength Interval</b>	<b>Resolution</b>
1	1986	Green	0.52 - 0.60	30
2	1986	Red	0.63 - 0.69	30
3	1986	Nir	0.76 - 0.90	30
4	1986	Mid infr.	1.55 - 1.75	30
5	2003	Green	0.52 - 0.60	30
6	2003	Red	0.63 - 0.69	30
7	2003	Nir	0.76 - 0.90	30
8	2003	Mid infr.	1.55 - 1.75	30

One objective of this research is to map out changes in biomass, specifically its magnitude and direction of change. Change in magnitude is determined by the euclidean distance between the two images across all image channels. Four bands are used to calculate CM (Change in Magnitude). Change in direction is specified by whether the change is positive or negative in each band in a pixel by pixel basis. Two bands are used to calculate CD, band 2 (red) and band 3 (NIR1), focusing in 4 directions.

In figure 3 the overall process is described in a flow chart. First, the composite image is used to derive the amount and direction of the changes. The amount represented by percentages of loss and growth and the direction is used to understand the nature of the changes. Next, by identifying the land cover/ land use involved in the changes it is possible to narrow down the specific changing classes and what the percentage of change per class is. The result is the amount of changes in the area of study linked to land cover/ land use categories.

The first step consists of building a model for magnitude change that is next used for determining the threshold using all ground truth information available. This threshold is visually defined and adjusted. This is fundamental for determining the extent and direction of the changes in the area of study. The results are color coded and then interpreted by using a basic table that describes the different possibilities for spectral reflectance.

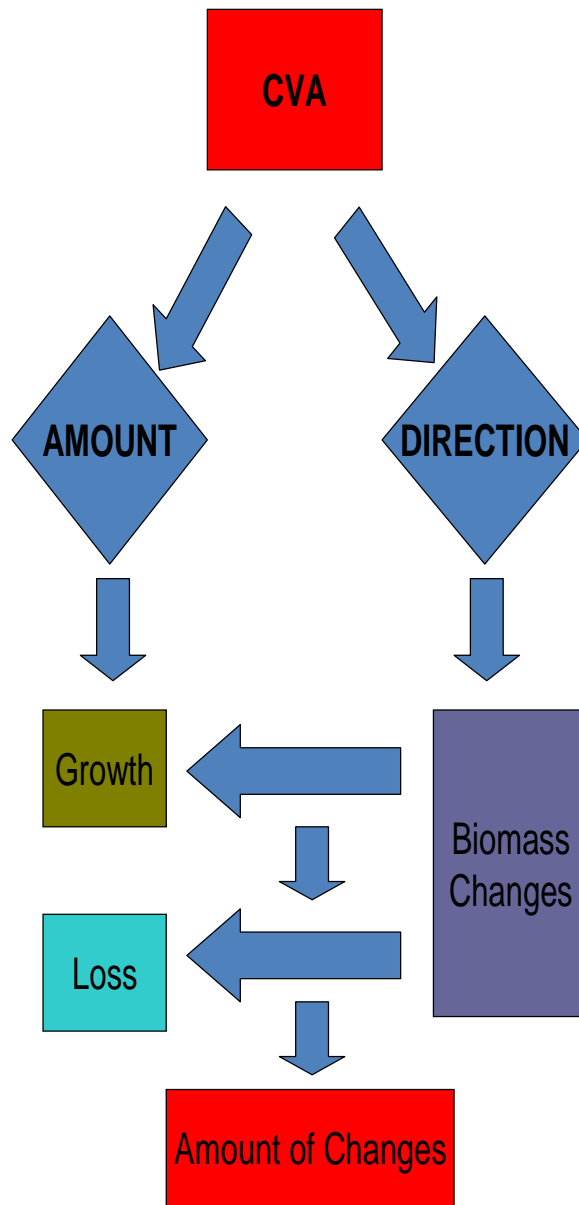


Figure 3. Flow chart for biomass calculation using Change Vector Analysis

#### 4.4.1 Model Maker and Change in Magnitude

Using ERDAS IMAGINE, a model to calculate change in magnitude is built. This model has three basic components: a raster object, a function and the output file.

The raster object corresponded to the chile.img file and the function to calculate change in magnitude is computed by determining the euclidean distance between the two images across all image bands in a pixel by pixel basis. The image obtained was used to define those areas that had significant changes between the two images. The formula is the following:

(4-6)

$$CM = \sqrt{(DN_{11} - DN_{21})^2 + (DN_{12} - DN_{22})^2 + (DN_{13} - DN_{23})^2 + (DN_{14} - DN_{24})^2}$$

#### 4.4.2 Determining the Threshold from CM

After running the model, the new file needs to be visually inspected to determine the changes among images. A fundamental part in understanding the changes in magnitude in the study area corresponds to defining the threshold. This process helps to differentiate changes that belong to significant variations in vegetation –biomass- and those that can be a result of fluctuations of other environmental characteristics. In order to identify vegetation loss and growth the image is opened in a viewer to evaluate pixels that represent areas of change. This can be accomplished by using ground truth, aerial photography and previous land cover classifications from the area.

With the help of the raster attribute editor the opacity for the image pixels can be set to 0 and a bright color assigned for all records. Next, using aerial photography,

previous land cover and land use classifications, ground data collected in a field trip and interactive maps from the area, a threshold is selected by examining those areas where changes are most apparent. This can be accomplished by switching the opacity values on the transparent image back to 1. These records represent CM values larger than or equal to the threshold selected. Higher values are targeted first because these are likely changes areas between the two images. Also, it is important to adjust the opacity values for records around the threshold until changes are clearly represented. After this is determined, the threshold helps to narrow the land cover or land use areas that are later classified depending on the spectral response in a change in direction model.

#### 4.4.3 *Change in Direction*

For the change in direction the previously defined threshold is used in a model. The model uses the following elements (Figure 6): the image representing change in magnitude, next the threshold is defined in a function in the model where all those areas of changes are represented by a 1 and the NC (no change) by a 0. Then, the output image is used in combination with the CVA image to sort the direction of the changes. Conditional statements were used to test for pixel DN ranges that are associated with change. Specific conditional statements are found in appendix A. This function specifies the rules to assign change direction codes (1 to 4) to the output image *direction.img*.

To understand the codes, the *chile\_chgdir.img* is opened in one viewer, and the 86's and 03's in two other viewers. Then, the three images are linked geographically.

Assigning different colors and labels to each category helps to define the spectral changes.

In order to color code the chile\_chgdir image to correspond to the type of change, the raster attribute editor is opened and a new column is added to the table called biomass changes. In this column the change direction is color coded by assigning the labels a) increased vegetation b) decreased vegetation c) small growth d) small loss.

#### 4.4.4 *Understanding the Changes*

In figure 4 pixels in direction 3 represent an increase in band 3 (NIR1) and a decrease in band 2 (Red). These pixels are likely to represent increased vegetation growth. Pixels in direction 2 show a decrease in band 3 and an increase in band 2. These pixels have undergone a decrease in vegetation amount. Pixels in direction 4 have increased both in band 2 and band 3 which indicates that biomass represented in the pixels have changed to a higher reflectance surface (row crop to urban developed or herbaceous successional). Pixels in direction 1 have decreased both in band 2 and 3 which represent a decrease in brightness that could be represented as transformation of urban developed into row crop or herbaceous successional into cropland.

Direction	- Red Band Changes (Band 6 – Band 2) +	
- NIR I Band Changes (Band 7 – Band 3)  +	1 Urban to Row Crop or Herbaceous Successional	2 Vegetation Loss
	3 Vegetation Growth	4 Row Crop to Urban Developed or Herbaceous Successional

Figure 4. Change in direction using Change Vector Analysis



## CHAPTER V

### RESULTS AND DISCUSSION

#### 5.1 Relative Radiometric Normalization

The objective of this process was satisfactory because it helped reducing redundancy in the dataset. The normalization results can be seen on the images and its statistics by comparing the image before and after the normalization process (Table 5-1 and 5-4). Each step along the process is fundamental for reducing the chances of misclassifying changes in biomass and improving the overall accuracy.

##### 5.1.1 *Composite Image and Statistics*

Using the Arc tool box in ArcMap a composite image was develop by putting together the bands that were useful for the study. These bands were 1) Green, 2) Red, 3) NIR1, 4) NIR2 from both Landsat Images, 1986 and 2003. The result of that process was the chile.img image. In order to delineate no-change areas (NC) only the NIR1 and 2 (bands 3 and 4) were used.

The statistics of the chile.img are shown in table 9.

Table 5-1 Chile.img Image info statistics in ERDAS IMAGINE

	1986				2003			
	Min	Max	Mean	Stdv	Min	Max	Mean	Stdv
Green	4	255	28.351	8.752	17	255	32.627	9.156
Red	6	255	27.839	12.819	1	255	32.054	15.102
NIR 1	3	255	73.757	19.395	8	255	66.341	16.215
NIR 2	1	255	69.07	24.872	5	173	45.469	20.236

5.1.2 Scattergrams to extract NC data

Next, scattergrams were created from bands 3\_7 and 4\_8. These corresponded to bands 3 and 4 from the image 1986 and 2003. Both images were opened in different viewers to identify the surface and water cluster. The coordinates for the scattergrams 3\_7 and 4\_8 helped to calculate a and b (Table 5-2).

Table 5-2 Coordinates statistics from scattergrams for identifying water and surface cluster

	$i_{umax}, j_{umax}$	$i_{lmax}, j_{lmax}$	a	B
Band 3-7 pair (NIR1)	71.37, 64.06	5.43, 9.26	.83106	4.7473
Band 4-8 pair (Mid infr.)	58.76, 37.17	4.88, 7.03	.5594	4.3001

## Feature Space Images

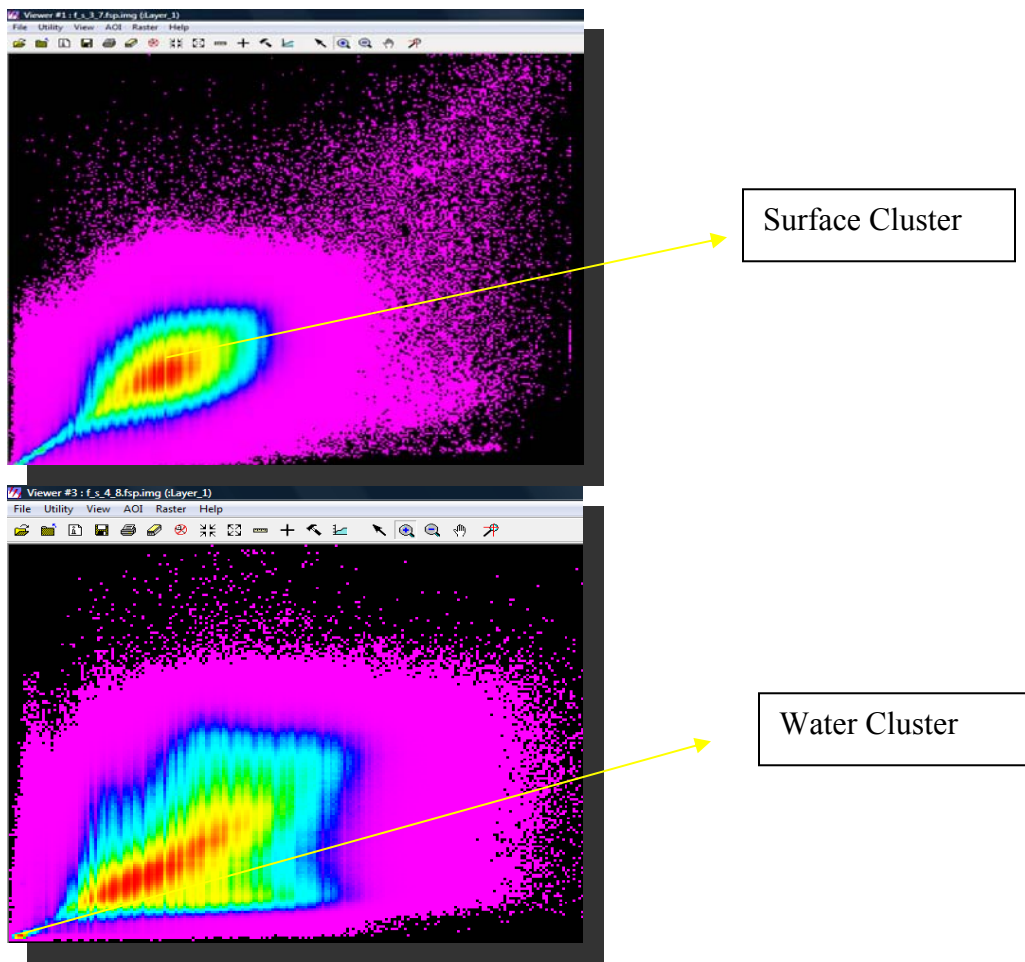


Figure 5. Scattergrams from bands 3\_7 and 4\_8 corresponding to bands 3 and 4 from image 1986 and 2003

### 5.1.3 HVW and HVP Calculations

With a and b was possible to calculate the half vertical width of no-change area from half perpendicular width (Table 5-3).

$$3\_7 \text{ HPW nc} = \sqrt{1 + (.83106)^2 * 4} = 5.2012 \quad (5-1)$$

$$4\_8 \text{ HPW nc} = \sqrt{1 + (.5594)^2 * 4} = 4.5832 \quad (5-2)$$

Table 5-3 Half vertical width for bands 3 and 4.

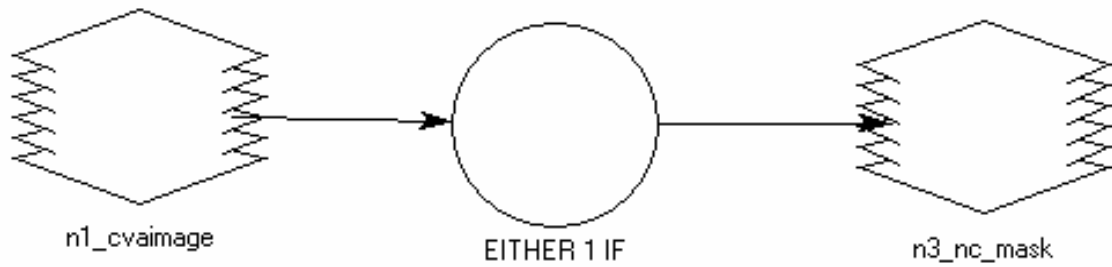
HVW <sub>NC3</sub>	265.68
HVW <sub>NC4</sub>	124.40

Following the mathematical definition of NC a model was created to extract those areas of no change from the image in order to normalize it.

### 5.1.4 Extracting Areas of No-Change

The construction of this model was based on assigning a value of 1 to those areas of interest, in this case no change areas, or, set an output pixel to 0 using the mathematical definition of NC as the function to discriminate those areas.

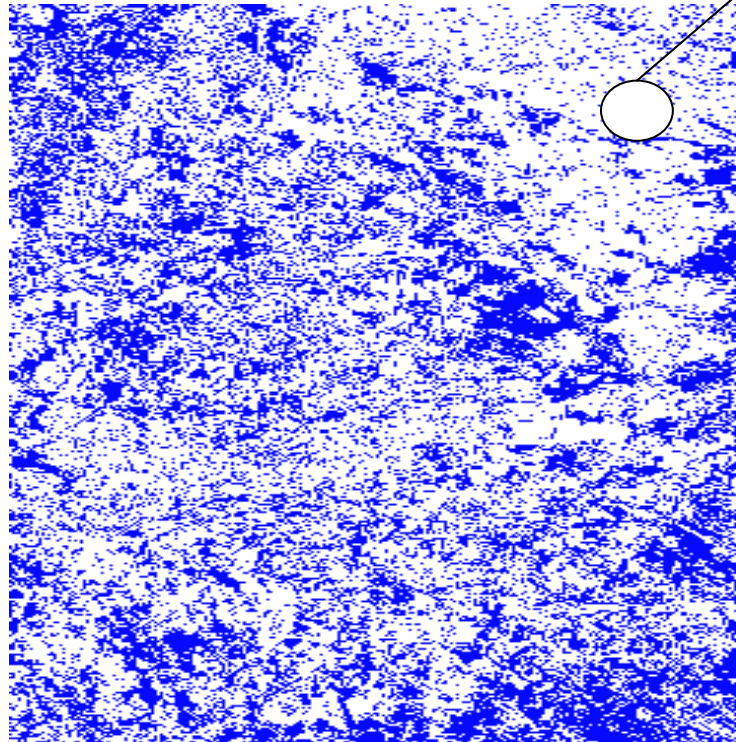
## No Change Areas Mask Model



**EITHER 1 IF**(( $\$n1\_cvaimage(7) - 4.7473 - .83106 * \$n1\_cvaimage(3)$ ) <= 5.2012) **OR 0 OTHERWISE AND**  
**EITHER 1 IF**(( $\$n1\_cvaimage(8) - 4.3001 - .5594 * \$n1\_cvaimage(4)$ ) <= 4.5832) **OR 0 OTHERWISE**

Figure 6. Model for extracting areas of no change for radiometric normalization

## No Change Pixels Image



No Change  
Areas

Figure 7. No change pixels represented in an image

### 5.1.5 Regression Model

The result of the mask model was a new image named nochange.img which was used to create an AOI file. This file was used to identify those areas of no change; therefore, only pixels values within the no change areas were used to estimate the regression equations for all pairs of bands from the two dates using the model in figure 8.

- Green, Red, NIR1, NIR2 -.

### Regression Model

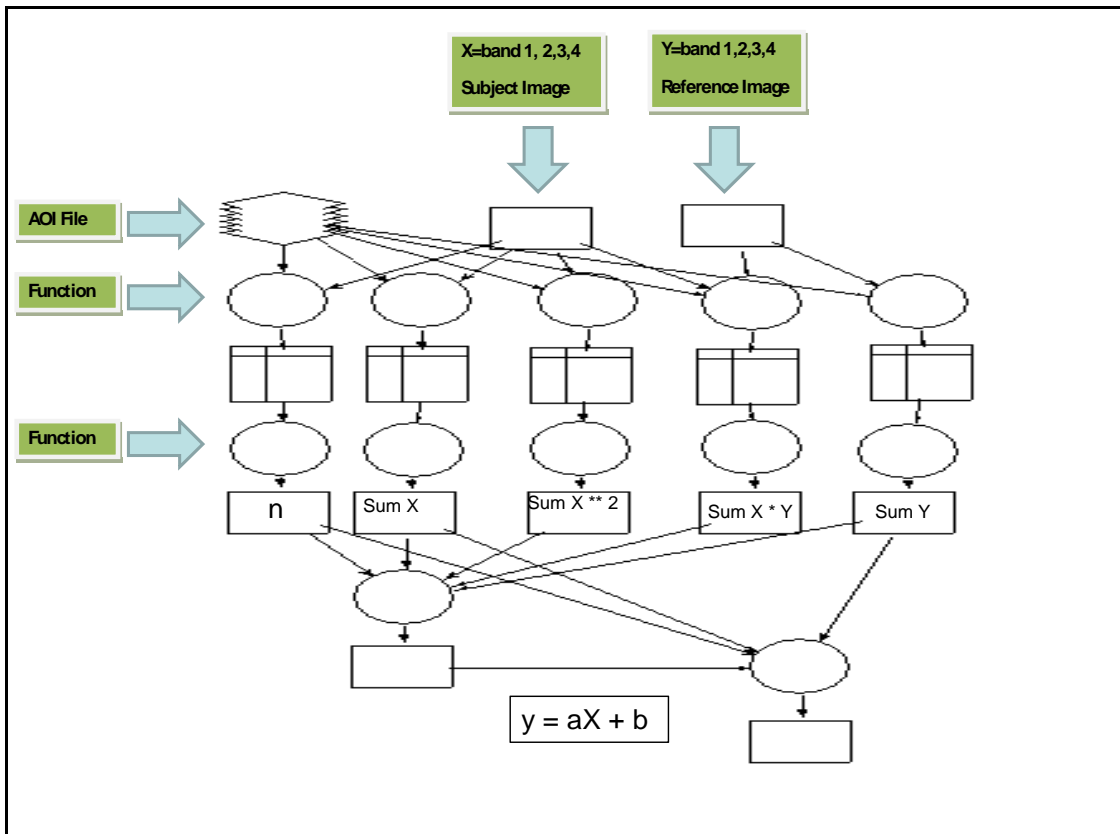


Figure 8. Regression model for Radiometric Normalization

Table 5-4 Final statistics of the normalized CVA image

	1986 MSS				2003 MSS			
	Min	Max	Mean	Stdv	Min	Max	Mean	Stdv
Green	0	255	20.032	14.913	0	255	23.074	9.156
Red	0	255	19.673	16.693	0	255	22.68	19.368
NIR 1	0	255	52.084	37.363	0	250	46.901	33.145
NIR 2	0	255	48.781	37.808	0	250	32.154	26.799

Finally a regression was used to find the relationship between the dataset from date 1 and 2 after the process of normalization using the NIR1 band, due to its radiometric characteristics linked to the absorption of the NIR light by water and reflection of bright objects such as urban developed it served the purpose of validating the use of this technique obtaining an R square of 0.8135.



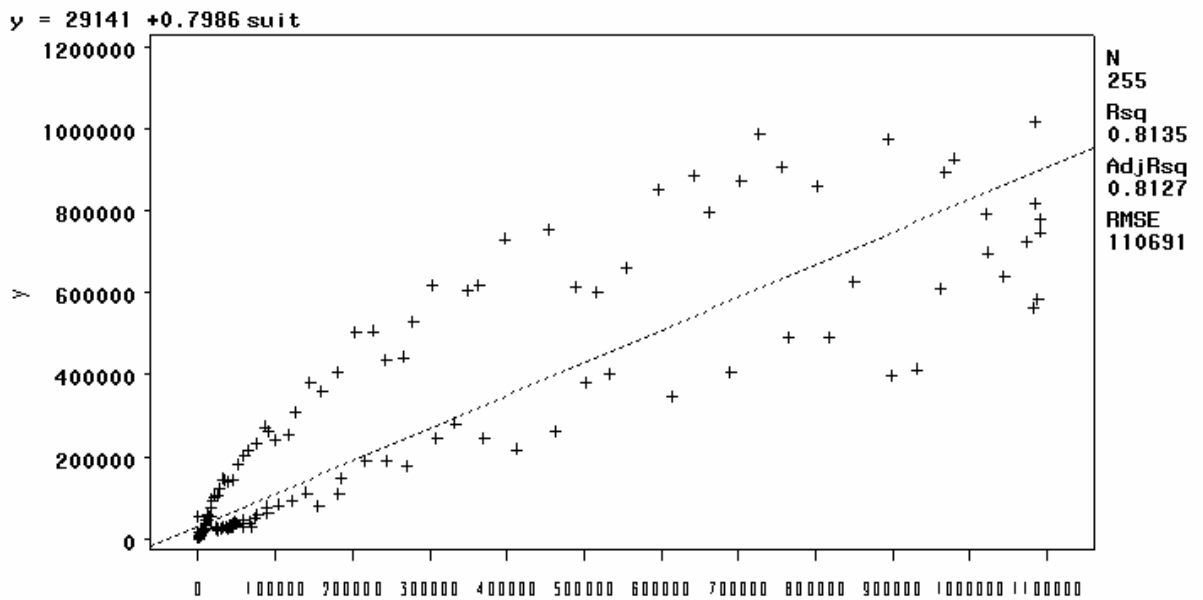


Figure 9. Regression of pixels from date 1 and 2 after the normalization process

## 5.2 Change Vector Analysis

The change vector analysis technique was used to detect those areas where full dimensional spectral changes were present. Changes were first detected by measuring magnitude, and then sorted. The nature of the changes of interest in this study corresponded to general growth and loss of biomass in the region of study. By measuring the euclidean distance between the vector endpoints, a magnitude of the change image was developed. The results showed widespread changes over the study area. Even though there was not great differences between loss and growth of biomass over the area of study, the type of change is fundamental. This corresponds mostly to classes such as row crop and pasture hay going into forestry plantation and row crop and pasture hay going

into herbaceous successional. The changes were divided and better understood when connected to specific eco-regions present in this region.

### 5.2.1 *Change in Magnitude*

In order to answer the first objective, changes in magnitude between the images acquired in 1986 and 2003 were calculated using all the bands from the composite image and computing the euclidean distance. One of the objectives of this study was to quantify the overall extent of biomass change in the VIII region in the country of Chile. In order to answer this question a model was developed formed by three basic parts: the composite image, function and output image (Figure 9). The result of this calculation had as a result an image where the attributes were represented by DN (digital numbers) and pixel frequency (Figure 10). The DN ranged from 0 to 255, where 0 represented no spectral response and 255 maximum spectral response. The total changes in the area of study corresponded to approximately 3304 square miles, which corresponded mostly to growth of biomass (row crop or pasture hay to woody cover), loss of biomass ( row crop and pasture hay to herbaceous successional), or loss (woody cover to row crop or pasture hay), and growth( row crop or pasture hay to woody cover). This region is recognized by its dynamic use of natural resources that was reflected in the results. The magnitude of the changes are clearly seen in the images and establishing the direction helped to understand the nature of them.

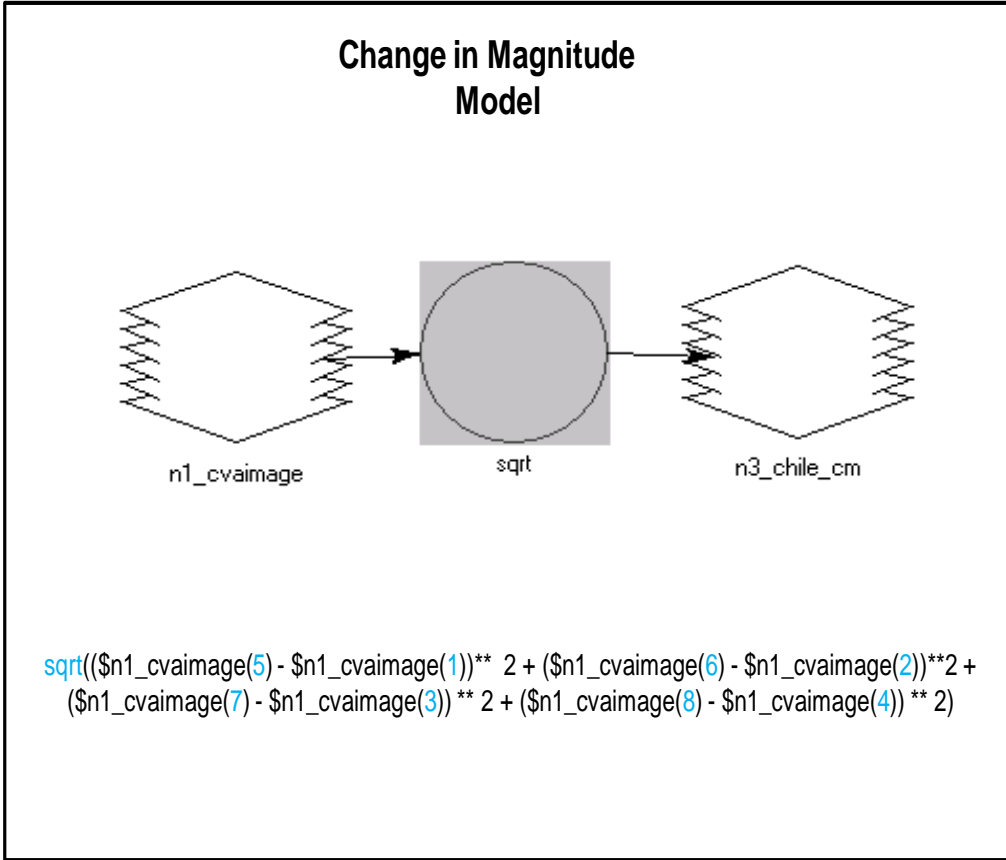


Figure 10. Model for calculating the euclidean distance between bands green, red, NIR infrared and Mid infrared from image from date 1 and 2.

Total Biomass Change VIII and IX  
Region 1986-2003

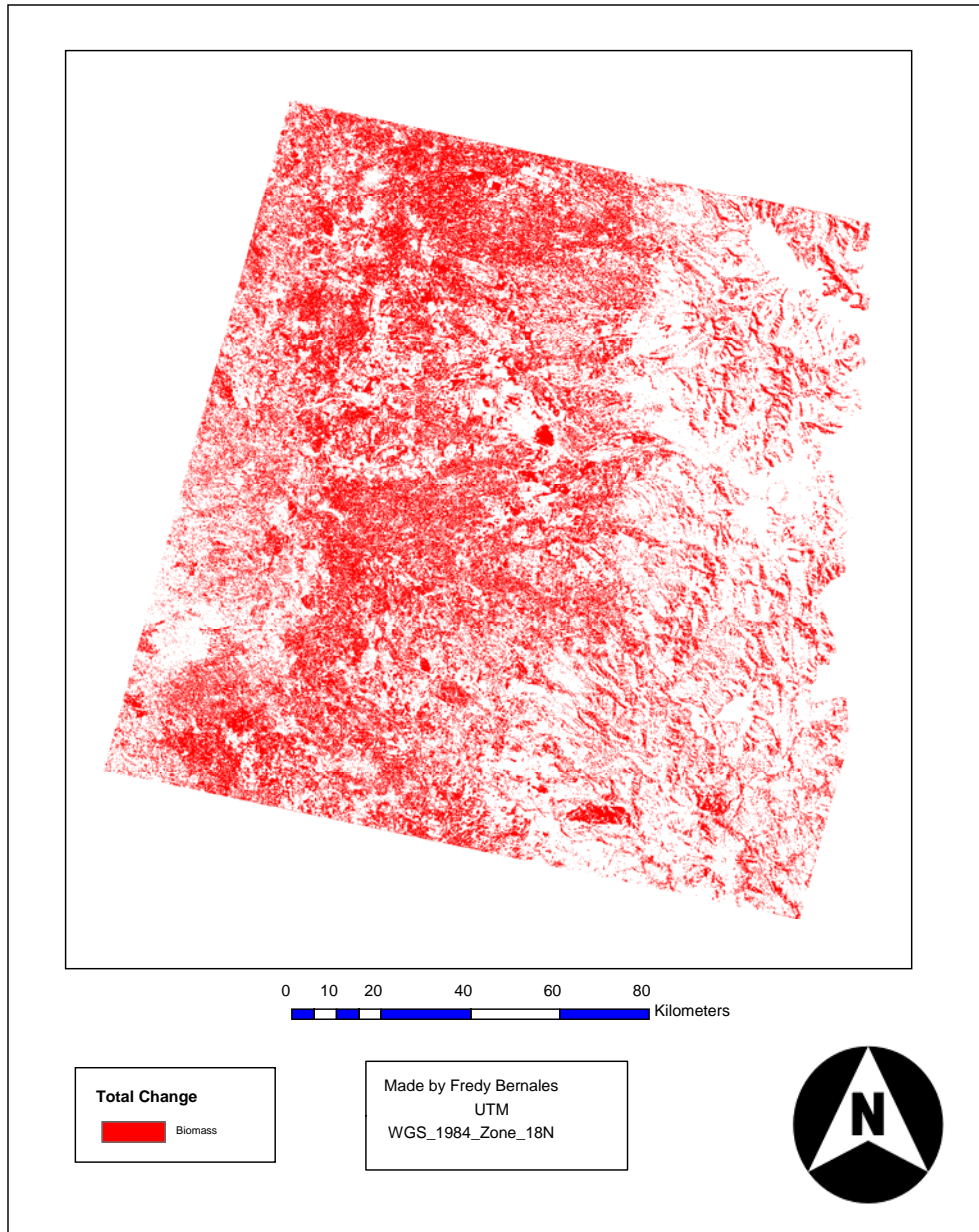


Figure 11. Total biomass change in the area of study

### 5.2.2 Direction Change

The second objective was to compare the changes of biomass divided into growth and loss. Due to the great amount of biomass changes present in the area of study, these categories helped to differentiate the most commonly found trajectories (Figure 14). The four types of changes established are: Growth of biomass, loss of biomass, small growth and a small loss. All these categories were within the digital number 30 and 60 (Figure 11), which represented areas of change in the CM image (Figure 10). The DN values were chosen by visually inspecting the image with the support of aerial photography, interactive maps and previous land cover and land use classifications from the study area.

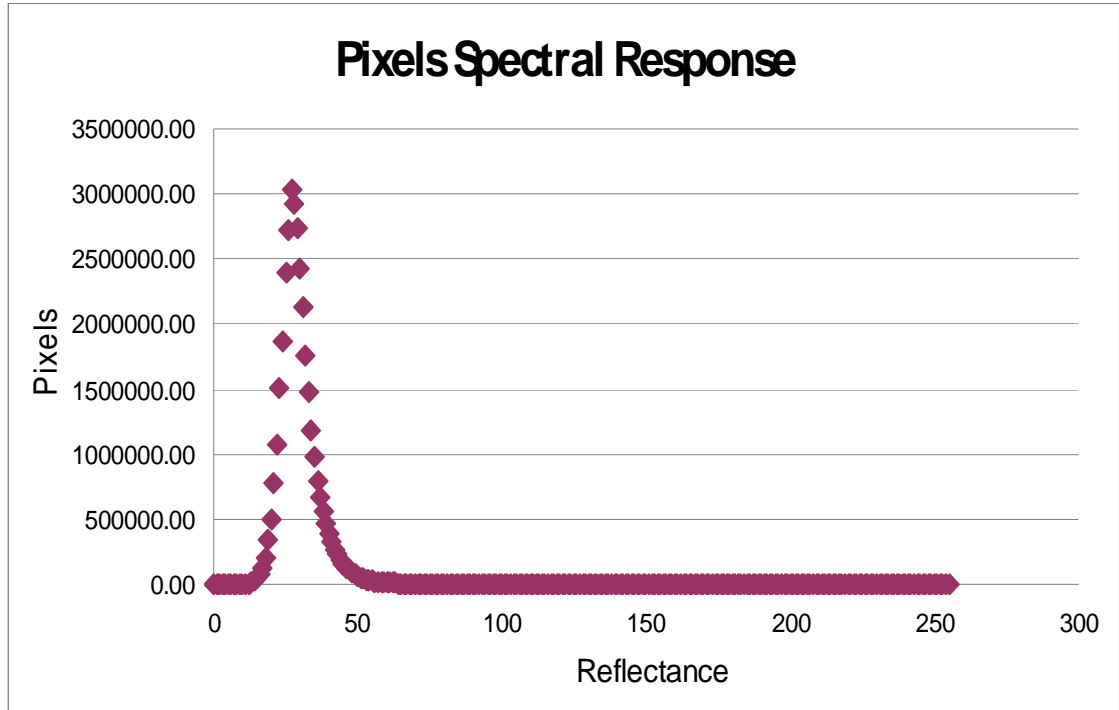


Figure 12. Pixel spectral response and threshold selection

Higher spectral reflectance values were coming from those areas of change in biomass. Theoretically, higher pixel values are likely to represent real changes in the landscape and not only environmental fluctuations (Elvidge, 1996). A Map showing the direction of the changes was produced to quantify the amount and difference between the classes (Table 5-5).

Table 5-5. Percentage of change in the area of study

Biomass Change	Percentage
Growth	44
Loss	30
Small loss	11
Small Growth	15
	100

Six main land cover/land use classes were used: Woody cover, row crop, herbaceous successional, pasture hay, open water, urban developed. The classes were obtained from the USGS, the main goal was to use classes that can be interpreted from aerial photography corresponding to scheme level 1. In addition, using aerial photography and ground truth the biomass changes were separated into the following categories (Table 5-6).

Table 5-6 Categories of changes in biomass

Growth	Biomass Growth Weights
Herbaceous Successional to Woody Cover	0.4
Herbaceous Successional to Row Crop	0.15
Pasture Hay to forest	0.15
Herbaceous Successional to Pasture Hay	0.1
Row Crop to Woody Cover	0.1
Pasture Hay to Row Crop	0.1
	1
Loss	Biomass Loss Weights
Woody Cover to Herbaceous Successional	0.4
Row Crop to Herbaceous Successional	0.15
Woody Cover to Pasture Hay	0.15
Pasture Hay to Herbaceous Successional	0.1
Forest to cropland	0.1
Cropland to grass	0.1
	1

Growth of biomass in the area of study corresponded to 44 % of the total change in biomass (Figure 15). The changes corresponded in a great extent to changes of some land cover/land use to woody cover. One of the main economical activities in the region is forestry, mainly the production of timber related products. From the four types of changes studied, woody cover is the most predominant in the area, replacing mainly row crop, pasture hay and herbaceous successional fields. Overall, green vegetation decreased substantially when down significantly from 1986 to 2003 (Figure 13). The changes in biomass are widespread around the area of study, including areas in the Andes Mountains where rich temperate forest is located, the alluvial valley showing an important decrease in row crop fields, and the coastal belt with an increment in the forestry plantations (Figure 12).



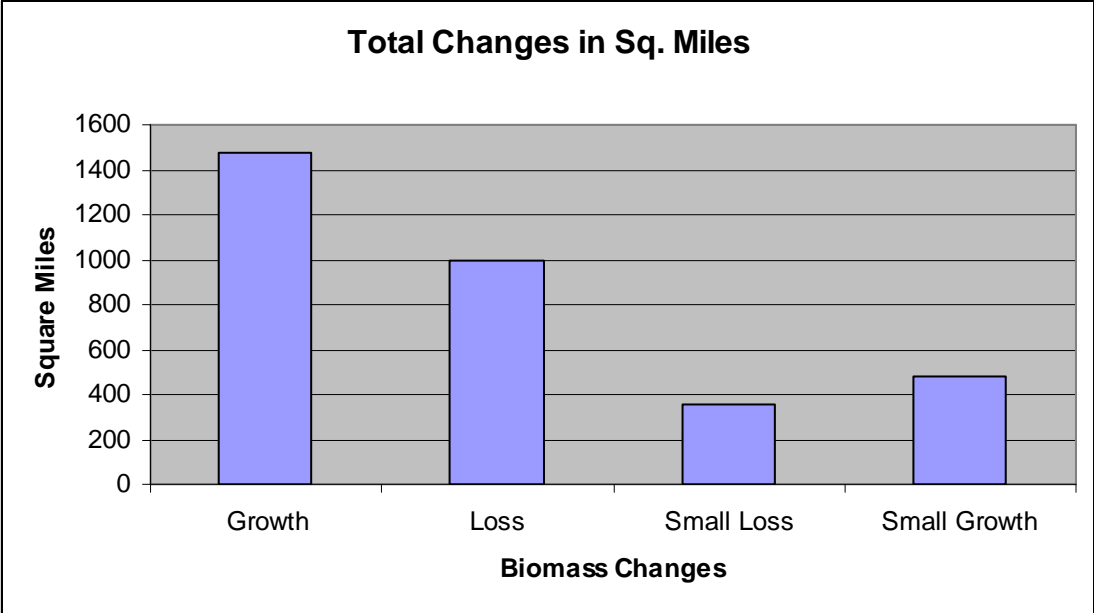


Figure13. Total changes in square miles in the area of study

# Loss of Biomass 1986-2003

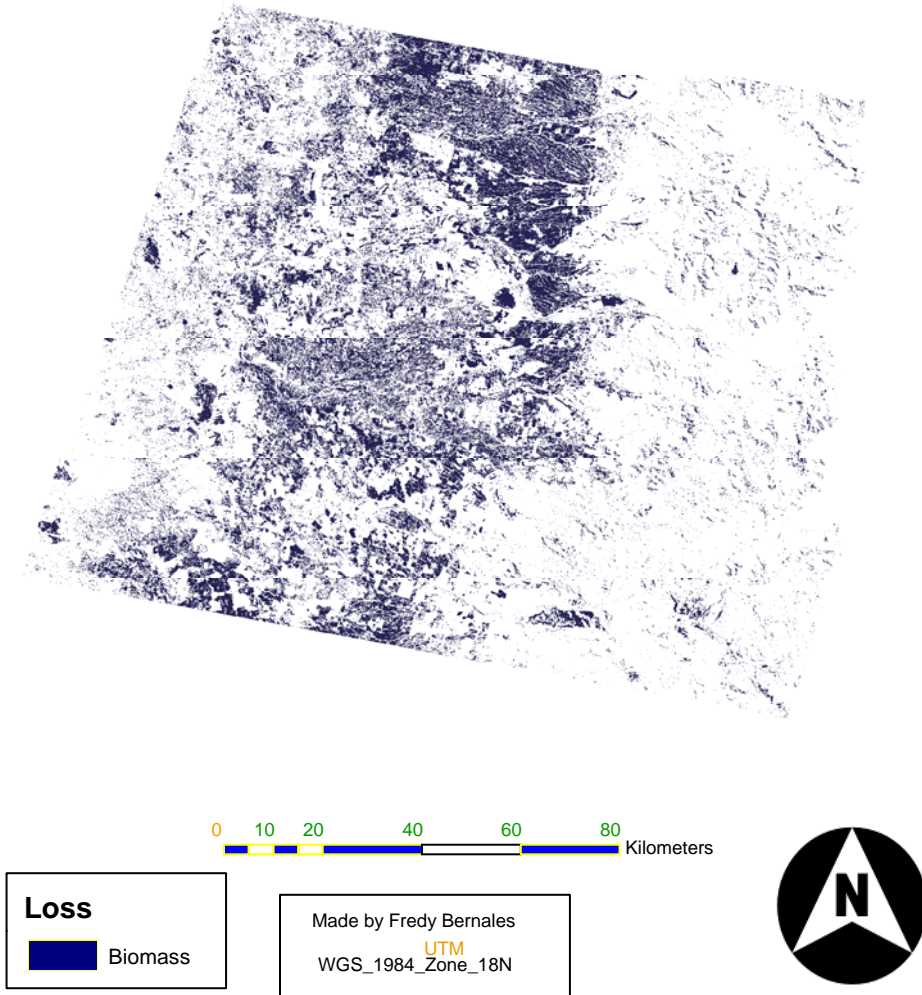


Figure 14. Biomass loss in the area of study

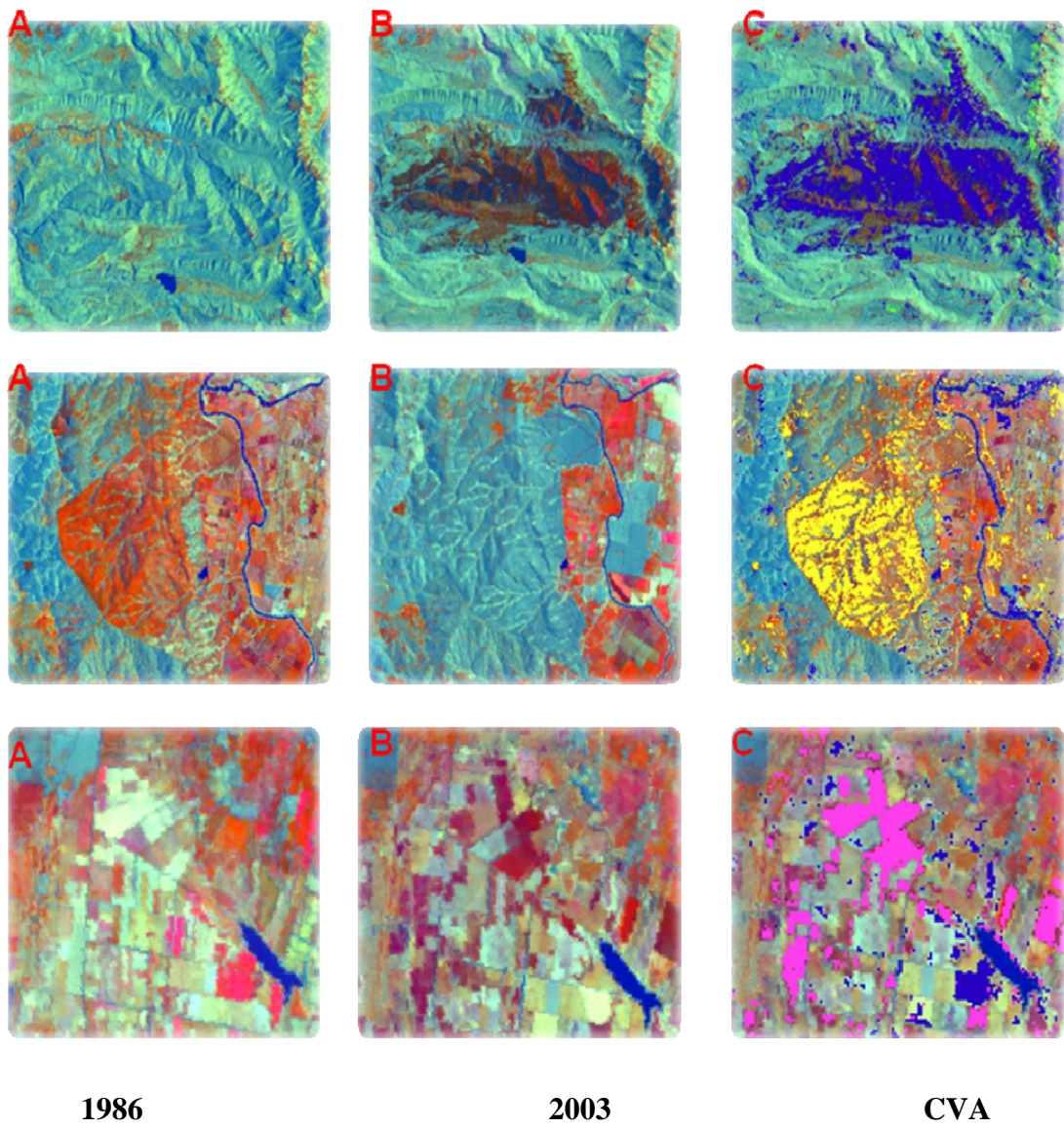


Figure 15. Specific land cover/land use changes detected with CVA

# Growth of Biomass 1986 - 2003

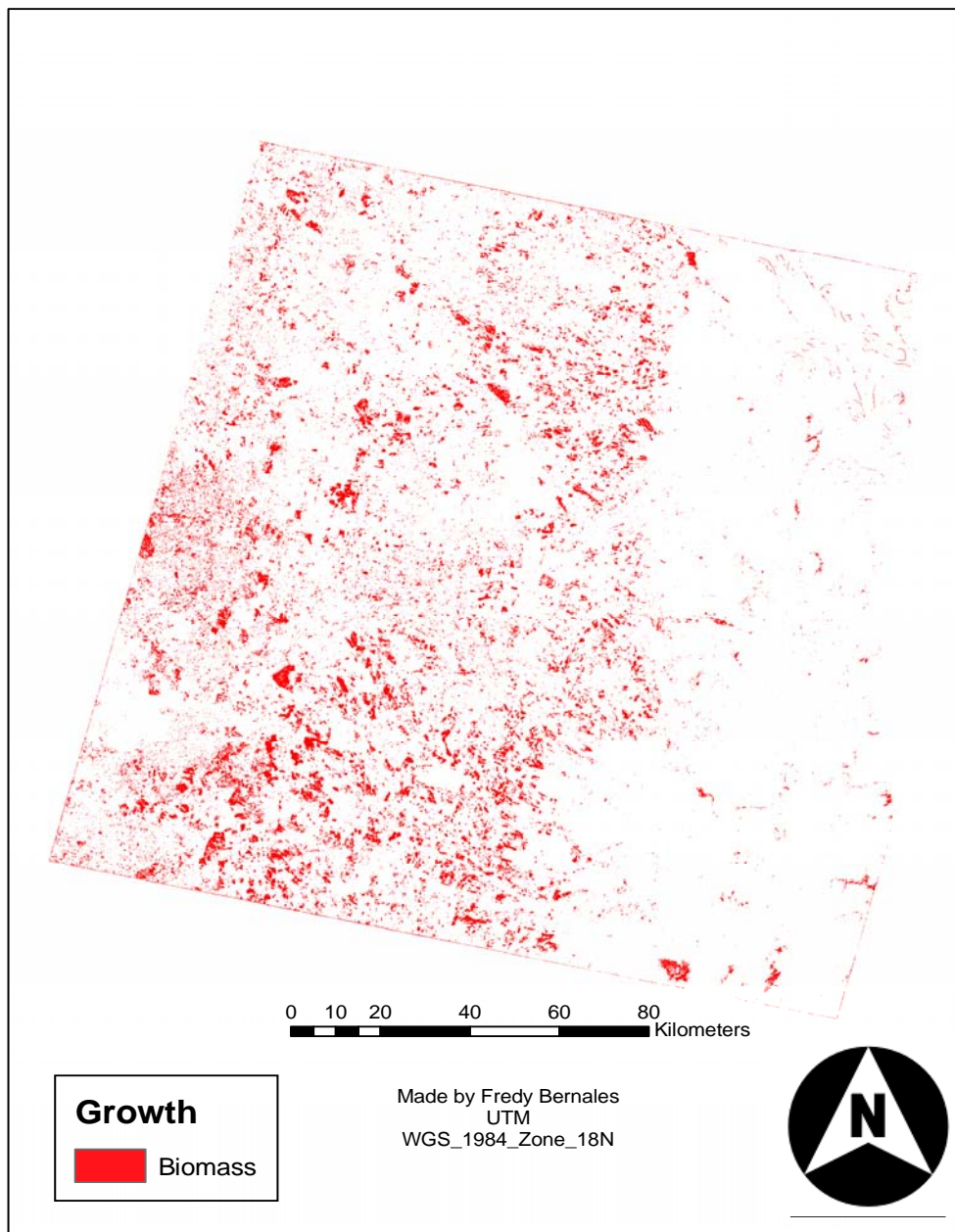


Figure 16. Biomass growth in the area of study

## 5.3 Changes in the Eco-Regions

### 5.3.1 *Andes Mountains*

The third objective was to use the three main eco-regions present in the area of study to further understand the changes in biomass. The Andes Mountains in the area of study ecologically represent a rich habitat for the country of Chile and the world, with 1/3 of the temperate forest left in the planet. It has several native species that are only found in this area. The results showed that approximately 201 square miles represent areas of biomass growth (Figure 16). These areas are understood as classes that were transformed into woody cover. The area of biomass loss was found to be approximately 218 m<sup>2</sup>. The main factor in these changes is connected to the type of woody cover involved. Growth is mostly linked to species as pine and eucalyptus and biomass loss in its major extent is connected to native species. Into the biomass loss, there is a spot on the south western corner of the image that represents an area of extensive clear cut (Figure 17). Some of the species present in the frontier forest are up to 3,000 years old, and represent a major ecological loss. As mentioned in previous chapters there are limited laws to secure the conservation of areas such as this. Moreover, the existent laws are rarely reinforced. The lack of reinforcement is proved by the few infractions coursed to people who break these laws in the last 20 years. Conversely multiple incentives exist to promote forestry plantations.



# Andes Mountains and Frontier Forest

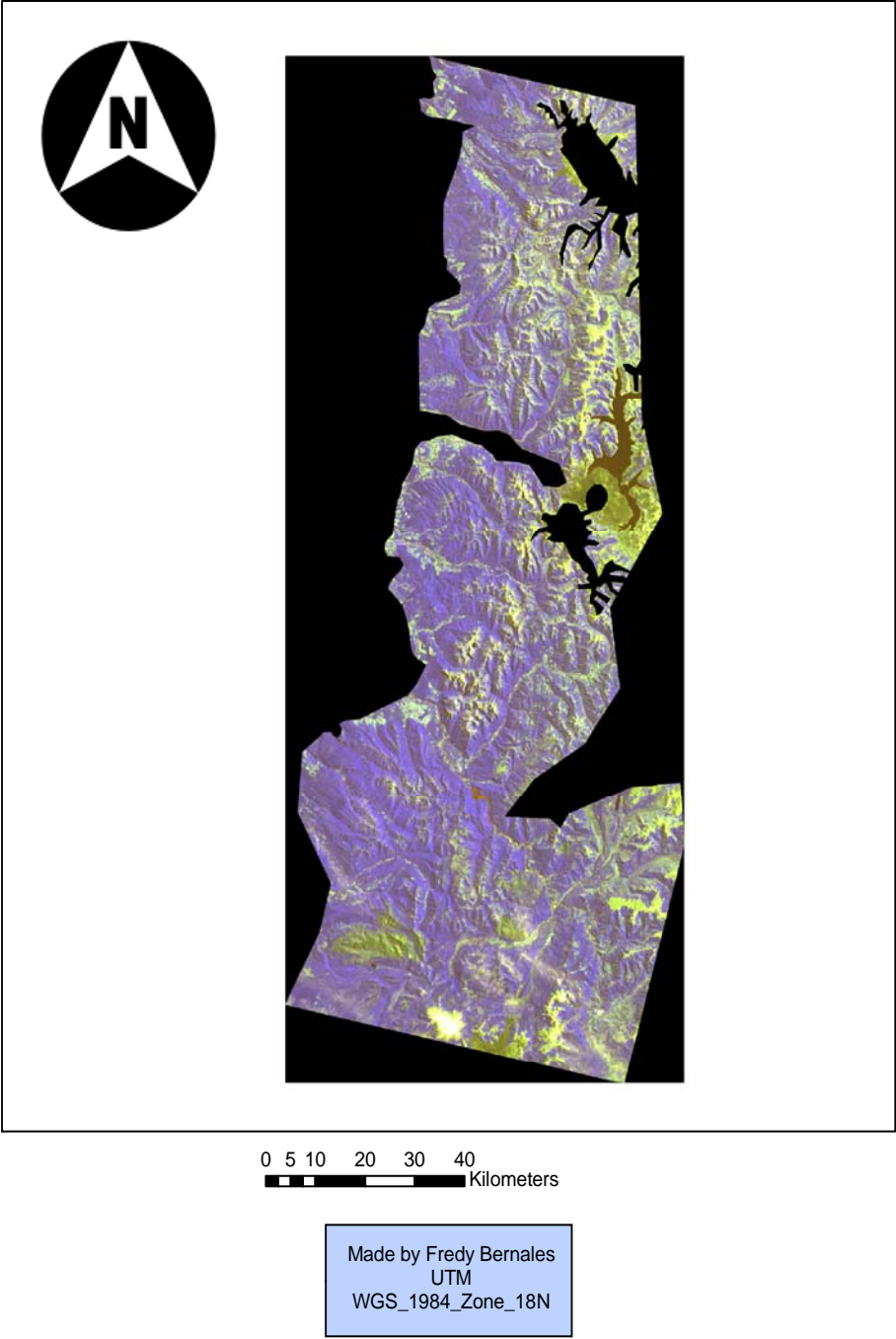


Figure 17. The Andes Mountains covered by native species known as frontier forest

# Direction of the Changes in the Andes

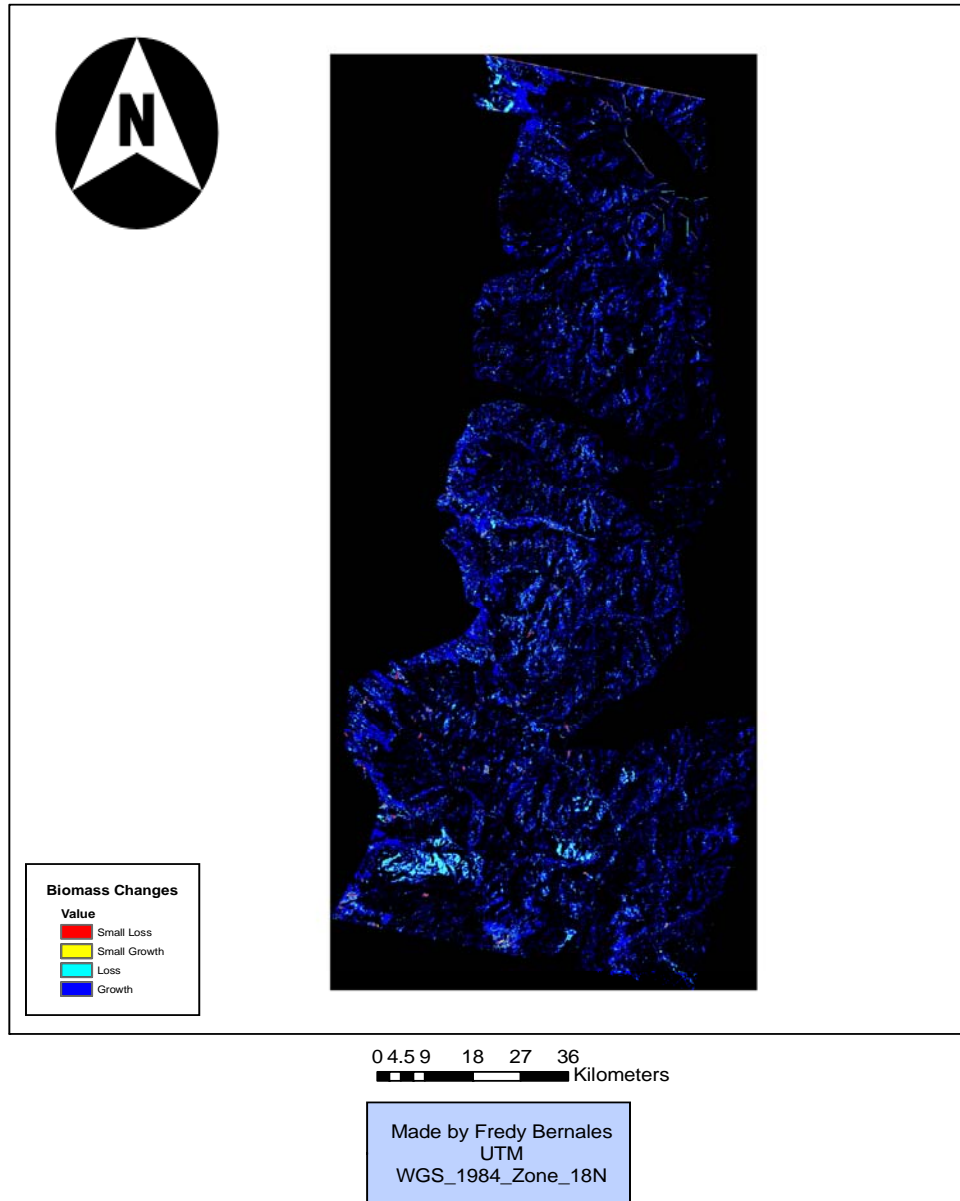


Figure 18. Direction of the changes in The Andes Mountains

### 5.3.2 *Central Valley*

Economically this area is fundamental for the country of Chile. In this valley agriculture and cattle are the most common activities (Figure 18). Products from this zone are destined for internal consumption and exports. The results show that an area of approximately 1118 m<sup>2</sup> represents growth of biomass in the study period. This growth is mostly characterized by direction, such as row crop to woody cover, pasture hay to woody cover and in a smaller degree herbaceous successional to row crop or pasture hay (Figure 19). The loss of biomass in the area of study covered an area of 890 m<sup>2</sup>, which is mostly represented by changes such as woody cover (majorly native) to pasture hay, row crop to herbaceous successional, and pasture hay to herbaceous successional. The main consequence in this area is a decrease in the amount of row crop and pasture hay that got replaced by woody cover, mostly forestry plantations. In addition, many fields abandoned agricultural practices, and these were covered by herbaceous successional vegetation. The statistics of migration in the area reinforced this fact, which showed that the rural population decreased and the bigger cities in the region increased in population. Due to the lack of incentives by the government to the small and medium size farmers, agriculture has decreased. In contrast, planting pines and eucalyptus is a better investment than farming which in the last ten years have gotten affected by factors such as lack of water or floods. As consequence, agriculture became too risky for people with a low to medium income; therefore they had to find other ways for sustaining their families.



# Central Valley VIII Region Chile

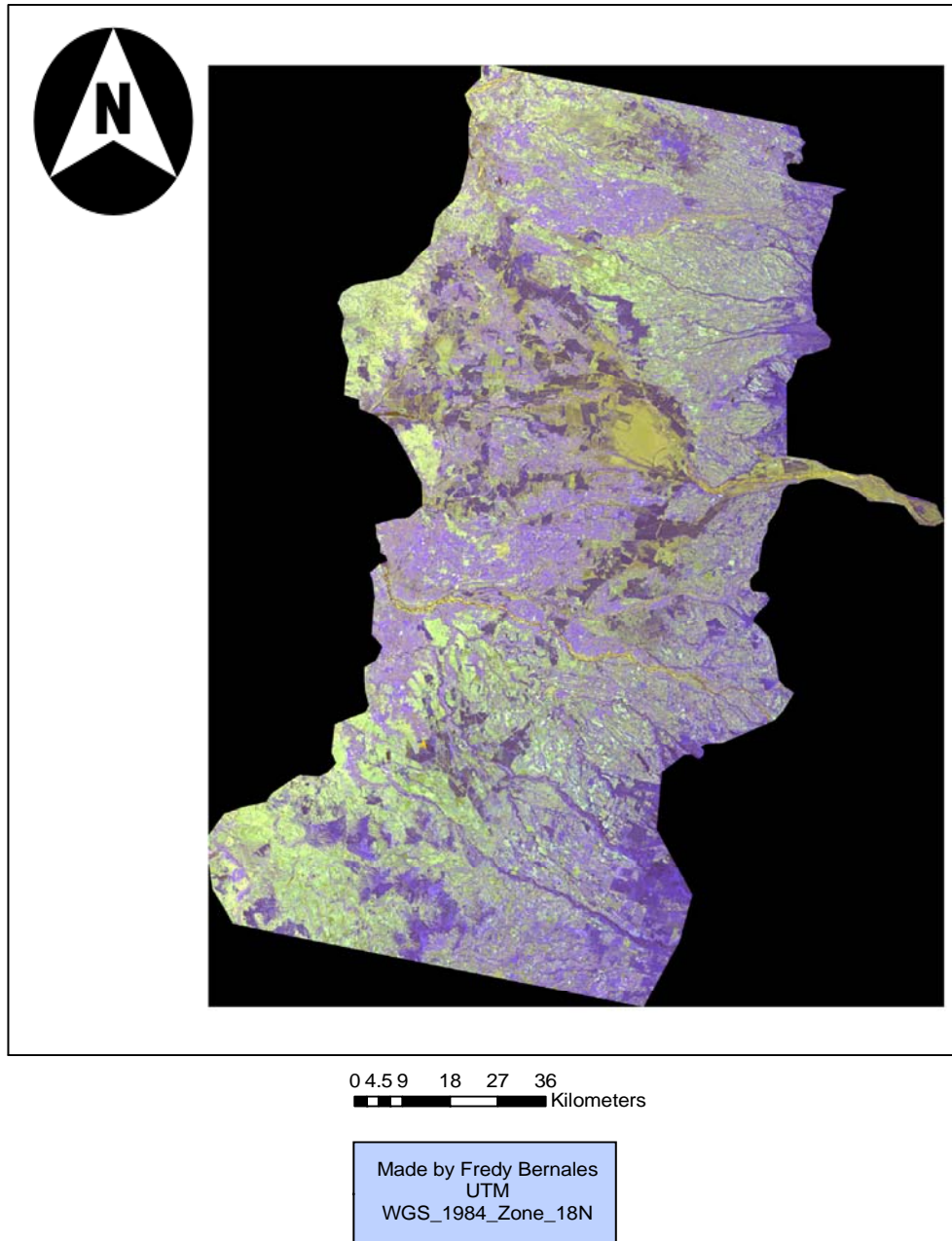


Figure 19. Central valley in the VIII region Chile

# Central Valley

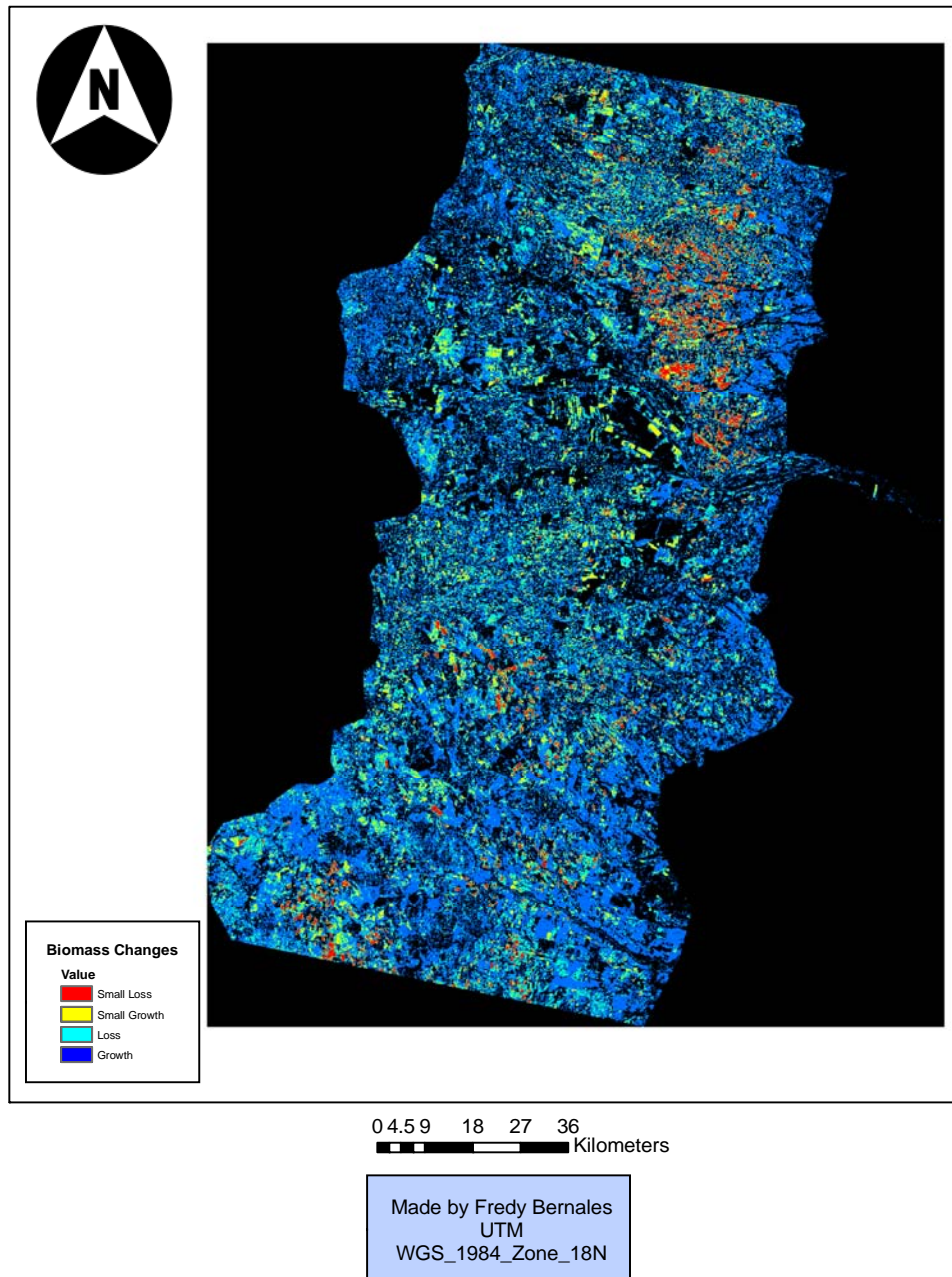
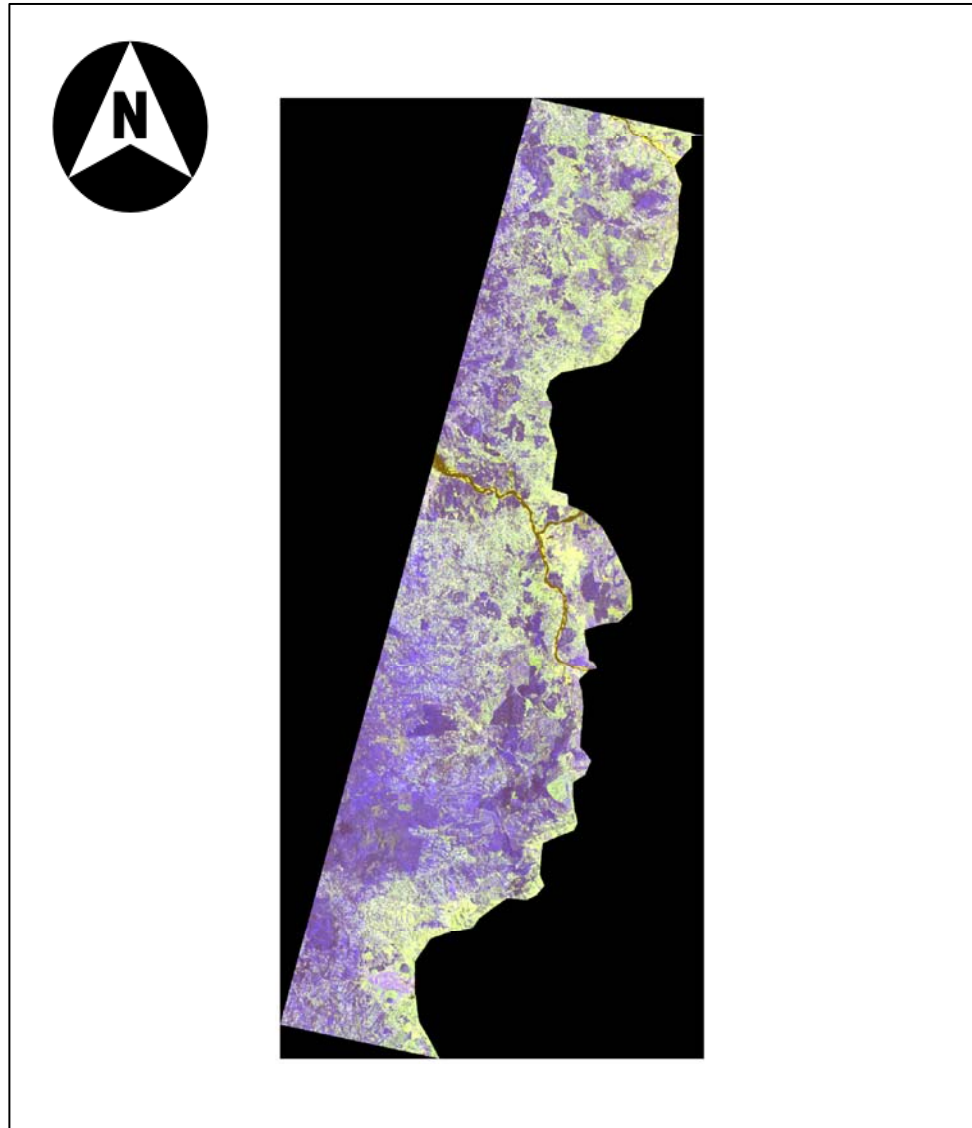


Figure 20. Changes in biomass in the central valley

### 5.3.3 *Coastal Belt*

The Coastal mountain belt in this region is smaller than the Andes, and goes from north to south along most of the country of Chile (Figure 20). This mountain belt is primarily characterized by the pine and eucalyptus plantations, except on the South Western corner where one of the most important national parks in the country can be found (Nahuelbuta). This park has many types of native species, and a few of the areas have been preserved. In terms of the changes, the results showed that approximately 599 m<sup>2</sup> represent growth of biomass and there are approximately 273 m<sup>2</sup> of loss in biomass. Most of the changes in this area are connected to forestry (Figure 21). In the field trip on 2006 I was able to see how the plantations have begun to get closer to the park, converting the slopes of many mountains around the it into pine plantations. Ecologically, this is probably one of the most sensitive in danger areas for conservation purposes.

# Coastal Mountain Belt



0 4.59 18 27 36  
Kilometers

Made by Fredy Bernales  
UTM  
WGS\_1984\_Zone\_18N

Figure 21. Image of the Coastal Mountain Belt in Chile

## Coastal Mountain Belt

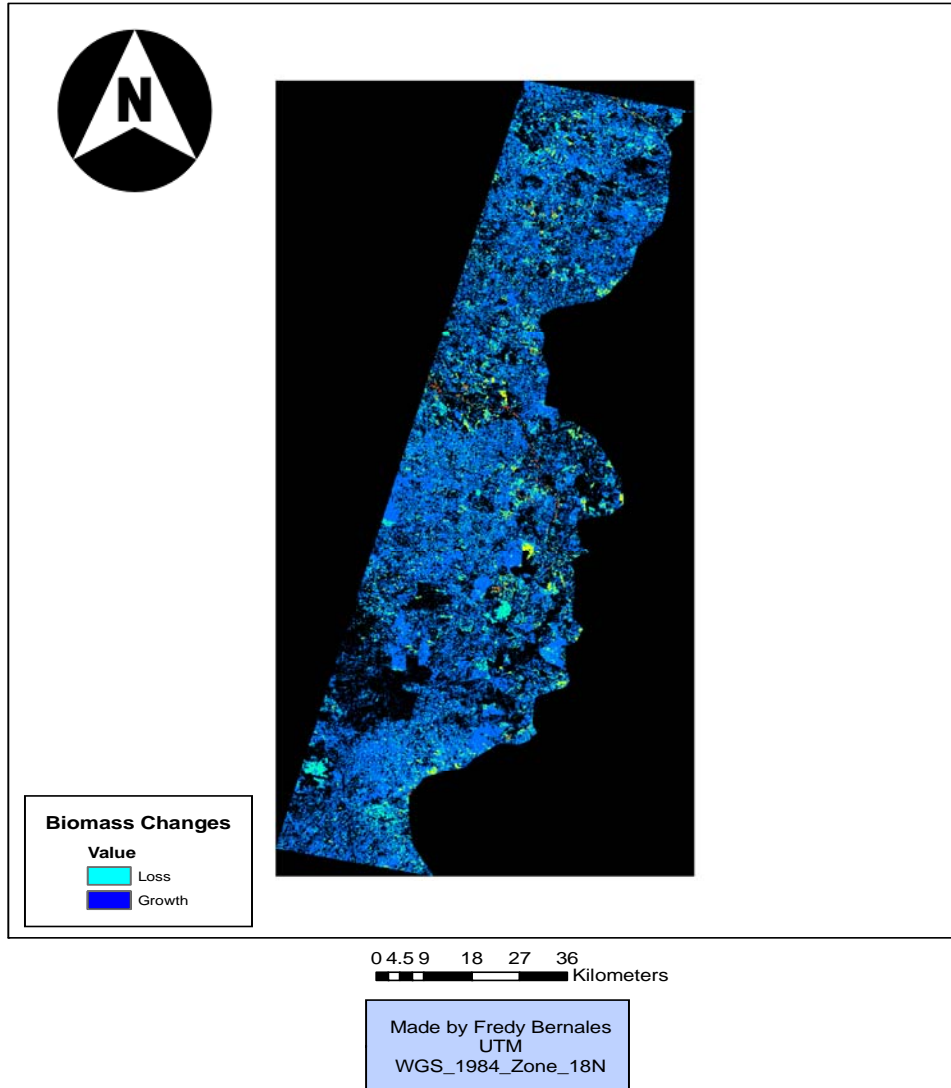


Figure 22. Direction of the changes in the Coastal Belt in the VIII region in Chile

#### 5.4 Accuracy Assessment

An error matrix was used to establish the overall accuracy of the study. This corresponds to a comparison between the reference data and the results obtained in this study using CVA (Lillesand and Kiefer 2000). The training data is cross-referenced with that obtained through the classification process. In addition, aerial photography was used to increase the number of sample plots. The aerial photography was obtained from the Chilean Institute of Agricultural Studies (INIA). Aerial photography from all the area of study was available, which facilitated the classification and accuracy assessment process. The overall accuracy was of 75% as seen in table 5-7. In this accuracy assessment the following classes were used: row crop, pasture hay, open water, herbaceous successional, woody cover and urban developed.

Table 5-7 Accuracy assessment results for the area of study

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	0	0			
Pasture Hay	18	15	11	61.11%	73.33%
Urban Develop	8	10	6	75.00%	60.00%
Row Crop	26	30	23	88.46%	76.67%
Herbaceous Succ.	15	16	12	80.00%	75.00%
Bared Ground	11	16	9	81.82%	56.25%
Woody Cover	31	23	19	61.29%	82.61%
Open Water	11	10	10	90.91%	100.00%
Totals	120	120	90		

Overall Classification Accuracy = 75.00%

## 5.5 Discussion

### 5.5.1 *CVA and Change Detection*

Change vector analysis is a method for detecting changes in magnitude and direction on the landscape. There is a great potential for this technique to be used in detecting changes using satellite images. Some of the factors that can condition the use of CVA are: characteristics of the area of study, image quality, resolution and radiometric normalization processing.

First, the type of changes in an area of study in a multi-temporal research could be fundamental for the results. If the changes on the landscape are in multiple directions, working with a greater amount of bands can increase the complexity for identifying the changes. By identifying the target of the research, for example identifying changes in urban developed or overall biomass it is possible to select those bands that can be useful for that type of spectral response. For the extent of this research CVA works great when measuring overall biomass changes from date 1 to date 2. However, more research needs to be done into differentiating those changes if more specific information is required. For the radiometric normalization process it is necessary to use radiance instead of reflectance to make sure that previously modify pixels are correctly normalized using its original characteristics.



### 5.5.2 *Landsat and Land Cover/Land Use Changes*

The image quality is an important factor because the CVA detection technique is based on spectral reflectance values. As a consequence, if the quality of the image is not satisfactory, the information can be misleading. In addition, atmospheric factors or noise can change the pixels reflectance values; therefore, the direction of the changes might not be accurate.

The resolution of the images can play an important role when identifying the type of changes present in the area of study. Image resolution is especially important when field work is not an alternative. The greater the image resolution connected to CVA the more accurate the answers that can be obtained. For the extent of this study the 30 meter resolution images performed adequately fine when measuring overall biomass changes. Landsat images work great when having other types of ground truth such as aerial photography or GPS data such as the ones used in this research.

Radiometric normalization is a fundamental part of working with CVA. If the normalization process is not correctly done, the results are more likely to be inaccurate. The reflectance values are the core of this technique, and improving the conditions of the image that has the lowest quality is very important. In this research, normalizing the image by using scattergrams turned to be a good option because this technique only uses those pixel that represent no change areas, whereas most normalization approaches all the pixels values from the image are used to correct the atmospheric variation or satellite calibration factors.

### 5.5.3 Change Producers

As seen in the maps the changes are extensive, and as a consequence the producers are more likely to be more than one factor. First, forest plantations increased due to governmental incentives and the lack of support for small and medium size farmers. As a consequence, forestry in the region keeps growing and lands that originally had different types of use turned into plantations. Chile is a country that in its geography is very long, but it is also very narrow at the same time; therefore, land productivity is in danger. In present days fruit and vegetable products has gone 200% to 300% higher in just a few years. The price of bread has also increased between 200% to 300% in the last two years. The consequences of the changes in the area of study and other regions began to affect the population who wondered what the reason is.

Table 5-8. Population migration in the area of study

	1992	2002
Total Population	1734305	1861562
Urban Population	1343097	1528306
Rural Population	391208	333256

Migration patterns in the region are reflected in the statistics obtained from the Statistic Institute of Chile. Rural population decreased notoriously from 1992 to 2002 just like biomass decreased during 1986 and 2003 (Table 5-8). It is well known the laws that incentive the timber production in the area in addition to the new extension of law 701 which is in function until 2010. Nevertheless, laws that support agricultural practices and

prevent farmers from abandoning their croplands are not enough to avoid the great changes in biomass present in the area. In terms of the world economy grain is one of the products that is raising its price because the rapid increase in the world population, so losing a 40% of biomass in the more productive area of the country, specially replacing row crop by forestry plantations is an important fact to consider (Figure 15).

#### *5.5.4 Techniques for Multispectral Studies in Developing Countries*

In a country like Chile where the rate of economical growth is steady, appropriate management is fundamental. The only way to monitor and develop long term planning is through research using technologies such as remote sensing and GIS in a large scale. The number of studies is so limited in the region that information from past and current conditions is not available. When the region that produces the greatest amount of agricultural products shows a 40% of biomass loss in a period of 17 years is to wonder what' s to expect in another 10 or more years (Figure 22). In order to prevent further dramatic changes, research must focus on the area and producers of the wide spread variation.

More research needs to be done into separating the changes in direction in order to identify the producers and the main consequences.

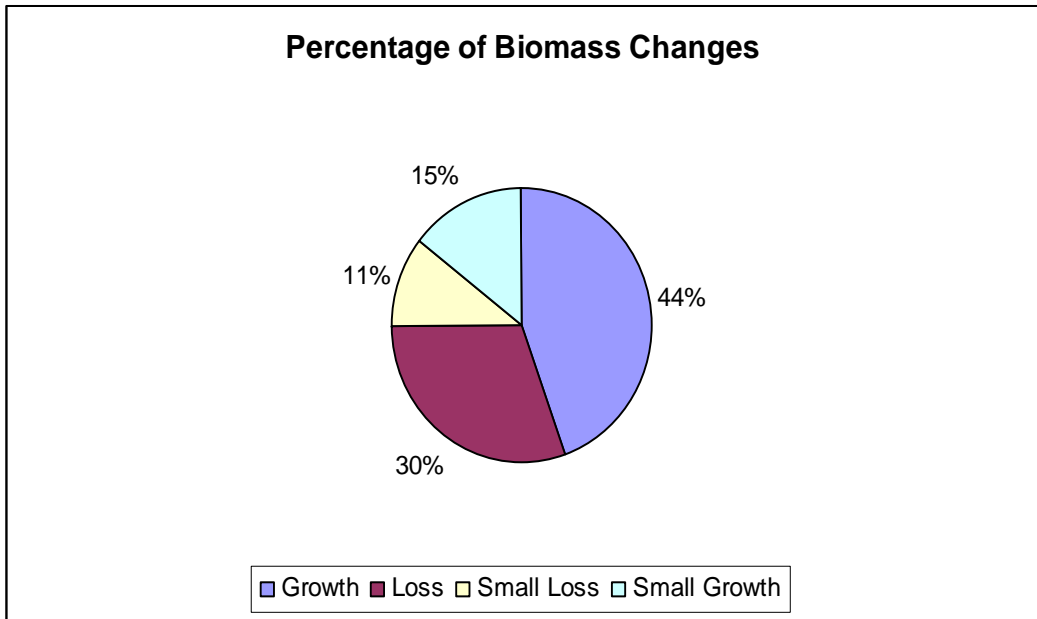


Figure 23. Percentage of changes in biomass

## CHAPTER VI

### CONCLUSION

Key Findings from this study indicate that CVA is an appropriate tool for assessing landscape change using remotely sensed data.

Change vector analysis enabled the assessment of major changes in the study area with an overall accuracy of 75%. The quantification of biomass growth and loss was the result of changes distributed into four quadrants that are closely correlated with economic and environmental issues. Linking changes to three eco-regions in the area of study had the following results:

- Primary forest in the Andes are diminishing
- Farmers are being displaced by pine plantations in the Central Valley
- Coastal resident are migrating to the cities due to loss of agriculture

Overall woody biomass has not changed dramatically in terms of total area, but original forest communities are being replaced at a rapid rate by plantations of pine forest (*Pinus radiata*). Also agricultural land area critical to Chilean farmers livelihood is also rapidly decreasing as plantation forest increase in the study area (Figure 24) . The results show dramatic changes in a period of 17 years (Figure 23). Now that the results reflect

the current condition of the region it is necessary to concentrate into analyzing causes, as well as short and long consequences. There is a great potential working with different bands using change vector analysis to sort and narrow down the types of changes.

In terms of the studies from the area, there is a need for independent studies that are not influenced by any economical powers. The availability of economical resources for universities seems to be creating this gap between development and sustainable development. Currently organizations such as UNESCO recognized the need for projects that protect the landscape from economical activities in Chile; however, this initiative must begin from the Chilean government in order to change the conditions to which the landscape is being exposed. The rising of technologies that allow researching areas of remote access are an advantage for conservation, however one big issue is the funding for making this research possible.

Image enhancing techniques such as CVA can be used to extract relevant information from certain habitats that can be combined with ground truth and aerial photography. There is a deep need for not only quantifying the natural resources but also opening the knowledge to the public which are eventually in charge of making policy changes. Without studies about the evolution of the landscape and appropriate information for people to be informed, the projections for the area of study in terms of productivity and preservation of the land point toward further degradation. Powerful multinational companies are operating in the area of study which is directly affecting the region not only economically in terms of the decrease of agriculture and cattle production, but ecologically as well. The most affected are the small a medium size

farmers who cannot continue to farm and compete with the prices of some imported products without the support of the Chilean government. The emigrational patterns continue to move people from rural areas to the cities. In addition, most of the people who stay in rural areas live under poverty conditions. 80% of the communities found to be in poverty conditions in the country correspond to rural areas. Finally, the area of study showed that serious changes occurred in the last 17 years in the country of Chile, which have to do with the lack of incentives to small and medium size farmers, the opening of the market for importing products from other countries and the intervention of our ecological and cultural patrimony by multi-national companies that look to increase their economical benefits.

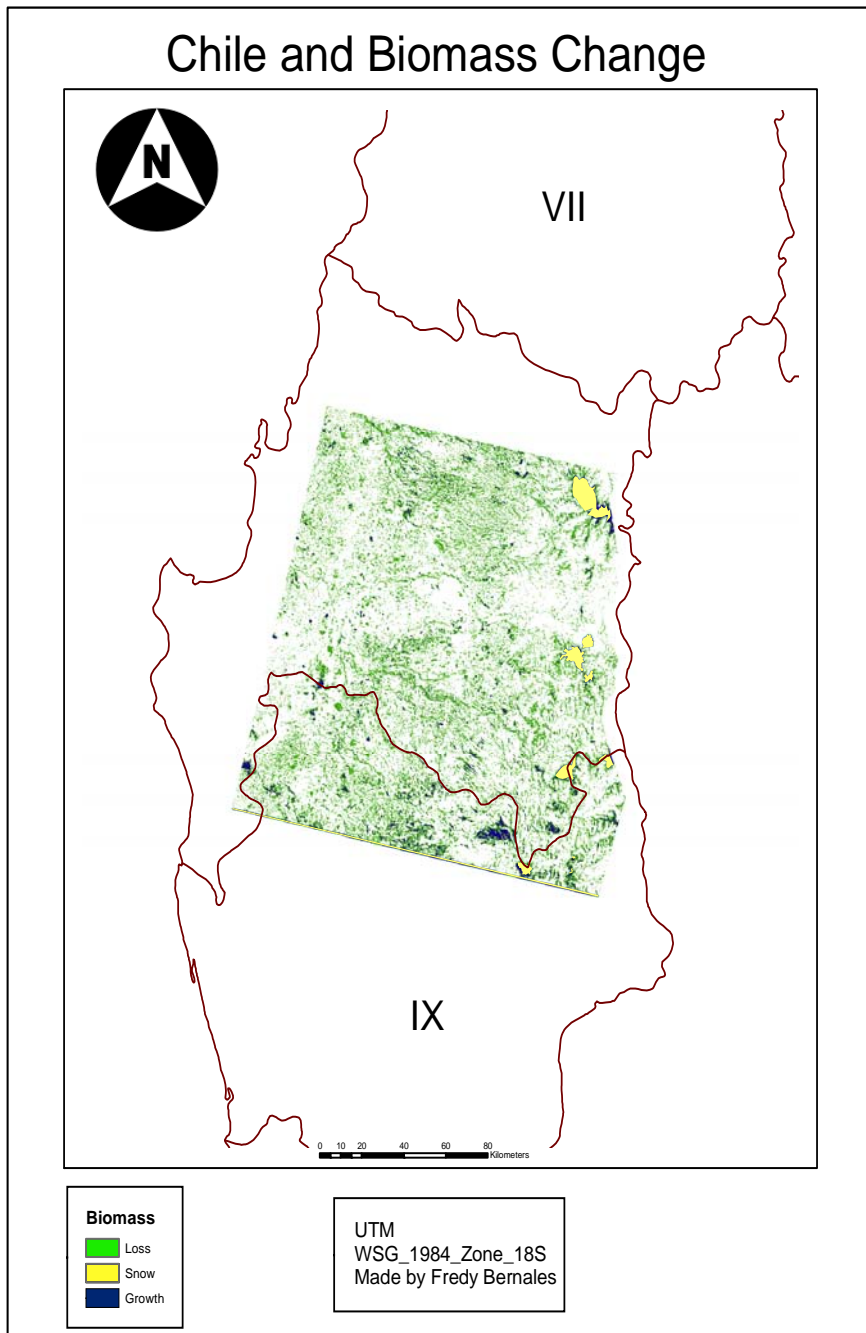


Figure 24. Area of study in the country of Chile



## LITERATURE CITED

- Achard F., Eva H., Glinni A., Mayaux P., Richards T., Stibig H.J., 1997, Identification of deforestation hot spot areas in the humid Tropics, TREES publ. series B, Research report no 4., EUR 18079 EN, European Commission, Luxembourg, 100 p.
- Bateson, C.A. and B. Curtiss, 1996, "A method for manual endmember selection and spectral unmixing", *RemoteSens. Environ.* 55:229-243.
- Byrne, G. F., Crapper, P. F., and Mayo, K. K. 1980. Monitoring landcover by principal components analysis of multitemporal Landsat data. *Remote Sensing of Environment*, 10, 175-184,.
- Chen, J. M., Liu, J., Leblanc, S. G., Lacaz, R., & Roujean, J. -L. 2003. Multi-angular optical remote sensing for assessing vegetation structure and carbon absorption. *Remote Sensing of Environment*, 84(4), 516–525.
- Conserving a Global Treasure. Chile's Frontier Forest. 2002. WRI, CODEFF and UACH, Washington DC.
- Chuvieco, E., and Salas, F.J. 1996. Mapping the spatial distribution of forest fire danger using GIS. *Int. J. Geogr. Inf. Syst.* 10: 333–345.
- Cooley, W.W. and Lohnes, P.R. *Multivariate Data Analysis*, 1971. John Wiley & Sons, Inc., New York.
- Coppin, P.R. and M.E. Bauer. 1996. Digital change detection in forest ecosystems with remotely sensed imagery. *Remote Sensing Reviews* 13:207-234.
- Eastman, J. R. and M. Fulk 1993. Long sequence time series evaluation using standardized principal components. *Photogrammetric Engineering and Remote Sensing*, 59(8):1307-1312.
- ERDAS Inc., 1999. ERDAS Imagine® Field Guide, ERDAS, Atlanta, pp. 217-260.

- Eckhardt, D. W., J. P. Verdin, and G. R. Lyford, 1990. Automated update of an irrigated lands GIS using SOPT HRV imagery. *Photogrammetric Engineering and Remote Sensing*, 56(11), pp. 1515-1522.
- Ecología Forestal, 1999. *El bosque y su medio ambiente*. Editorial Universitaria., Universidad Austral de Chile.
- Eldredge, Niles. 1998. *Life in the Balance: Humanity and the Biodiversity Crisis*. Princeton, N.J.: Princeton University Press.
- Elvigde, C. D. (1997): Mapping City Light With Nighttime Data From the DMSP Operational Linescan System, *Photogrammetric Engineering & Remote Sensing*, 63, 727-734.
- Farias F. 2003. Land cover change in a rural area of the forest-steppe ecotone of Andean Patagonia, Argentina: Utilizing LANDSAT data for the detection and analyzing the change. Lund University, Sweden.
- Hall, F. G., D. E. Strebel, J.E. Nickeson and S. J. Goetz, 1991. Radiometric rectification toward a common radiometric response among multitemporal, multisensor images. *Remote Sensing of Environment*, 35(1), pp. 11-27.
- Hobson, S. and J. Lubchenco, 1997. *Revelation and the environment, AD 95-1995*. Singapore; London, World Scientific. .
- INE. 2003. Censo 2002. Síntesis de resultados. Instituto Nacional de Estadísticas (Chile).
- INFOR. 2005. Estadísticas forestales 2004. Boletín Estadístico 101. Instituto Forestal. Santiago, Chile. 159 pp.
- Jensen, J. R. and D. L. Toll, 1982. Detecting Residential Land-Use Development at the Urban Fringe. *Photogrammetric Engineering and Remote Sensing*, 48(4):629-643.
- Jensen, J. R., 1983. Urban/suburban land use analysis. In. R. N. Colwell (Ed.), *Manual of Remote Sensing*, 2<sup>nd</sup> ed., American Society of Photogrammetry, Falls Church, VA, pp. 1571-1666.
- Jensen, J.R., 1996. *Introductory Image Processing: A Remote Sensing Perspective* (2nd ed.). Upper Saddle River: Prentice-Hall.
- Jolliffe, I.T., 2002. *Principal Component Analysis*, 2nd Ed., 487pp, Springer, New York.

- Kumar, L., Schmidt, K.S., Dury, S. and Skidmore, A.K., 2001. Imaging spectrometry and vegetation science. In: F.d.J. van de Meer, S.M (Editor), *Imaging Spectrometry. Basic principles and prospective applications*. Kluwer Academic Press, Dordrecht, pp. 111-155.
- Lillesand, T. and Kiefer, R., 1994. *Remote Sensing and Image Interpretation*. John Wiley and Sons, Inc., New York, p. 468.
- Lodwick, G.D., 1979. "Measuring Ecological Changes in Multitemporal Landsat Data Using Principal Components", *Proceedings, 13th International Symposium on Remote Sensing of Environment*, April 1979, Ann Arbor MI, pp. 1131-1141.
- Loveland, T. R., Zhu, Z., Ohlen, D. O., Brown, J. F., Reed, B. C. and Yang, L., 1999. An analysis of the IGBP global land-cover characterization process, *Photogrammetric Engineering and Remote Sensing*, 65, pp. 1021-1032.
- Markham, B. L.; Barker, J. L 1987. Radiometric properties of U.S. processed Landsat MSS data Data. *Remote Sensing of Environment*, v.22, p. 39-71.
- Mausel, P., Y. Wu, Y. Li, E. Moran, and E. Brondizio, 1993. Spectral Identification of Successional Stages Following Deforestation in the Amazon, *Geocarto International*, 4: 61-71.
- Meyer, W. B., B. L. Turner, et al. 1994. *Changes in land use and land cover: a global perspective*. Cambridge, Cambridge University Press.
- Michalek, J. L., T. W. Wagner, J. J. Luczkovich and R. W. Stoffle. 1993. Multispectral change vector analysis for monitoring coastal marine environments. *Photogramm. Eng. Remote Sensing* 59:381-384.
- Milward, A. and Piwowar, J. 2002. *Exploring Ordination as a method for normalization disparate datasets: implications for digital change detection*. University of Waterloo, Ontario.
- Mittermeier, R. A., N. Myers and C. G. Mittermeier. 2000. *Hotspots: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*. Chicago: University of Chicago Press.
- Moran, E.F., 1993. *Through Amazonian Eyes: The Human Ecology of Amazonian Populations*. University of Iowa Press.
- Myers, Norman et al, 2000. "Biodiversity hotspots for conservation priorities," *Nature*, Vol. 403, 24 February, pages 853-858.

- Nelson, R.F., 1983, Detecting Forest Canopy Change Due to Insect Activity Using Landsat MSS. *Photogrammetric Engineering and Remote Sensing*, 49:1303 - 1314.
- Nomikos, P. and MacGregor, J.F. 1994. Monitoring of Batch Processes using Multi-way Principal Component Analysis. *AIChE Journal*, 40 (8), pp. 1361-1375.
- Piwowar, Joseph M. and Ellsworth F. LeDrew, 1995. Hypertemporal Analysis of Remotely Sensed Sea-Ice Data for Climate Change Studies, *Progress in Physical Geography*, Vol. 19, No. 2, pp. 216-242.
- Piwowar, Joseph and Milward, A. 2002. Multitemporal Change Analysis of Multispectral Imagery Using Principal Component Analysis. *Geosciences and Remote Sensing Symposium*, Vol. 3, pp. 1851 -1853.
- Robert E. Crippen, 1990. Calculating the Vegetation Index Faster. *Remote Sensing of Environment*, 34:71–73.
- Schott, J. R., C. Salvaggio and W. J. Volchok, 1988. Radiometric scene normalization using pseudoinvariant features. *Remote Sensing of Environment*, 26(1), pp. 1-16.
- Segura M., Reinaldo y Trincado G., 2003. Cartografía digital de la Reserva Nacional Valdivia a partir de imágenes satelitales Landsat TM. *Bosque (Valdivia)*, vol.24, no.2, p.43-52.
- Showalter, P. S., W. R. Travis, et al. 1993. Natural hazard trends in the United States: a preliminary review for the 1990s. Boulder, Colo., Natural Hazards Research and Applications Information Center, Institute of Behavioral Science, University of Colorado.
- Singh, A., and A. Harrison. 1985. Standardized principal components. *Int. J. Remote Sens.* 6:883–896.
- Singh A., 1986, "Change detection in the tropical forest environment of northern India using Landsat. In *Remote Sensing and Land management*, edited by M. Eden and J. Parry, pp. 237-253.
- Singh, A., 1989, "Digital change detection techniques using remotely-sensed data", *International Journal of Remote Sensing*, 6: 989-1003.

- Sohl, Terry, 1999. Change Analysis in the United Arab Emirates: An Investigation of Techniques. *Photogrammetric Engineering & Remote Sensing*, 65 (4): 475-484.
- Stow, D. A., Burns, B. H., & Hope, A. S. 1993. Spectral, spatial and temporal characteristics of Arctic tundra reflectance. *International Journal of Remote Sensing*, 14, 2445–2462.
- Trisirisatayawong, I., Samchimchom W., 2003. Large Areas Change Detection by Differencing Radiometrically-Normalized Images. *Asian Association of Remote Sensing*.
- Tompkins, S., Mustard, J.F., Pieters, C.M. and Forthys, D.W., 1997, Optimization of endmembers for spectral mixture analysis. *Remote Sensing of Environment*, 59, pp. 472–489.
- Tso, B. and P. M. Mather, 2001. *Classification methods for remotely sensed data*. London; New York, Taylor & Francis.
- Tucker, C. J., 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, 8:127-150.
- Valenzuela, P. 1984. Contribución del sector forestal a la economía nacional. pp 188-199 En: *Actas XI Jornadas Forestales*. Concepción, Chile.
- Vitousek, P.M., Ehrlich, P.R., Ehrlich, A.H. and Matson, P.A., 1986. Human Appropriation of the Products of Photosynthesis. *BioScience* 36, 368-373.
- Vogelmann, J.E. and B.N. Rock, 1986. Assessing forest decline in coniferous forests of Vermont using NS-001 Thematic Mapper Simulator data. *International Journal of Remote Sensing*, 7:1303-1321.
- Warner, T., 2005. Hyperspherical direction cosine change vector analysis. *International journal of remote sensing*. Vol. 26, No. 6, 1201-1215.
- Weismiller, R. A., S. J. Kristof, D.K. Scholz, P.F., 1977. Anuta and S.A. Momin. Change Detection in Coastal Zone Environments. *Photogrammetric Engineering and Remote Sensing*. 43(12), 1533-1539.
- Wilkie, D. S. and J. T. Finn 1996. *Remote sensing imagery for natural resources monitoring: a guide for first-time users*. New York, Columbia University Press.
- Wilson, E. 1988. *Biodiversity*. National Academy Press, Washington, DC.

- Wylie, B.K.M., D.J.; Tieszen, L.L. & Mannel, S., 2002. Satellite mapping of surface biophysical parameters at the biome scale over the North American grasslands A case study. *Remote Sensing of Environment*, 79(2-3): 266-278.
- Yafit, C. and Shoshani, M.,2001. Study of Land Use Classification in Central West African tropical Forest. The Center of Tropical Research.
- Yang, X. J. and C. P. Lo, 2000. Relative radiometric normalization performance for change detection from multi-date satellite images. *Photogrammetric Engineering and Remote Sensing*, 66(8), pp. 967-980
- Yuan, D. and C. D. Elvidge, 1996. Comparison of relative radiometric normalization techniques. *ISPRS Journal of Photogrammetry and Remote Sensing*, 51(3), pp. 117-126.
- Thomas, M. and Lillesand R. 2000. *Remote Sensing and Image Interpretation*. University of Wisconsin, John and Wiley & Sons: New York.
- Zhang Q., Devers D., Desch A., Justice C., Townshend J., 2006. *Environmental Monitoring and Assessment*. Volume 101, Numbers 1-3.