THE USE OF OBJECT-BASED CLASSIFICATION

of

HIGH RESOLUTION PANCHROMATIC SATELLITE IMAGERY

FOR THE

INVENTORY OF SHELTERBELTS

IN THE

PROVINCE OF SASKATCHEWAN

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Joey Ryan Pankiw
Regina, Saskatchewan
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Joey Ryan Pankiw, candidate for the degree of Master of Science in Geography, has presented a thesis titled, *The Use of Object-Based Classification of High Resolution Panchromatic Satellite Imagery for the Inventory of Shelterbelts in the Province of Saskatchewan*, in an oral examination held on December 13, 2012. The following committee members have found the thesis acceptable in form and content, and that the candidate demonstrated satisfactory knowledge of the subject material.

External Examiner: *Dr. Xulin Guo, University of Saskatchewan*

Supervisor: Dr. Joseph Piwowar, Department of Geography

Committee Member: Dr. Mark Brigham, Department of Biology

Committee Member: Dr. David Sauchyn, Department of Geography

Committee Member: Dr. John Kort, Adjunct

Chair of Defense: Ddr. Malek Mouhoub, Department of Computer Science

*Participated via SKYPE*
Abstract

The Prairie Shelterbelt Program of Agriculture and Agri-Food Canada, has produced many benefits for farmers and the prairie landscape: reducing soil erosion, protecting crops, controlling snow drifting over highways/roads and providing wildlife habitat. Due to growing concerns about rising levels of carbon dioxide in the atmosphere, the ability of shelterbelts to sequester carbon dioxide may also be of importance. Although the Prairie Shelterbelt Program has been distributing tree and shrub seedlings for more than 100 years, and records of the numbers of trees shipped have been kept, an inventory of the number of trees that have been successfully planted and their locations on the landscape does not exist.

When observed on Spot- 2.5 m. panchromatic satellite imagery, shelterbelts have distinct shapes, textures, and spatial relationships with other objects within the landscape. Object-based image classification methods are well suited to segmenting remotely sensed imagery based on these characteristics and have the potential to be used for delineating shelterbelts. In this thesis, Definiens object-based image classification software is shown to be an effective way to create a provincial-scale shelterbelt inventory.

The primary objective of this research was to develop a process by which the spatial coverage of shelterbelts in the Province of Saskatchewan could be determined to facilitate the estimation of the amount of carbon being sequestered. The results show that due to the large diversity of agro-
environmental conditions across the province, and seasonal and contrast inconsistencies of the panchromatic satellite data used, this was not possible. Nonetheless, the results show that object-oriented classification methods have the potential to detect the location of shelterbelts with an accuracy of over 80%. It is also possible to obtain a reasonable estimate of carbon sequestration. Future shelterbelt inventories should focus on the enhanced data potential found in high-resolution colour-infrared imagery.
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Dedication

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CHAPTER 1 - Introduction

Shelterbelts have been planted on the Canadian Prairies for over 100 years and have become a vital part of the prairie landscape (Wiseman et al., 2007). Shelterbelts are vegetation barriers used to mitigate the effects of wind in agricultural areas. Shelterbelts are composed primarily of either trees or shrubs, although some contain other perennials, annual crops, grasses, fences and other materials (Brandle et al., 2004). Shelterbelts act as protection for cropped land against soil erosion (Brandle et al., 2004). In recent years, it has been noted that shelterbelts provide other benefits, such as improving air quality, providing habitat for wildlife, and removing carbon dioxide from the atmosphere (Kulshreshtha and Kort, 2009).

Agriculture and Agri-Food Canada (AAFC) has operated a shelterbelt tree nursery in Indian Head, Saskatchewan for over 100 years. Each year, the nursery distributes seedlings to agricultural producers across the Prairies. While the AAFC Agroforestry Development Centre has records of the numbers of trees shipped and their destination, they have no data on where the seedlings were actually planted (if at all). As a result, it is not known how many shelterbelts exist on the Canadian Prairies. An accurate inventory of the shelterbelt stock is important, not only to assess the success of the program, but also to estimate the amount of atmospheric carbon that is being sequestered by these trees.

Rising levels of atmospheric greenhouse gases (GHG) - such as carbon dioxide - have prompted governments to take action. Increased GHG levels are predicted to contribute to climate change, thereby threatening many of Canada’s natural ecosystems.
(Environment Canada, 2006). A reduction of atmospheric GHG can be achieved by sequestering GHG into another medium, such as plant biomass (Meyer and Tyrchniewicz, 1996). Thus, increasing the land area planted as shelterbelts has the potential to reduce the amount of carbon in the atmosphere. The use of shelterbelts for the purpose of sequestering carbon has been a focus of much research (Schoeneberger, 2008; Kort and Turnock 1999; Brandel et al., 1992; Meyer and Tyrchniewicz, 1996) and necessitates an inventory of the existing shelterbelt area across the Prairies.

One means to determine how many shelterbelts exist is to complete a ground survey. This process is impractical, however, due to the time and resources that would be needed to complete such an inventory over the 26 million ha of agricultural area of Saskatchewan. Remote sensing systems, with their synoptic perspective and repetitive coverage, have the potential to capture images of the entire province in an efficient manner. When coupled with new image analysis techniques, such as object-based classification methods, remote sensing has the potential to be the most economical and timely way to document shelterbelts over wide areas (Wiseman et al., 2007; Dulin, 2010).

Object-based image classification is a new paradigm in remote sensing image processing. Traditionally, per-pixel classifications based on spectral data have been the dominant method for image feature identification. Object-based classification differs from this approach by examining the spatial characteristics of features. While pixel-based classification segments an image by comparing the spectral values of each individual pixel to a known area of pixels in the image, object-based image classification
makes inferences about objects by evaluating them in the context of surrounding objects (Definiens, 2007).

1.1 Purpose and Objectives

The main purpose of this research was to develop a means to identify shelterbelts in the province of Saskatchewan using object-based classification of high resolution panchromatic remote sensing imagery. This study was driven by three primary research questions:

1) What is the potential of using high-resolution panchromatic satellite imagery and object-based classification methods to identify shelterbelts?

2) How do different factors within each image, such as acquisition time and contrast enhancement, affect the identification of shelterbelts?

3) Is it possible to estimate the amount of atmospheric carbon that is sequestered by shelterbelts in Saskatchewan?
CHAPTER 2 – Literature Review

This section has three objectives. First, the history, design and utility of shelterbelts is provided (2.1). Second, carbon sequestration as a process for greenhouse gas reduction is discussed, and the use of plants and shelterbelts for carbon sequestration is assessed (2.2). Third, after a review of remote sensing and previous classification techniques for shelterbelts, the object-based classification method is discussed (2.3).

2.1 Shelterbelts

Shelterbelts are vegetative barriers used to mitigate the effects of wind in grassland agricultural areas. Shelterbelts are composed primarily of trees or shrubs although some contain other perennials, annual crops, grasses, fences and other materials (Brandle et al., 2004). They are planted in rows, generally oriented perpendicular to the prevailing wind direction. Traditionally, shelterbelts have been used to reduce soil erosion; protect homes, crops, and livestock; control blowing snow over roads and highways; and provide wildlife habitat (Wiseman et al., 2007).

2.1.1 Shelterbelt Planting on the Canadian Prairies

In 15th century Scotland, the Scottish Parliament encouraged the planting of shelterbelts as a means of reducing soil erosion on agricultural lands (Brandle et al., 2004). The planting of shelterbelts on the North American Prairies started when settlers came to the realization that trees were needed to protect their homes and livestock against the strong winds on the open plains. Early settlers in Manitoba attempted to
transplant seedlings from riverbanks - which only benefited those near riverbanks - while others imported trees and shrubs from Eastern Canada and the United States.

Imported and transplanted seedlings were often unsuccessful because there was a lack of hardiness in the planting stock or they were not cared for properly (Dick, 1996). To improve the success rate the Canadian government opened several experimental farms to study plant hardiness and appropriate handling techniques. Two of the biggest farms were established in 1888 in Brandon, Manitoba and Indian Head, Northwest Territories (now Saskatchewan) (Howe, 1986). In 1902 the Indian Head experimental farm was selected as the permanent nursery and from 1906 to 1912 all tree production for the Prairie Provinces was based there. The first Superintendent of the Tree Nursery (now known as the Agroforestry Development Centre), Norman M. Ross, would see the nursery expand by 146 hectares (eventually to grow by another 65 hectares) and become a major centre for prairie shelterbelt research (Massie and Smith, 2006). In 1912 a second nursery was created in Sutherland, Saskatchewan which operated until 1966.

Between 1901 and 1935 the two federal nurseries distributed and supervised the planting of 145 million trees by more than 100,000 farmers (Dick, 1996). The federal government's vision of the tree nurseries and the tree planting programs mandated that seedlings were grown in large quantities and distributed to farmers at no cost. Due to a growing demand for trees in the 1940s, the Province of Alberta started its own nursery at Oliver in 1950 and provided seedlings exclusively to Alberta farmers (Howe 1986). The Oliver nursery was recently closed.
During the first period of shelterbelt planting on the prairies (1892 to 1930) nearly all trees were planted for protection around farmyards. In 1931, however, a devastating drought resulted in extensive soil drifting. To help farmers cope with the widespread drought, the Canadian government created the Prairie Farm Rehabilitation Administration (PFRA) in 1935 with the objective of securing "the rehabilitation of drought and soil drifting areas in the provinces of Manitoba, Saskatchewan and Alberta and to develop and promote within these areas systems of farm practices, tree culture, water supply, land use and land settlement that will afford greater economic security" (Howe, 1986). Management of the Indian Head and Sutherland nurseries was delegated to the PFRA. The focus of the tree production shifted away from farmyard shelterbelts and more effort was placed into developing species that could be planted along field boundaries to assist in the reduction of soil erosion.

Local initiatives were also encouraged. For example, the Conquest Field Shelterbelt Association planted 2,483 km of field shelterbelts between 1935 and 1964 in Conquest, with other associations established in Aneroid, Lyleton and Porter Lake (Howe, 1986). Many of these shelterbelts still exist.

To date the AAFC Agroforestry Developement Centre has distributed over 600 million trees to farmers across the Prairie Provinces. In recent years the Centre ships about four million seedlings to approximately 7000 farmers annually (Agriculture and Agri-food Canada, 2008). The 2006 Census of Agriculture reported that 18,104 farms in Saskatchewan were using shelterbelts for soil conservation (Statistics Canada, 2006). The PFRA Prairie Shelterbelt Program has transformed the prairie landscape from a
virtually treeless are to one where trees are used as tools in the management of the prairie environment (Howe, 1986).

2.1.2 Shelterbelt Design

Properly designed shelterbelts can enhance the vitality of the surrounding land. For example, they influence the microclimate by affecting solar radiation, air temperature, soil temperature, frost occurrence, precipitation (through the distribution of snow), humidity and evaporation (McNaughton, 1988; Brandle, et al., 2004). Shelterbelt effectiveness can be maximized through proper design of its internal and external structure (Brandle et al., 2004). Internal structure includes the amount and distribution of the solid and open portions, the vegetative surface area, and the shape of individual plant elements. External structure includes factors like height, length, orientation, continuity, width, and cross-section shape (Brandle et al., 2004).

External structures are the most important for providing wind protection, with height being the most important factor. Ground areas can be protected by two to five times the height of a shelterbelt on its windward side and 10 to 30 times the height on its leeward side (Wang and Takle, 1995). The length of a shelterbelt should be a minimum of ten times the height and should be oriented perpendicular to the prevailing winds (Brandle et al., 2004). Gaps and openings should be kept to a minimum, as wind speed actually increases when funneled through gaps. The width of the shelterbelt, which is achieved by the number of rows planted, contributes to effectiveness by increasing the density (Heisler and DeWalle, 1988).
The Agroforestry Development Centre recommends shelterbelt designs for farmyards, fields, roadsides and for livestock yards in the Prairies. The Centre recommends that farmyard shelterbelts be located at least 30 metres from any buildings or structures and be five rows wide. The five rows should be comprised of an outer row of shrubs, two rows of tall decidous trees and two inner rows of coniferous trees, to allow for proper snow collection in the winter (Agroforestry Development Centre, 2010). Field shelterbelts should be at least 200 m apart while roadside shelterbelts should be located 45 m away from any roads and 90 m away from main highways. Livestock shelterbelts should be 40 to 60 m away from the livestock area and be composed of three to six rows, composed of shrubs and tall decidous and coniferous trees (Agroforestry Development Centre, 2010).

2.1.3 Economic Benefits

The environmental changes created by well-designed shelterbelts contribute to the success of the economic and social fabric of the Prairie landscape. For example, in a study on the economic benefits of shelterbelts, Kulshreshtha and Kort (2009) proposed that they reduced soil erosion, improved air and water quality, reduced GHG emissions, enhanced energy conservation, and had aesthetic value. They estimated the soil benefits of shelterbelts was valued at $14.8 million, principally through the reduction of erosion. Since every kilometre of shelterbelt protects an area of about 26 hectares (Kort, 1988), the soil stabilization effect of shelterbelts produce additional off-site benefits, such as improving air and water quality and promoting shoreline stabilization (Dickson and Fox, 1989). Kulshreshtha and Kort (2009) reported that shelterbelts provide buffers which slow, or disperse, the flow of water which aids in
reducing water-borne toxins. They estimated the improved water quality to be worth $1.21 million, or about $40 per household that had shelterbelts (Kulshreshtha and Kort, 2009).

Another benefit of shelterbelts is their ability to sequester carbon, contributing to a general reduction of greenhouse gas (GHG) concentrations. Kort and Turnock (1999) estimated that 8.46 megatonnes of carbon were stored in shelterbelts planted between 1981 and 2001. Further, since cultivated land typically releases more carbon into the atmosphere than is captured over the same area, shelterbelts reduce GHG emissions by replacing land under cultivation with trees.

Shelterbelts protect and enhance biodiversity by providing habitat for soil organisms, plants, arthropods, birds, mammals, and other fauna, with an economic benefit calculated to be $4.72 million (Kulshreshtha and Kort, 2009). Shelterbelts also provide economic benefits from consumptive (hunting) and non–consumptive (bird-watching) wildlife practices with a total value of $42.8 million (Havengaard, et al., 1989; Kulshreshtha and Kort, 2009).

Shelterbelts may also reduce GHG emissions by lowering energy use in nearby buildings (DeWalle and Heisler, 1988; Moyer, 1990). Other unquantifiable benefits include odour reduction, reduced pesticide drift, improved aesthetics and property values, and improved transportation safety through a reduction in drifting snow (Kulshreshtha and Kort, 2009).
In sum, the economic benefits of shelterbelts were estimated to be $140 million, this number is based on the number of tree seedlings distributed between 1981 and 2001 (Kulshreshtha and Kort, 2009).

2.2 Carbon Sequestration

As indicated above, shelterbelts play an important role in reducing greenhouse gas emissions by sequestering atmospheric carbon.

2.2.1 Global Concerns

Rising levels of atmospheric GHGs have prompted governments around the world to take action. At the 1992 Earth Summit in Brazil, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted. Its objective was to develop ways to reduce GHG emissions. Although the original goal of reducing GHG levels to 1990s levels by the year 2000 was not met, it did force countries to track and address their own GHG levels.

As a result of the UNFCCC, Canada created a national communication, Canada’s National Report on Climate Change (1993), to enhance the understanding of changing climatic conditions and to develop ways to mitigate and respond to these changes (Environment Canada, 2006). Since 1993, there have been three other National Reports (1997, 2001, and 2006). These reports have provided updates on GHG emission levels but also suggest policy changes to reduce these levels in Canada.

A follow-up meeting to the Brazil Earth Summit was held in 1997 in Kyoto where a protocol was established that set GHG emissions targets for industrialized countries to be between -8% and -10% of their 1990 emissions levels (Environment Canada, 2006).
The Kyoto Protocol was signed by Canada in April 1998 and ratified by the Government of Canada in December 2002 and established a goal to reduce national GHG emissions to 6% below 1990 levels during the period of 2008 to 2012 (Environment Canada, 2006).

2.2.2 Reducing Carbon Emissions

The ability to control rising carbon dioxide (CO$_2$) levels due to emissions can be done in three ways. First, is to replace high carbon-emitting energy sources with lower carbon-emitting sources. Some initiatives include replacing coal- and oil-fired power generation with natural gas, replacing all these fossil fuels with biomass fuels (such as wood or ethanol), and using lower emitting natural energy sources such as solar, wind, geothermal, tidal, and hydro in place of fossil fuels.

Second, CO$_2$ emissions can be lowered by reducing activities that cause emissions. Reduced and responsible vehicle use, greater use of public transportation, and switching to more energy-efficient cars and home building materials all qualify as reduction activities (Meyer and Tyrchniewicz, 1996).

A third way of controlling rising CO$_2$ levels is by removing it from the atmosphere and sequestering it into other media, such as oceans, soil, and the tissues of trees and plants (Meyer and Tyrchniewicz, 1996). Thus, the more shelterbelts there are, the greater the amount of captured atmospheric carbon. Shelterbelts can also reduce GHGs through the creation of biomass fuels from the wood produced by them. Additionally, plantings around farmyards protect buildings from winds in the winter,
thereby reducing heating energy use, and provide shade in the summer, thereby reducing the energy used to cool buildings (Kulshreshtha and Kort, 2009).

2.2.2 Carbon Sequestration in Plants

Carbon sequestration is the process in which plants take carbon from the atmosphere during the process of photosynthesis. New plant tissue is formed from the carbohydrates produced during photosynthesis. During this process, carbon is fixed and accumulates as organic carbon within plant tissues. The amount of atmospheric carbon used is regulated by plant growth. Absorption of CO$_2$ continues as long as the plant continues to respire (Meyer and Tyrchniewicz, 1996).

As long as the rate of plant growth exceeds decomposition there will be a net gain of carbon sequestered. When a plant dies, its residues, roots and exudates are further broken down by microbes. As a result, a portion of the organic carbon is released back to the atmosphere by respiration as CO$_2$, while an other portion becomes fixed within the soil in the form of organic matter. Organic matter within the soil decomposes slowly, making it a reservoir for carbon originally captured by plants (Meyer and Tyrchniewicz, 1996).

The ability of soil to hold carbon is dependent on microbial activity, temperature, moisture, and soil disturbances. Soil disturbances result from agricultural activities (e.g., field tilling), the clearing of forests, and fires (Meyer and Tyrchniewicz, 1996).
2.2.3 Carbon Sequestration in Shelterbelts

Agroforestry is "the working tree practices that are intentionally planted and managed in rural and urban landscapes" (Schoeneberger, 2009). The potential of trees for sequestering atmospheric carbon cannot be overstated. Sedjo (1989) estimated that if 465 million hectares of new forests were planted worldwide, 2.9 billion tonnes of carbon could be removed from the atmosphere. Consequently, increasing the land area planted as shelterbelts is potentially an effective way of mitigating carbon emissions. Agroforestry represents a larger net gain of carbon per unit land area than other activities such as no-till soil management, and it does not interfere with any other agricultural activity (Schoeneberger, 2009).

Kort and Turnock (1999) estimated the amount of carbon that could be removed from the atmosphere in Canadian Prairie shelterbelts by combining an estimate of the carbon storage potential each tree species produced by the Prairie Shelterbelt Program with the number of trees distributed on an annual basis. They concluded that a shelterbelt program that planted six million trees a year could sequester 0.4 million tonnes of carbon (Kort and Turnock, 1999).

In the 2006 Canada National Reports on Climate Change a Shelterbelt Enhancement Program (SEP) was noted as a means to reduce GHG (Environment Canada, 2006). The goal of this program was to create 8,000 linear km of new tree and shrub plantings, consisting of riparian, field, and farmyard shelterbelts on agricultural lands in the Prairie region. By March 2005, the program had created 2,895 linear km of shelterbelts at a cost of four million dollars (Environment Canada, 2006). With over 61
million hectares of agricultural land available, the Prairies represent a prime location in
Canada to plant trees with the goal of reducing carbon emissions (Agriculture and Agri-
Food Canada 2010).

2.3 Object-based Classification

When observed on high resolution satellite imagery, shelterbelts have distinct
shapes, textures, and spatial relationships with other objects within the landscape. Object-based image classification methods are well suited to segmenting remotely sensed imagery based on these characteristics and have the potential to be used for delineating shelterbelts. This section describes remote sensing (2.3.1) and object-based classification (2.3.2). It presents an overview of previous shelterbelt classifications (2.3.3) and thus leads to an understanding of how object-based classification methodology could be applied to the management of shelterbelts and the promotion of greenhouse gas reduction.

2.3.1 Remote Sensing/Scale

Remote sensing can be defined as the gathering of information from a distance. More formally, remote sensing according to (Campbell, 2007) is:

“the practice of deriving information about the Earth’s land and water surfaces using images acquired from an overhead perspective, by employing electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth’s surface.” (pg.6)

Remote sensing provides a means to look at landscapes at different scales and, as a result, allows users to view different geographic occurrences from a variety of scales. Remote sensing has been extensively used for the monitoring and management of natural and constructed resources globally (Campbell, 2007).
Remote sensing techniques have been used for over 150 years, beginning with the invention of photography in 1839 by Louis Daguerre. Remote sensing began in earnest with the attachment of a camera to a tethered hot air balloon in 1858. The invention of the airplane by the Wright brothers in 1907 and the outbreak of World War I lead to rapid advancements in methods (Campbell, 2007). The term remote sensing was first used in the 1960s to describe images being collected outside the visible spectrum (Campbell, 2007). The launch of the first Landsat satellite in 1972 allowed, for the first time, the systematic and repetitive observation of the Earth’s surface (Hathout, 2005). This was supported by the emergence of the computer in the 1960s and 1970s that enabled the digital analysis of images and the proliferation of much more data about the surface of the Earth (Hathout, 2005). The advancement of sensor technology to collect data at higher spatial and spectral resolutions has increased our knowledge of the Earth and our ability to manage the resources on, above, and below its surface (Campbell, 2007).

Due to the spatial nature of any geographic study, consideration of scale is necessarily a priority in the development of theory and methods. The ability to understand how observations of an object or phenomenon are affected by scale allows the researcher to place their results in context. This importance can be seen in the number of published works in recent years dealing with the problems associated with scale (e.g., Cox, 1998; Jonas, 2006; Marston et al., 2005; Swyngedouw, 1997). Scale also plays a crucial role in the understanding of remote sensing imagery, since these data may be acquired at multiple scales (Benz et al., 2004).
Development of new remote sensing instruments with higher spatial resolutions allow finer details to be distilled. Still, this increase in scale has not resulted in a concomitant increase in classification accuracy when traditional pixel based classification processes are used (Marceau and Hay, 1999).

The selection of a proper scale is necessary to achieve the best possible classification results. The appropriate scale is determined by the objectives of the research. Low spatial resolution imagery is best applied to large area problems, such as the land classification of a whole region. Conversely, high resolution imagery is needed to address local issues, such as classification of shelterbelts.

By design, object-based image classification software addresses the problem of appropriate scale selection for analysis. Such software allows the user to process the data at multiple scales simultaneously thereby drawing conclusions despite different resolutions (Benz et al., 2004). Additionally, this type of classification promotes awareness of the subject being studied. As a result, the researcher’s recognition of the subject in the image becomes greater at different resolutions, and allows for improved classification.

2.3.2 Object-based Classification

Object-based image classification is a new paradigm in classification methodology, although the concept has been around since the 1970s. Due to a lack of computing power in the past, the method has only come into widespread use in the past decade (Rutherford and Rapoza, 2008; Benz, et al., 2004). Further, the increased
spatial resolution of new remote sensing images has enabled the broader application of object-based classification (Blaschke et al., 2004).

Object-based classification differs from traditional pixel-based classification by examining the spatial characteristics of features rather than their spectral properties. While pixel-based classification segments an image by comparing the spectral values of each individual pixel to a known area of pixels in the image, object-based image classification makes inferences about objects by evaluating them in the context of surrounding objects (Definiens, 2007; Benz et al., 2004).

Expert knowledge is the basis for feature identification during object-based classification. Users apply their knowledge of the objects that need to be classified to derive the parameters related to those objects (Rutherford and Rapoza, 2008). This differs from pixel-based approaches where limited knowledge is incorporated into the classification because it is based primarily on spectral values.

Rutherford and Rapoza (2008) and Oruc et al. (2004) both compared the accuracy of the object-oriented approach to pixel-oriented methods for land use/land cover classifications. They found that object-oriented classification produced greater accuracy than that of pixel-based classification. For example, the overall accuracy of an object-oriented classification of land cover in Zonguldak, Turkey was 81.3%, while the most accurate pixel-based classification, using the maximum likelihood algorithm, produced an accuracy of 66.8% (Oruc et al., 2004). Other land use/cover classification comparisons conducted by Rutherford and Rapoza (2008) in a rural area northwest of Baltimore and Washington, D.C., produced similar results.
2.3.2.1 Segmentation

Object-oriented classifications are applied in two stages: segmentation and classification. Segmentation is the process of subdividing an image, which is represented as discrete pixels, into image-objects and is generally considered the most important step. Image-objects can be defined as;

“Basic entities, located within an image that are perceptually generated from high resolution pixel groups, where each pixel group is composed of similar digital values, and possesses an intrinsic size, shape, and geographic relationship with the real-world scene component it models.” (Hay et al., 2001, pg 475)

Segmentation parameters must be set to match the size and shape of the objects that are to be classified in the image. Establishing proper segmentation parameters is done by testing several different parameter values to visually determine which parameters best fit the objects to be classified (Rutherford and Rapoza, 2008). Dulin (2009) reported that this approach “introduces some subjectivity into the segmentation process but little has been done to generalize segmentation parameters in the interest of isolating any given set of features” (pg. 15). There is a trade-off between setting the parameters too high, resulting in large polygons that incorporate other areas and objects that are not to be classified. While setting the parameters too low will split objects into many sub-objects that may not be representative of the larger whole and thereby become more difficult to classify (Definiens, 2008).

There are three approaches to segmentation: pixel-, edge-, and region-based methods. Pixel-based methods require image thresholding and segmentation in feature space. Since these results do not fulfil the true requirement and definition of object-oriented segmentation their outputs must be clumped (Blaschke et al., 2004). Edge-
based segmentation attempts to find edges between different regions of the image and determines the segments as regions based on the changes in values that create an edge. Lastly, the region-based segmentation approach divides the image into sub-regions and these sub-regions are merged to create larger regions. Region-based segmentation can also be applied in reverse by taking larger regions and further breaking them down to meet certain homogeneity criteria (Blaschke et al., 2004).

2.3.2.2 Classification

Classification is the second stage of the object-oriented procedure and is closely related to image texture. With the increased availability of high resolution remote sensing imagery, texture analysis has become more significant in land use/cover classification (Narashimha Rao, et al., 2002). Texture analysis is concerned with the spatial distribution of tonal variations within an image (Haralick, et al., 1973). Haralick et al. (1973) and Haralick (1979) pioneered the use of texture as a classification feature by developing the grey level co-occurrence matrix (GLCM) which,

"is an \( n \times n \) matrix containing the relative frequencies with which two pixels linked by a spatial relation (displaced vector) occur on a local domain (often a sliding window) of the image, one with grey level \( i \) and the other with grey level \( j \), with \( i, j \in [0 \ldots n-1] \), where \( n \) is the number of the grey level with which the image has been digitized." (Pesaresi, 2000 pg. 44-45)

The GLCM has become one of the most used approaches for texture analysis (Pesaresi, 2000).

Land cover classification using panchromatic and high resolution imagery has become increasingly more dependent on texture analysis for classification. Several
studies have analyzed the impact of texture on land cover classification, especially using GLCM (Guangrong and Apostolos, 2008; Pesaresi, 2000; Zhang et al., 2003; Narashimha Rao, et al., 2002). Pesaresi (2000) used a panchromatic image from the IRS-IC Indian satellite of Athens, Greece to determine how classification accuracy was affected by texture, in terms of land cover/use classification. Pesaresi was able to increase classification accuracy to more than 98% by using a combination of different textural features, including homogeneity and contrast.

In this study, texture analysis was applied to differentiate between shelterbelts and the surrounding landscape.

2.3.3 Previous Shelterbelt Classifications

Object-oriented image classification methods are viable solutions to the problem of inventorying shelterbelts across the Prairies, where manual surveys are impractical (Wiseman et al., 2007; Pankiw et al., 2009; Dulin, 2009). Wiseman et al. (2007) used object-based shelterbelt classification of high resolution aerial photography of the rural municipality of North Cypress, Manitoba. He found that 96.3% of shelterbelts identified on the ground could be identified using high resolution aerial photos. However, this approach may not be practical for provincial-scale surveys because acquiring aerial photos for an expansive area could be prohibitively expensive and the processing time would still be high.

The use of higher resolution satellite imagery has the potential to allow larger areas to be covered more quickly. For example, Pankiw et al. (2008) classified the shelterbelts near the town of Biggar, Saskatchewan using an object-oriented
classification of 2.5 m panchromatic imagery acquired by the SPOT satellite. Although the results were not as accurate as Wiseman et al. (2007) analysis (largely because of the absence of spectral information in the satellite imagery that was available in the aerial photography), Pankiw et al. (2008) were able to extend the previous analysis by separating the shelterbelts into three types: field, farmyard and roadside. Shelterbelt classification in that study was only done with spatial features.

Research on shelterbelt classification using object-based methods is not limited to the Canadian Prairies. Dulin (2009) used an object-based classification of air photos to identify shelterbelt locations in Kansas, to assess their condition (good, fair, poor), and to determine whether they were located on highly erodible or impaired soils. When comparing region-based with edge-based segmentation, Dulin (2009) found that the edge-based segmentation was more accurate although there was considerable confusion between windbreaks/shelterbelts and riparian areas, ditches, and some croplands remained. It was also noted that the boundaries of the shelterbelts were not consistent with the actual boundaries found on the ground, and that most shelterbelts were not completely classified. Snags and gaps in the shelterbelt rows and poor growing conditions were identified as complicating factors. Although there were problems, Dulin (2009) concluded that the object-based classification methods were far superior to manual digitizing.

2.4 Conclusions

Agriculture and Agri-Food Canada, through the PFRA and the Prairie Shelterbelt Center, now the Agroforestry Development Centre, have been at the forefront of conservation practices in the Prairie Provinces for over 100 years. Since early in its
existance, soil conservation has been one of the main goals of PFRA. Reducing atmospheric carbon levels fits with this objective.

The first step in the appraisal of carbon sequestration on the Prairies is an inventory of how many/large shelterbelts currently exist. Creation of such an inventory of shelterbelts would be best done by an efficient assessment method, and object-based classification of high-resolution satellite imagery would potentially achieve this goal. The use of object-based image classification is a successful way to classify land cover over a wide spectrum of applications. This approach has also been viewed as highly effective in the field of shelterbelt classification (Wiseman et al., 2007; Dulin 2009). The effectiveness of the object-based approach comes from the use of spatial features which can be identified from the design characteristics of both field and farmyard shelterbelts. Although previous studies have found object-based classification approaches to be successful for small areas, the method has not been tested at regional scales, where there is considerable inherent environmental variation.
Statistics Canada divides Saskatchewan's agricultural zone into twenty different Agricultural Census regions based on soil types, climate, and agriculture uses (Fig. 3-1). To capture the diversity of agro-environmental conditions found across the province, one township was selected from each of these regions for detailed analysis (Fig. 3-2). Because shelterbelts are found in rural areas, locations that included large urban developments were not used. As defined by the Dominion Land Survey, a township is a (nominal) 6 mile by 6 mile (9.66 km by 9.66 km) area of land which was further subdivided into 36 one mile by one mile (1.61 km by 1.61 km) sections (McKercher, 2006).

![Figure 3-1 Agricultural regions of Saskatchewan (Statistics Canada, 2001)]
Selecting one study site from each region provided a cross section of the different climatic conditions, soil types, land uses, agricultural regions and shelterbelt applications found throughout the province (Tab. 3-1). Each of these different factors
likely contributes to different shelterbelt growing conditions, resulting in differing appearance from image to image. This chapter describes the land use/land cover considerations (3.1), soils (3.2), landscape (3.3) and climate (3.4) of the study regions.

Table 3-1: Site Locations, agricultural region, ecoregion, soils, mean annual precipitation, surface geology.

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>Agricultural Census Region</th>
<th>Agricultural Region(^1)</th>
<th>Ecoregions(^2)</th>
<th>Soils</th>
<th>Mean annual Precipitation (mm.)</th>
<th>Surface Geology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>T. 1 R. 32 W 1(^{st}) M</td>
<td>1A</td>
<td>MF</td>
<td>AP/MMG</td>
<td>Black</td>
<td>425-450</td>
<td>Moraine</td>
</tr>
<tr>
<td>Site B</td>
<td>T. 16 R. 32 W 1(^{st}) M</td>
<td>1B</td>
<td>MF/WF</td>
<td>AP</td>
<td>Black</td>
<td>425-450</td>
<td>Moraine</td>
</tr>
<tr>
<td>Site C</td>
<td>T. 11 R. 17 W 2(^{nd}) M</td>
<td>2A</td>
<td>GOS/MF</td>
<td>MMG</td>
<td>Dark Brown</td>
<td>400-425</td>
<td>Glaciolacustrine</td>
</tr>
<tr>
<td>Site D</td>
<td>T. 20 R. 16 W 2(^{nd}) M</td>
<td>2B</td>
<td>GOS/WF</td>
<td>AP/MMG</td>
<td>Black</td>
<td>400-425</td>
<td>Moraine/ Glaciolacustrine</td>
</tr>
<tr>
<td>Site E</td>
<td>T. 4 R. 28 W 2(^{nd}) M</td>
<td>3AN</td>
<td>WF/BC</td>
<td>MG</td>
<td>Brown</td>
<td>400-425</td>
<td>Moraine</td>
</tr>
<tr>
<td>Site F</td>
<td>T. 1 R. 2 W 3(^{rd}) M</td>
<td>3AS</td>
<td>GOS/WM</td>
<td>MG</td>
<td>Brown</td>
<td>375-400</td>
<td>Moraine</td>
</tr>
<tr>
<td>Site G</td>
<td>T. 17 R. 14 W 3(^{rd}) M</td>
<td>3BN</td>
<td>WF/BC</td>
<td>MG</td>
<td>Brown</td>
<td>325-350</td>
<td>Moraine/ Glaciofluvial</td>
</tr>
<tr>
<td>Site H</td>
<td>T. 2 R. 18 W 3(^{rd}) M</td>
<td>3BS</td>
<td>WF/BC</td>
<td>MG</td>
<td>Brown</td>
<td>325-350</td>
<td>Moraine</td>
</tr>
<tr>
<td>Site I</td>
<td>T. 12 R. 25 W 3(^{rd}) M</td>
<td>4A</td>
<td>BC/MF</td>
<td>MG/CU</td>
<td>Brown</td>
<td>375-400</td>
<td>Glaciofluvial/ Eolian</td>
</tr>
<tr>
<td>Site J</td>
<td>T. 22 R. 22 W 3(^{rd}) M</td>
<td>4B</td>
<td>WF/BC</td>
<td>MG</td>
<td>Brown</td>
<td>325-350</td>
<td>Glaciolacustrine</td>
</tr>
<tr>
<td>Site K</td>
<td>T. 25 R. 7 W 2(^{nd}) M</td>
<td>5A</td>
<td>GOS/WM</td>
<td>AP/BC</td>
<td>Grey</td>
<td>475-500</td>
<td>Glaciofluvial/ Glaciolacustrine</td>
</tr>
<tr>
<td>Site L</td>
<td>T. 33 R. 3 W 2(^{nd}) M</td>
<td>5B</td>
<td>GOS/WM</td>
<td>AP/BC</td>
<td>Grey</td>
<td>475-500</td>
<td>Glaciofluvial/ Glaciolacustrine</td>
</tr>
<tr>
<td>Site M</td>
<td>T. 30 R. 24 W 2(^{nd}) M</td>
<td>6A</td>
<td>GOS/WM</td>
<td>MMG</td>
<td>Dark Brown</td>
<td>400-425</td>
<td>Glaciofluvial/ Glaciolacustrine</td>
</tr>
<tr>
<td>Site N</td>
<td>T. 29 R. 9 W 3(^{rd}) M</td>
<td>6B</td>
<td>GOS/WM</td>
<td>MMG</td>
<td>Dark Brown</td>
<td>325-350</td>
<td>Moraine</td>
</tr>
<tr>
<td>Site O</td>
<td>T. 28 R. 22 W 3(^{rd}) M</td>
<td>7A</td>
<td>MF/WM</td>
<td>MG</td>
<td>Brown</td>
<td>325-350</td>
<td>Glaciolacustrine</td>
</tr>
<tr>
<td>Site P</td>
<td>T. 36 R. 17 W 3(^{rd}) M</td>
<td>7B</td>
<td>WF/BC</td>
<td>MMG</td>
<td>Dark Brown</td>
<td>350-375</td>
<td>Moraine/ Glaciolacustrine</td>
</tr>
<tr>
<td>Site Q</td>
<td>T. 51 R. 13 W 2(^{nd}) M</td>
<td>8A</td>
<td>MF</td>
<td>B</td>
<td>Grey</td>
<td>425-450</td>
<td>Glaciolacustrine</td>
</tr>
<tr>
<td>Site R</td>
<td>T. 39 R. 20 W 2(^{nd}) M</td>
<td>8B</td>
<td>GOS</td>
<td>AP/BC</td>
<td>Grey</td>
<td>400-425</td>
<td>Moraine</td>
</tr>
<tr>
<td>Site S</td>
<td>T. 50 R. 2 W 3(^{rd}) M</td>
<td>9A</td>
<td>BC/MF</td>
<td>B</td>
<td>Grey</td>
<td>425-450</td>
<td>Moraine</td>
</tr>
<tr>
<td>Site T</td>
<td>T. 50 R. 27 W 3(^{rd}) M</td>
<td>9B</td>
<td>BC</td>
<td>AP/BC</td>
<td>Grey</td>
<td>400-425</td>
<td>Glaciolacustrine</td>
</tr>
</tbody>
</table>

\(^1\) Agricultural Regions: BC- Beef Cattle, GOS- Grain & Oil Seed Farming, MF- Mixed Farming and WF- Wheat Farming (Carlyle, 2006)

3.1 Land Use/ Land Cover

Agricultural lands make up 266,925 km² of the total 651,036 km² in the province (Stewart, 2006). The original pre-European settlement land cover of the agricultural region was predominately grassland. In the southwest corner of the province, mixed grasslands composed of short grasses, such as blue grama grass and mid-height grasses like wheatgrass, are found. Increasing precipitation towards the east and northeast regions of the province produced mixed grasslands with more trees and shrubs. The most northern and eastern agricultural regions receive the most moisture, producing an ecoregion landscape known as aspen parkland (Secoy, 2006).

Within the agricultural regions of the province, cultivated lands make up 58.5% of the area while the rest is composed of pasture and summer fallow (Stewart, 2006). The main crops in Saskatchewan are grains and oilseeds. These areas also have the soil and climate types suitable to grow tame hay and feed grains for livestock (Carlyle, 2006). Cultivated lands are found mostly in the central and eastern areas of the province. The south-western and north-western part of the agricultural region are mainly used for cattle ranching due to aridity and topography (Carlyle, 2006; Tab. 3-1).
3.2 Soils

Soils are natural terrain elements configured by the collective effects of climate, vegetation, geological material, topography, and drainage (Padbury, 2006). The dominant soil types found within the different agricultural regions of Saskatchewan are black, brown and dark brown soils (Fig. 3-3). In the southwest, the predominant soil types are brown and dark brown soils. An exception to this is within the Cypress Hills where black soils are commonly found along with dark brown soils. Dark brown and
brown soils are found in short grass prairie areas and are composed of a thin layer of organic material resulting from a dry climate over a long period of time (Padbury, 2006). Soils are black in the more northern and eastern edges of the agricultural regions. These regions are cooler and receive more moisture, and there is a mix of aspen groves and fescue grasslands. With more organic material available, the soil in these areas becomes very dark and black in colour (Padbury, 2006).
3.3 Landscape

The landscape of the agricultural regions of Saskatchewan was heavily influenced by glaciation. The area of central Saskatchewan is dominated by flat topography characterized by level ground moraine (till plains), and glaciolacustrine and glaciofluvial plains (Tab. 3-4) (Acton et al., 2006). This region also features many potholes, gently rolling hills, ridge moraines and sand dunes. Kettle lakes are a
dominant feature in the eastern part of the province where they can be found encircled by riparian areas.

The Qu'Appelle Valley, through which flows the Qu'Appelle River, runs from western Saskatchewan to the eastern boundary of the province. It dissects the rolling plains that compose a large part of the Saskatchewan agricultural landscape (Henderson, 2006).

The Missouri Couteau, a band of moraine upland that stretches from southern Saskatchewan to South Dakota, is another important feature of the landscape of the province (Penner, 2006). The eastern border of the couteau is comprised of a predominantly linear escarpment, and moving west from there the landscape is frequently hummocky and covered by kettle lakes that dot the grasslands.

The Cypress Hills, another upland region, occurs in the south west part of the province. The hills are forested in the wetter and higher elevations, with grasslands at lower elevations and on dry south facing slopes.

3.4 Climate

The climate of Saskatchewan can be described as continental with great variation in temperatures from season to season (Cote, 2006). Precipitation is seasonally variable but generally sufficient to support agriculture. Other climate characteristics found in Saskatchewan are a large number of days with sunshine, strong winds and the possibility of severe weather such as thunderstorms and blizzards (Cote, 2006).
Precipitation in the agricultural regions of SK averages 400 - 550 mm (Fig. 3-4). Most falls during the summer months, accounting for two-thirds of the annual accumulation. The southwest corner of the province receives the least amount; as result it has a semi-arid climate and mixed grasslands. More precipitation falls in the northern and easterly regions which supports a mix of grasslands and aspen groves (Cote,
High precipitation events, such as convection thunderstorms, are common in the summer.

Temperature variation predominates the climate of Saskatchewan. Temperatures can vary by 80°C annually. In the summer months temperatures reach the mid-thirties regularly. The hottest temperature ever recorded in Canada, 45°C, occurred in Midale, Saskatchewan. Winter temperatures often fall below -30°C, with lows of -40°C not uncommon (Cote, 2006).

Saskatchewan is also known for its strong winds. A combination of strong winds and abundant sunshine creates a high evapotranspiration. This is especially true in the southern portions of the province where the semi-arid grassland vegetation has little protection against the wind. In the northern parts the potential for evapotranspiration is less and the region supports a mix of grasslands and aspen parklands (Cote, 2006).

The combination of different climates, landscapes, soils, land cover and agricultural uses has influenced the distribution, design and composition of shelterbelts in the agricultural regions of the province. Study sites were selected from each agricultural region to sample this variety.
CHAPTER 4 – Data

This chapter documents the data needed to create an inventory of shelterbelts to estimate carbon sequestration. The data described include: imagery (4.1), GIS layers (4.2), tree distribution data (4.3), and carbon sequestration calculations (4.4).

4.1 Imagery

The imagery used was SPOT-5 panchromatic satellite imagery at a spatial resolution of 2.5 m acquired from the Saskatchewan Geospatial Imagery Collaborative (SGIC). The SGIC is a partnership of government and non-governmental organizations that share the cost and knowledge of geospatial data for the Province of Saskatchewan (Flysask, 2010).

Although my research focused on Saskatchewan, the desire to replicate the classification methods throughout the Prairies necessitated the use of geocoded imagery that (i) covered large areas, (ii) was easily accessible, and (iii) had a minimum cost. The SPOT-5 panchromatic 2.5 m imagery was the most suitable for this purpose. This decision was further supported by the use of these data at the AAFC Agri-Environment Services Branch and the University of Regina.

Data for the 20 Saskatchewan townships selected for this study were downloaded from the SGIC website (www.flysask.ca). Images for each study site are included in Appendix A. The SGIC images were available as mosaicked GEOTIFF files, georeferenced to the Universal Transverse Mercator projection, zone 13 north, North
American Datum of 1983. Imagery acquisition dates ranged from 16 April 2005 to 12 September 2006 (Tab. 4-1).

**Table 4-1: Acquisition dates of imagery**

<table>
<thead>
<tr>
<th>Site</th>
<th>Image Acquisition Date</th>
<th>Site</th>
<th>Image Acquisition Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>April 26/2006</td>
<td>K</td>
<td>April 16/2005</td>
</tr>
<tr>
<td>B</td>
<td>July 18/2006</td>
<td>L</td>
<td>July 18/2005</td>
</tr>
<tr>
<td>C</td>
<td>April 25/2006</td>
<td>M</td>
<td>May 15/2006</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>August 27/2006</td>
</tr>
<tr>
<td>E</td>
<td>April 25/2006</td>
<td>O</td>
<td>May 15/2006</td>
</tr>
<tr>
<td></td>
<td>April 25/26 2006</td>
<td></td>
<td>August 1/2006</td>
</tr>
<tr>
<td></td>
<td>May 15/2006</td>
<td></td>
<td>August 22/2006</td>
</tr>
<tr>
<td>I</td>
<td>April 29/2006</td>
<td>S</td>
<td>August 27/2006</td>
</tr>
</tbody>
</table>

1 See Table 3-1 for locations of sites

### 4.1.1 Limitations

Although the SPOT-5 panchromatic 2.5 m imagery was most suitable for this purpose, the pre-processing that had been applied to the data created issues that limited its use in some areas. As noted in Tab. 4-1, the available image mosaics for some study sites had been created from individual images acquired on different dates. Unfortunately, since many different growing conditions are found through the province at different times of year, these mosaics limited some of the classification procedures and negatively impacted the results.
In addition, the image data had been previously processed to enhance contrast for overall visual appearance. Unfortunately, these enhancements sometimes altered the data to such an extent that they negatively affected the classification procedures.

While it would have been possible to retrieve the original unprocessed SPOT scenes, the time and effort required to geo-reference and enhance each image individually would have negated their utility for this application.

4.2 GIS Layers

Specific geographic information system (GIS) layers were used in conjunction with the SPOT-5 panchromatic imagery in the segmentation and classification procedures. The GIS layers came from the National Topographic Data Base, which has vector-based data that have been digitized from topographic maps. They were downloaded from the Natural Resources Canada website (www.geogratis.ca).

The GIS layers were produced at a scale of 1:50,000 and were in geographic (i.e., latitude and longitude) coordinates positioned according to the North American Datum of 1983. The files were projected into the Universal Transverse Mercator projection zone 13 north, to match the SPOT-5 imagery. The GIS layer files were obtained in shapefile format for use in ArcGIS. The GIS layers included buildings, roads, limited roads (roads that are not heavily used, such as rural gravel and dirt roads), built up areas, railways, water bodies (including lakes, small ponds, streams, and rivers), and wetlands.
4.3 Tree Distribution Data

Tree distribution data were used to calculate the percentage of each tree species distributed within each study area. The Agroforestry Development Centre has kept records, including quantities and species, on the distribution of tree samplings for over 100 years. While they don’t record the exact location that the trees were planted, they do record the location where trees were delivered to. In this study, it was assumed that the trees were planted in the township to which they were shipped. This enables the use of the distribution records as indicators of the composition of shelterbelts within the area.

Seedling distribution records for each township in the study were examined to gain insight into the makeup of shelterbelts in that area. Most tree species that are used in shelterbelts live for an average of 30 to 75 years (Kort & Turnock, 1999). Therefore, approximately 70 years of distribution records encompassing 1942 to 2009 were looked at in this study.

4.4 Carbon Sequestration Calculations

Kort and Turnock (1999) calculated the above-ground carbon contents of shelterbelts in Saskatchewan (Tab. 4-2). The calculation of above-ground carbon content is based on the collection of samples taken from trees in Saskatchewan and southwestern Manitoba. Carbon content was calculated by estimating the percent of total biomass of each tree species. Carbon content in shelterbelt trees was represented by both kg/tree and t/km. For the spatial analysis purposes of this study, the carbon content unit used was t/km. Although below-ground carbon, Kort and Turnock (1999)
suggest that below-ground carbon storage is approximately 40% of the above-ground carbon for deciduous trees, 30% for coniferous trees, and 50% for shrubs.

Kort and Turnock (1999) only calculated the carbon content of a selection of dominant shelterbelt species. The carbon content for other species sometimes found in shelterbelts was estimated to be 50 percent (J. Kort, Pers. Comm.) (Tab. 4-2). These other species included Colorado spruce, white spruce, Scots pine, choke cherry, viliosa lilac, buffalo berry, sea buckhorn. Willow carbon content was estimated to be midway between hybrid poplar and manitoba Maple (J. Kort, Pers. Comm.)

Table 4-2: Tree species carbon content (from Kort and Turnock, 1999).

<table>
<thead>
<tr>
<th>Species</th>
<th>Above-Ground Carbon Content (%)</th>
<th>Above-Ground Carbon Content (t/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deciduous Trees</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green Ash</td>
<td>48.6</td>
<td>31</td>
</tr>
<tr>
<td>Manitoba Maple</td>
<td>48.0</td>
<td>34</td>
</tr>
<tr>
<td>Hybrid Poplar</td>
<td>48.2</td>
<td>104</td>
</tr>
<tr>
<td>Siberian Elm</td>
<td>49.4</td>
<td>40</td>
</tr>
<tr>
<td>Willow</td>
<td>50</td>
<td>75</td>
</tr>
<tr>
<td><strong>Coniferous Trees</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colorado Spruce</td>
<td>50</td>
<td>29</td>
</tr>
<tr>
<td>White Spruce</td>
<td>50</td>
<td>41</td>
</tr>
<tr>
<td>Scots Pine</td>
<td>50</td>
<td>24</td>
</tr>
<tr>
<td><strong>Shrubs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caragana</td>
<td>50.1</td>
<td>26</td>
</tr>
<tr>
<td>Choke Cherry</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>Viliosa Lilac</td>
<td>50</td>
<td>17</td>
</tr>
<tr>
<td>Buffaloberry</td>
<td>50</td>
<td>15</td>
</tr>
<tr>
<td>Sea Buckthorn</td>
<td>50</td>
<td>11</td>
</tr>
</tbody>
</table>
CHAPTER 5 – Methods

The creation of a carbon sequestration inventory in prairie shelterbelts was a three-step process. The first step was to create an accurate inventory of shelterbelts using object-based classification (described in sections 5.1, 5.2 and 5.3). Secondly, tree seedling distribution records were used to estimate the percentage of species found in the inventory (5.4.1). Finally, a regional sequestered-carbon assessment was compiled based on the length of shelterbelts for each species and the amount of carbon sequestered by different tree species (5.4.2). These steps are outlined in Fig-5-1.

Figure 5-1: Analysis flow chart
### 5.1 Object-based Classification

The object-based classification of an image is based on features. Features are defined by the spectral, morphological (i.e., shape), textural, and hierarchical characteristics of objects found in the imagery ("image-objects"; Definiens, 2007). Two main feature types are recognized: object and global features. Object features are attributes of image-objects, such as the width or length of an object, while global features are external properties not connected to individual image-objects, such as an object’s relation to other objects in the scene (Definiens, 2007). Knowing the general characteristics of the objects such as their width, alignment, composition and relation to other objects is essential when using both object and global features (Benz et al., 2004).

The object-oriented classification software used in this study, Definiens Developer 7, was first released in 2000 (originally called "eCognition") (Willhauck, 2007). The main segmentation algorithm used by Definiens Developer 7 is the region-based approach by means of a multi-resolution segmentation algorithm. This is an optimized procedure which locally minimizes the average heterogeneity of image-objects for a given resolution (Definiens, 2007; Baatz and Schape, 2000).

The multi-resolution segmentation algorithm proceeds in three stages (see Fig. 5-1): segmentation of the image into image-objects (described in section 5.1.1); reduction of the image-objects into shelterbelt and non-shelterbelt objects (5.1.2); and classifying the shelterbelt objects as field or farmyard shelterbelts (5.1.3).
5.1.1 Segmentation

Segmentation is the basis for the object-based classification program. Segmentation is the process of subdividing an image, which is represented as discrete pixels, into image-objects. Five segmentation algorithms are available in Definiens: chessboard segmentation, quad-tree based segmentation, contrast split segmentation, multi-resolution segmentation, and spectral difference segmentation. Based on previous research (Pankiw et al. 2008), the multi-resolution approach produced the most usable candidate shelterbelt objects from the SPOT imagery.

Multi-resolution segmentation takes smaller objects, starting with one pixel objects, and merges them into larger objects. Benz et al., (2004) describes this process,

“The underlying optimization procedure minimizes the weighted heterogeneity $n h$ of resulting image-objects where $n$ is the size of a segment and $h$ a parameter of heterogeneity. In each step, that pair of adjacent image-objects is merged which results in the smallest growth of the defined heterogeneity. If the smallest growth exceeds the threshold defined by the scale parameter, the process stops.” (pg 246)

The multi-resolution segmentation algorithm is based on three parameters that need to be set: scale, colour, and shape (Fig. 5-2) (Benz et al., 2004).
The scale parameter is used to vary the size of the image-objects found during segmentation (Fig. 5-3). This is done by determining the maximum desired heterogeneity for the resulting image-objects. Heterogeneous data will create smaller objects, compared to homogeneous data (Definiens, 2007). Colour and shape parameters are part of the composition of the homogeneity criterion (Fig. 5-2).
The shape criterion is defined by a feature’s smoothness and compactness (Fig. 5-4). The smoothness parameter is used to optimize the smoothness of the object image borders while the compactness parameter directs the software to identify image-objects with minimal deviation from the ideal compact (i.e., circular) form (Definiens, 2007).
The segmentation procedure created a large set of image-objects, many of which were not shelterbelts. Separating these objects into non-shelterbelt and shelterbelt candidates was the next step in the process. This is outlined in Fig. 5-5.
First, thematic GIS layers from the National Topographic Database were used to target features such as buildings, roads, natural vegetation and water for deletion as non-shelterbelts. Then, image-objects that were obviously not shelterbelts, such as agricultural fields, grass pastures, large water bodies, and large patches of natural vegetation, were removed. These were identified principally by their large size and brighter image tones.

The most advantageous way to separate large areas such as grasslands and crop lands from shelterbelts was using of texture-based feature analysis (see also Pesaresi, 2000). This approach exploits the black-and-white nature of the SPOT-5

Figure 5-5: Reduction of candidate area flow chart
imagery where many features within a scene appear with similar tone and brightness. This was especially true for grassy areas, such as ditches, and cultivated land.

Texture-based, grey level co-occurrence matrix (GLCM) analysis is based on a tabulation of how often different combinations of pixel grey levels occur, in a given direction, in a panchromatic image. In particular, the GLCM homogeneity index (Equation 5-1) measures the closeness of the distribution of elements in the GLCM to the GLCM diagonal (Definiens, 2007). The closer the GLCM to the GLCM diagonal, the higher its feature value will be.

\[
\sum_{i,j=0}^{N-1} \frac{P_{i,j}}{1 + (i - j)^2}
\]

Equation 5-1: GLCM homogeneity index (Definiens 2007)

Parameters:
- \(i\): row number
- \(j\): column number
- \(P_{i,j}\): normalized value in the cell \(i,j\)
- \(N\): number of rows or columns

Another measure, mean brightness, was incorporated to remove non-shelterbelt areas. Mean brightness was calculated based on the average pixel value of those cells found within an object. Since shelterbelts have a darker tone than surrounding areas, those features with average brightness above a certain threshold could be eliminated as non-shelterbelts from further analysis.
The objects remaining after thematic feature deletion, large homogeneous area reduction, and bright object elimination were considered to be candidate shelterbelts. In the next step, these candidates were separated into field and farmyard shelterbelts.

5.1.3 Classification of Shelterbelts

Two different processes were needed to classify the candidate shelterbelt objects as field shelterbelts or farmyard shelterbelts because these two types take on different forms in the landscape. The classifications used a combination of spatial, textural, and relationship features. Spatial features were based on the external characteristics of the shelterbelts while the textural features depended on differences in their internal structures. The relational features were the distances calculated from the image-object to other entities such as buildings, roads, and vegetation.

5.1.3.1 Classification of Farmyard Shelterbelts

Farmyard shelterbelts have a large number of design permutations so it was not possible to define an image-based measure that could be applied to consistently isolate these features. As a result, an external relationship – maximum distance from a building - was a primary mode of identification. All candidate shelterbelt objects that were within 150 m of buildings were classified as candidate farmyard shelterbelts. These candidates were further refined using a mean brightness threshold to remove brighter features that had a low likelihood of actually being a shelterbelt.

The candidate farmyard shelterbelt objects still included many non-shelterbelt features so a GLCM contrast texture measure was applied. The GLCM contrast index is a measure of the amount of local variation in the image tones (Definiens, 2007;
Equation 5-2) and was applied in this study under the assumption that shelterbelts, with their inherent diversity of treed and non-treed areas, have a higher contrast than surrounding areas. This measure was used to eliminate those objects whose contrast values were below a set threshold. The remaining image-objects were classified as farmyard shelterbelts.

\[ \sum_{i, j=0}^{N-1} P_{i,j} (i - j)^2 \]

Parameters:
- \( i \): the row number
- \( j \): the column number
- \( P_{i,j} \): the normalized value in the cell \( i, j \)
- \( N \): the number of rows or columns

**Equation 5-2: GLCM contrast index**  
(Definiens 2007)

### 5.1.3.2 Classification of Field Shelterbelts

Field shelterbelts have a distinctive pattern. In most cases they are long narrow features oriented north-south or east-west along field boundaries. Since field shelterbelts are dissimilar in layout to that of farmyard shelterbelts, a different classification process was needed (Fig. 5-6).
The first step applied to separate field shelterbelts from the set of candidate shelterbelt objects was to enumerate asymmetric shape characteristics. The greater the length of an object is relative to its width, the more asymmetric it is (Definiens, 1997).

Aside from asymmetry, the most distinctive spatial characteristic of field shelterbelts is orientation. A majority of field shelterbelts in Saskatchewan are oriented in a north/south or east/west direction since they follow the field boundaries originally
laid out in the Dominion Land Survey. The main direction algorithm was applied to calculate eigenvectors for each possible axis of orientation for an image-object. The direction of the largest eigenvector determined the orientation of the object (Equation 5-3). The main direction algorithm has values between 0-180. Candidate shelterbelt image-objects that were not between the values of 175 to 180 and 0-5 (north-south) or between 85 and 95 (east-west) were removed.

\[
\frac{180^\circ}{\pi} \tan^{-1}(\frac{Var \hat{X} Y - Var \hat{Y}}{\lambda_1}) + 90^\circ
\]

Equation 5-3: Main direction algorithm (Definiens 2007)

A shape index was determined by dividing the image-object’s border length by four times the square root of its area (Equation 5-4). The optimum shape index for a near-circular object is 1. The shape index was used to describe the smoothness of the image-object’s edges and threshold values were set to isolate true shelterbelts. Additionally, all image-objects with widths greater than 30 m and areas less than 250 m^2 were removed.
In the previous reduction to candidate image-objects stage, most image-objects with high brightness value were removed. However, a few false candidate objects passed through the procedure, necessitating additional fine-tuning of the image brightness removal thresholds. Dark features, such as water features that had not previously been masked out, were responsible for this rule.

As for farmyard shelterbelts, the GLCM contrast measure was used to remove image-objects that were not, in fact, shelterbelts. For example, grassy areas often had similar spatial characteristics with field shelterbelts. Since field shelterbelt objects typically had higher contrast values than their surrounding areas, arising from their diverse mixture of trees and shadows, the GLCM contrast measure was an effective means to separate these.

Relationship features were also useful for separating field shelterbelt from non-shelterbelt image-objects. For example, most falsely classified field shelterbelts were
grassy ditches, which are long, narrow features that are usually oriented north-south or east-west and have similar spatial characteristics to field shelterbelts. By using a relationship measure, such as minimum distance between field shelterbelts and roads, all candidate objects that were within this distance could be removed.

Lastly, candidate objects that were in close proximity to bodies of water (i.e., riparian areas) and natural forests (i.e., remnant tree stands) were removed.

The image-objects that remained were classified as field shelterbelts.

5.2 Impact of Season and Location on Classification

The lack of consistency in imagery from region to region had a large impact on the repeatability of the classification procedure. Large distances between each of the study sites and seasonal variation in the satellite image acquisition dates necessitated adjustments in the segmentation features used in the classifications. To determine which factor - location or season - imparted a larger impact on the classification rules, both variables were examined separately.

Four different sites were selected, two in a location in the southeast corner of the province and two in the northwest. Location I was in the northwest corner of the agricultural region of the province and contained sites W and X. Location II was in the southeast corner of the province and encompassed sites Y and Z. The two sites in each location had different acquisition dates (Tab. 5-1). Each site was processed
independently and the resulting classifications and rule sets were compared with respect to location and season.

Table: 5-1: Location and acquisition dates used in season and location impact analysis

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. W</td>
<td>T. 40 R. 28 W. 3rd M.</td>
<td>September 1, 2006</td>
</tr>
<tr>
<td>I. X</td>
<td>T. 39 R. 26 W 3rd M.</td>
<td>April 19, 2005</td>
</tr>
<tr>
<td>II. Y</td>
<td>T. 5 R. 33 W 1st M.</td>
<td>July 18, 2006</td>
</tr>
<tr>
<td>II. Z</td>
<td>T. 4 R. 31 W 1st M.</td>
<td>April 26, 2006</td>
</tr>
</tbody>
</table>

5.3 Classification Accuracy Assessment

The accuracy of each object-oriented classification was determined by comparing the object-oriented results with a set of shelterbelt objects that had been manually digitized, on screen, from the SPOT 5 - 2.5 m image. High-resolution (62 cm) colour airphotos and/or Google Earth imagery was used to collaborate if the shelterbelts actually were found on the ground. Using IDRISI Andes software, both farmyard and field shelterbelts from each site were manually digitized to vector files. These manually digitized features were considered to be an accurate representation of actual shelterbelt distribution in each study site.

The classified shelterbelts were compared to the digitized features by overlaying them in ArcGIS. Overlapping areas were considered to be correctly classified. Areas classified as shelterbelts using Definiens but which were not actually shelterbelts were
identified as commission errors. The remaining areas that were manually digitized but not identified in the classification procedures were categorized as omission errors.

Classification accuracy was measured in two different ways. The first was based on the area of classified objects. The total area classified as shelterbelts was compared to the actual area found by manual digitization to determine the size of the over- or under-classified areas. Secondly, to calculate how well the classification process could simply locate shelterbelts, a tally was made of how many classified objects were coincident with an actual shelterbelt.

5.4 Carbon Sequestration in Shelterbelts

To estimate the amount of above-ground carbon sequestration present in shelterbelts three parameters were considered: the total area classified as shelterbelts, as determined by the methods in this thesis; the seedling distribution records from the Agroforestry Development Centre in Indian Head; and estimates of the amount of carbon that could be sequestered by each individual tree species.

5.4.1 Species Distribution

Tree seedling distribution records were provided by the Agroforestry Development Centre for the 20 townships studied. Distribution records were used to estimate percentage of each tree species planted in each township. This percentage was then applied to the total shelterbelt area to estimate the area each species occupied within the site.

When determining the percentage of each tree species planted, similar species were grouped into one category. Species with many different varieties were all pooled
for analysis. For example, poplar and willow species were pooled into one category while trees not included by Kort and Turnock (1999) were combined into “other”.

Plant spacing data from Kort and Turnock (1999) were combined with the number of trees per species and the number of kilometres per species to calculate the actual percentage of each species planted.

5.4.2 Carbon Sequestration Inventory

The amount of above-ground carbon sequestered per species was based on the tonnes of carbon that could be sequestered per kilometre of shelterbelt. The number of kilometres of shelterbelts per species was calculated by dividing the total shelterbelt area by the percentage area occupied by each species found in the study area and the nominal shelterbelt width for each species (Kort and Turnock 1999).

Estimates of the amount of maximum possible amount of above-ground carbon that could be sequestered during the life of each tree were obtained from Kort and Turnock (1999). For species, such as willows, where there were no published data available, an estimate (John Kort, Pers. Comm). Carbon sequestration was a product of species sequestration value and the estimated shelterbelt length composed of each species.

The accuracy of the carbon sequestration estimates for the shelterbelts was assessed using the same process described above for determining the areal accuracy of the shelterbelt classifications.
CHAPTER 6 – Results

6.1 Object-Based Classification

Although one of the original motivations of this research was to define a shelterbelt identification procedure that could be applied across Saskatchewan, it became evident that due to the large diversity of agro-environmental conditions across the province, wide seasonal variations in the satellite image acquisition dates, and inconsistent image contrast enhancements, this was not possible. Nonetheless, the results document those identification procedures that are broadly applicable while also highlighting conditions that require special attention.

6.1.1 Segmentation

The first step in the object-oriented classification process is segmentation. Recall that segmentation is the process of subdividing an image, which is represented as discrete pixels, into image-objects. When the satellite images were originally segmented 35,000 to 65,000 image-objects were created. Segmentation was heavily reliant on the contrast of the pixels in the image and the features that were found.

Determining the most appropriate segmentation parameters is a subjective process and the most effective set is often achieved by trial and error (Dulin, 2009). In this study, found that larger scale parameters (e.g., 50) created objects that included areas around the shelterbelts that were not in fact actually part of the shelterbelts (Fig. 5-3). When a lower scale parameter (e.g., 10) was tested, the shelterbelt objects were segmented into several different image-objects and not a single object (Fig. 5-3).
Consequently, a scale parameter of 25 was used to create candidate shelterbelts objects. This compromise minimized both the amount of extra area being included within the object and the number of sub-objects that would later need to be joined to create a single shelterbelt feature.

The shape and compactness parameters can be set with weights between 0.1 and 0.9. Upon experimentation, it was found that values near 0.1 included too many extra areas around the shelterbelts, while values near 0.9 produced large objects that did not adequately segment the shelterbelts (Fig. 5-4). Field and farmyard shelterbelts typically have distinct shapes (long and linear for field shelterbelts and nominally rectangular for farmyard shelterbelts) that values of 0.5 for both colour and shape created the best objects for classifying both types of shelterbelts.

6.1.2 Reduction to Candidate Objects

To assist classification, areas that did not contain shelterbelts were removed using the process of reduction. The reduction of image-objects into shelterbelt candidates and non-shelterbelt candidates used two different features: GLCM homogeneity and mean brightness.

When used in the reduction of candidate areas the GLCM homogeneity feature worked best to separate large grassy and crop areas from the treed areas. Objects with high values, such as grassy and cropped areas, were classified as open areas. In general, a GLCM homogeneity threshold of 0.22 provided a useful discrimination between shelterbelt and non-shelterbelt objects. Exceptions included study area D, where the image used was acquired in late April, before springtime vegetative growth
had occurred (Fig. 6-1). The open fields had less homogeneous values than they would have later in the season after crops had emerged, and a threshold value of 0.14 was more effective. Wider shelterbelts in sites Q and S produced GLCM homogeneity values that were much higher than in other areas necessitating a higher homogeneity threshold, 0.28 (Fig. 6-2). These sites are close to the southern limit of the boreal forest, near Nipawin and Prince Albert. Shelterbelts found in this region are most likely remnants of contiguous forests, rather than having been purposefully planted.

Figure 6-1: Cultivated and un-vegetated open areas
Mean image brightness values were also used in the reduction of candidate areas. Most sites had a mean brightness threshold of 130, although these values ranged from less than 120 at site P to 140 at site A and to more than 150 at sites J and L (Tab. 6-1). Inter-site variation in mean brightness was due, in part, to the differential contrast enhancements that had been applied to the imagery. When deriving an appropriate brightness threshold, it was found that lower values reduced the number of candidate objects but increased errors of omission. Thus, the values reported in Tab. 6-1 are a compromise between processing efficiency and accuracy.
6.1.3 Farmyard Shelterbelt Classification

A key parameter that was used to classify objects as either farmyard shelterbelts or field shelterbelts, was the distance to the nearest building. A general distance threshold of 150 metres worked because of similar farmyard shelterbelt designs. The only site, for which the 150 m distance was not used, was site S. The yards in this region were slightly larger than any other region and a maximum distance of 175 m was used (Tab. 6-2).

When the distance to buildings threshold was applied to the cottage areas in site L, a large number of falsely classified farmyard shelterbelt objects were created (Fig. 6-3). In this site, the problem was corrected, not by adjusting the distance threshold, but by removing any buildings that were close to the shore of the lake so that these trees were not classified as shelterbelts. A rule was also implemented to remove any objects

<table>
<thead>
<tr>
<th>Site</th>
<th>GLCM Homogeneity</th>
<th>Brightness Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&gt;.2</td>
<td>&gt;140</td>
</tr>
<tr>
<td>B</td>
<td>&gt;.22</td>
<td>&gt;130</td>
</tr>
<tr>
<td>C</td>
<td>&gt;.2</td>
<td>&gt;130</td>
</tr>
<tr>
<td>D</td>
<td>&gt;.15</td>
<td>&gt;130</td>
</tr>
<tr>
<td>E</td>
<td>&gt;.2</td>
<td>&gt;130</td>
</tr>
<tr>
<td>F</td>
<td>&gt;.25</td>
<td>&gt;130</td>
</tr>
<tr>
<td>G</td>
<td>&gt;.2</td>
<td>&gt;130</td>
</tr>
<tr>
<td>H</td>
<td>&gt;.2</td>
<td>&gt;130</td>
</tr>
<tr>
<td>I</td>
<td>&gt;.2</td>
<td>&gt;130</td>
</tr>
<tr>
<td>J</td>
<td>&gt;.22</td>
<td>&gt;150</td>
</tr>
<tr>
<td>K</td>
<td>&gt;.2</td>
<td>&gt;130</td>
</tr>
<tr>
<td>L</td>
<td>&gt;.22</td>
<td>&gt;150</td>
</tr>
<tr>
<td>M</td>
<td>&gt;.2</td>
<td>&gt;130</td>
</tr>
<tr>
<td>N</td>
<td>&gt;.22</td>
<td>&gt;130</td>
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<tr>
<td>O</td>
<td>&gt;.22</td>
<td>&gt;130</td>
</tr>
<tr>
<td>P</td>
<td>&gt;.22</td>
<td>&gt;120</td>
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<td>Q</td>
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</tr>
<tr>
<td>R</td>
<td>&gt;.2</td>
<td>&gt;130</td>
</tr>
<tr>
<td>S</td>
<td>&gt;.28</td>
<td>&gt;130</td>
</tr>
<tr>
<td>T</td>
<td>&gt;.22</td>
<td>&gt;130</td>
</tr>
</tbody>
</table>
that had areas over 5000 square metres. When looking at these large objects it was determined that they were natural forested areas and not planted shelterbelts.

Figure 6-3: Removal of falsely classified farmyard shelterbelts (yellow areas) around cottages (right) (white = rows of trees, pink = cottage, yellow = farmyard shelterbelts, dark green = possible trees, light green = vegetation, red = open areas, light blue = wetlands, dark blue = water, purple = field shelterbelts)

Table 6-2: Farmyard shelterbelt classification feature values

<table>
<thead>
<tr>
<th>Site</th>
<th>Distance to Buildings</th>
<th>Brightness</th>
<th>GLCM Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>150</td>
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<td></td>
</tr>
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<td>B</td>
<td>150</td>
<td>115</td>
<td>150</td>
</tr>
<tr>
<td>C</td>
<td>150</td>
<td>125</td>
<td>300</td>
</tr>
<tr>
<td>D</td>
<td>150</td>
<td>120</td>
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<td>G</td>
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<tr>
<td>R</td>
<td>150</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>S</td>
<td>175</td>
<td>90</td>
<td>500</td>
</tr>
<tr>
<td>T</td>
<td>150</td>
<td>110</td>
<td>25</td>
</tr>
</tbody>
</table>
Additional farmyard shelterbelt classification methods included applying minimum mean brightness and GLCM contrast thresholds. Minimum mean brightness values ranging from 100 to 120 were typical for most sites (Tab. 6-2). In a few sites, lower (90) or higher (125) thresholds were needed because of variation in growing conditions, changes in the time of year of image acquisition, and inconsistencies of contrast enhancements that had been applied.

The GLCM contrast feature was used to remove remaining non-farmyard shelterbelt objects. GLCM contrast thresholds were extremely variable, with values ranging from 50 to 500 (Tab. 6-2). The highest value was applied at site S because the farmyard shelterbelts here were much wider and denser than at the other sites, often being composed of several rows of trees. This created an inverse contrast relationship at site S where the farmyard shelterbelt objects had low values while many non-shelterbelt objects had relatively high GLCM contrast values.

Location I was also a determinate in the variation in GLCM contrast values that are found from site to site. Sites located toward the south and west of the province (e.g., sites H, J and P) had higher contrast values because of the stronger tonal differences between vegetated and non-vegetated areas in this semi-arid region. Conversely, sites that are located to the east and north, where there is more precipitation were more consistently vegetated thereby reducing the ability of GLCM contrast to consistently distinguish shelterbelts. The GLCM contrast measure was not used at sites A, E, F, G and Q because it did not significantly reduce the number of falsely classified farmyard shelterbelts.
6.1.4 Field Shelterbelt Classification

The classification of field shelterbelts required the use of more object features than farmyard shelterbelts. Field shelterbelts were not located in a specific location (e.g., near a farm building) and required the use of more shape features to identify. When dealing with the spatial properties of field shelterbelts there was consistency in their morphological indices (i.e., asymmetry, shape, width) but considerable variation from site to site in their tonal and relationship features (i.e., brightness, contrast, distance to roads) (Tab. 6-3).

Table 6-3: Field shelterbelt classification feature values

<table>
<thead>
<tr>
<th>Site</th>
<th>Area</th>
<th>Asymmetry</th>
<th>Shape Index</th>
<th>Brightness</th>
<th>Width</th>
<th>GLCM Contrast</th>
<th>Distance to Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>250</td>
<td>0.9</td>
<td>2</td>
<td>130</td>
<td>30</td>
<td>400</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>250</td>
<td>0.8</td>
<td>-</td>
<td>110</td>
<td>30</td>
<td>125</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>250</td>
<td>0.9</td>
<td>2</td>
<td>125</td>
<td>25</td>
<td>400</td>
<td>25</td>
</tr>
<tr>
<td>D</td>
<td>250</td>
<td>0.9</td>
<td>2</td>
<td>100</td>
<td>30</td>
<td>500</td>
<td>50</td>
</tr>
<tr>
<td>E</td>
<td>250</td>
<td>0.9</td>
<td>2</td>
<td>125</td>
<td>30</td>
<td>600</td>
<td>-</td>
</tr>
<tr>
<td>F</td>
<td>250</td>
<td>0.9</td>
<td>2</td>
<td>115</td>
<td>30</td>
<td>250</td>
<td>25</td>
</tr>
<tr>
<td>G</td>
<td>250</td>
<td>0.9</td>
<td>2</td>
<td>125</td>
<td>30</td>
<td>500</td>
<td>50</td>
</tr>
<tr>
<td>H</td>
<td>250</td>
<td>0.9</td>
<td>1.5</td>
<td>125</td>
<td>30</td>
<td>3000</td>
<td>-</td>
</tr>
<tr>
<td>I</td>
<td>250</td>
<td>0.9</td>
<td>1.5</td>
<td>100</td>
<td>30</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>J</td>
<td>250</td>
<td>0.9</td>
<td>2</td>
<td>150</td>
<td>30</td>
<td>400</td>
<td>100</td>
</tr>
<tr>
<td>K</td>
<td>250</td>
<td>0.9</td>
<td>2</td>
<td>125</td>
<td>30</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>L</td>
<td>250</td>
<td>0.9</td>
<td>-</td>
<td>130</td>
<td>30</td>
<td>300</td>
<td>-</td>
</tr>
<tr>
<td>M</td>
<td>250</td>
<td>0.9</td>
<td>1.75</td>
<td>125</td>
<td>30</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>N</td>
<td>250</td>
<td>0.9</td>
<td>1.75</td>
<td>120</td>
<td>30</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>O</td>
<td>250</td>
<td>0.8</td>
<td>1.75</td>
<td>125</td>
<td>30</td>
<td>300</td>
<td>-</td>
</tr>
<tr>
<td>P</td>
<td>250</td>
<td>0.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>300</td>
<td>50</td>
</tr>
<tr>
<td>Q</td>
<td>250</td>
<td>0.9</td>
<td>-</td>
<td>-</td>
<td>30</td>
<td>500</td>
<td>-</td>
</tr>
<tr>
<td>R</td>
<td>250</td>
<td>0.9</td>
<td>2</td>
<td>125</td>
<td>30</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>S</td>
<td>250</td>
<td>0.8</td>
<td>-</td>
<td>125</td>
<td>30</td>
<td>-</td>
<td>150</td>
</tr>
<tr>
<td>T</td>
<td>250</td>
<td>0.9</td>
<td>2</td>
<td>125</td>
<td>30</td>
<td>250</td>
<td>-</td>
</tr>
</tbody>
</table>
Asymmetry worked well with field shelterbelts because they were, in most cases, long narrow features on the landscape. Asymmetry thresholds of 0.9 were used in the majority of the sites. Three sites, B, O and S, required slightly reduced asymmetry values because they were slightly wider.

The shape index was used to describe the smoothness of the image-object's edges. Field shelterbelts had rough edges and typically had shape indices greater than 2 and candidate image-objects with index values less than this were removed. Sites M, N, and O had field shelterbelt objects with slightly smoother borders so their shape indices were lower. The classification of sites B, P, Q and S did not improve significantly with the inclusion of the shape index feature.

Field shelterbelt objects typically had higher contrast values than their surrounding areas, arising from their diverse mixture of trees and shadows. The GLCM contrast measure was an effective method to separate such areas of spectral similarity. Typically, contrast thresholds between 300 and 400 were effective, but the wide variety of field shelterbelt conditions resulted in a broad range of contrast values. The GLCM contrast threshold was ineffective at sites N and S because their images were acquired late in the growing season and the contrasts between swaths of grain and the surrounding fields were similar to the shelterbelt objects. At the other end of the scale, site H had an extremely high GLCM contrast value of 3000, a result of the high contrast enhancement that had been applied to the image (Fig. 6-4).
Relationship features were also useful for separating field shelterbelts from other similar features, such as ditches. Road distance thresholds of 25 to 50 metres were generally successful at removing false shelterbelt objects. At sites, A,B,E,H,M,O,Q,R, and T this threshold could not be effectively applied because of mis-registration between the roads and imagery data (Fig. 6-5).
Other distinguishing features of field shelterbelts were principal orientation and image tone. Prairie shelterbelts are planted relative to the prevailing winds and the settlement patterns of the province, thus they did not vary from an east/west or north/south orientation. Dark features, such as water that had not previously been masked, were responsible for the need for the implementation of a brightness threshold rule. In most cases, brightness thresholds in the range of 100-125 were sufficient to remove non-shelterbelts.
6.2 Impact of Season and Location on Classification

Large distances between each of the study sites and seasonal variation in the satellite image acquisition dates necessitated adjustments in the segmentation features used in the classifications. The effects of these differences were examined by comparing the classifications in sites situated close to each other but whose images were acquired in different seasons and other sites located some distance apart with images acquired in the same season. Both field and farmyard shelterbelts were identified using the procedures described above.

Table 6-4 enumerates those classification procedures that could be applied equally across each site and those sites where unique threshold values were required. A review of Tab. 6-4 shows that the set of spatial features did not vary from site to site, with the notable exception of the shape index. The shape index could not be used in either of the two sites in Location II (situated in the northwest of the province's agricultural zone) due to the presence of numerous small sloughs, lakes and ponds that were indistinguishable from shelterbelts, based on shape alone. Since the shape confusion arises from features other than shelterbelts, it can be deduced that location is not a primary factor affecting shelterbelt classification.
Table 6-4: Shape and contrast features uses in each location and site

An "X" indicates that a common threshold value was applied across all sites.

<table>
<thead>
<tr>
<th></th>
<th>Location I Site W</th>
<th>Location I Site X</th>
<th>Location II Site Y</th>
<th>Location II Site Z</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>September 1, 2006</td>
<td>April 19, 2005</td>
<td>July 18, 2006</td>
<td>April 26, 2006</td>
</tr>
<tr>
<td><strong>Spatial Features</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brightness</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Asymmetry</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Main Direction</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Area</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Shape Index</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Contrast Features</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLCM Homogeneity</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>GLCM Contrast</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

With respect to seasonality, a GLCM contrast value of 200 was useful for classifying farmyard shelterbelts in the April imagery from both Locations I and II (sites X and Z). This early-season difference is most likely a result of enhanced contrast between the leafless tress and the surrounding barren areas. As the season progressed and the leaves and grass reach their full development, however, the contrasts between fields and shelterbelts become is reduced rendering the contrast
threshold ineffective. Thus, timing of image acquisition plays a stronger role in determining feature classification than location.

### 6.3 Classification Accuracy

The classification accuracy was measured in two different ways: by aerial coverage and by location. When evaluating the classification accuracy in terms of the total area classified as shelterbelt, it was found that the object-based process did not perform well, with the classifier generally underestimating the total areas of field shelterbelts and overestimating the farmyard areas (Tab. 6-5). When the field and farmyard classifications were evaluated separately, the correctly classified area was 48% for farmyard shelterbelts (Tab. 6-6) and 52% for field shelterbelts (Tab. 6-7).
Table 6-5: Shelterbelt areas

<table>
<thead>
<tr>
<th>Site</th>
<th>Manually Digitized Shelterbelts</th>
<th>Shelterbelt Areas Classified using Classification Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Field Shelterbelt Area m²</td>
<td>Farmyard Shelterbelt Area m²</td>
</tr>
<tr>
<td>Site A</td>
<td>85,775</td>
<td>155,729</td>
</tr>
<tr>
<td>Site B</td>
<td>304,923</td>
<td>230,805</td>
</tr>
<tr>
<td>Site C</td>
<td>6,155</td>
<td>104,983</td>
</tr>
<tr>
<td>Site D</td>
<td>5,281</td>
<td>80,125</td>
</tr>
<tr>
<td>Site E</td>
<td>25,656</td>
<td>200,798</td>
</tr>
<tr>
<td>Site F</td>
<td>439,819</td>
<td>197,965</td>
</tr>
<tr>
<td>Site G</td>
<td>32,673</td>
<td>155,599</td>
</tr>
<tr>
<td>Site H</td>
<td>31,675</td>
<td>144,900</td>
</tr>
<tr>
<td>Site I</td>
<td>84,835</td>
<td>102,287</td>
</tr>
<tr>
<td>Site J</td>
<td>380,969</td>
<td>182,542</td>
</tr>
<tr>
<td>Site K</td>
<td>47,412</td>
<td>272,587</td>
</tr>
<tr>
<td>Site L</td>
<td>228,821</td>
<td>208,888</td>
</tr>
<tr>
<td>Site M</td>
<td>209,187</td>
<td>398,443</td>
</tr>
<tr>
<td>Site N</td>
<td>3,280,304</td>
<td>225,536</td>
</tr>
<tr>
<td>Site O</td>
<td>337,032</td>
<td>97,992</td>
</tr>
<tr>
<td>Site P</td>
<td>356,610</td>
<td>43,345</td>
</tr>
<tr>
<td>Site Q</td>
<td>1,289,583</td>
<td>193,633</td>
</tr>
<tr>
<td>Site R</td>
<td>246,543</td>
<td>640,656</td>
</tr>
<tr>
<td>Site S</td>
<td>1,272,874</td>
<td>362,416</td>
</tr>
<tr>
<td>Site T</td>
<td>176,037</td>
<td>328,331</td>
</tr>
<tr>
<td>Totals</td>
<td>8,842,164</td>
<td>4,327,560</td>
</tr>
</tbody>
</table>
Table 6-6: Farmyard shelterbelt classification accuracy

<table>
<thead>
<tr>
<th>Site</th>
<th>Classified Shelterbelt Areas m²</th>
<th>Manual Shelterbelt Area m²</th>
<th>Correctly Classified Areas km²</th>
<th>Classification Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>166,917</td>
<td>155,729</td>
<td>77,967</td>
<td>50%</td>
</tr>
<tr>
<td>Site B</td>
<td>266,694</td>
<td>230,805</td>
<td>134,172</td>
<td>58%</td>
</tr>
<tr>
<td>Site C</td>
<td>132,827</td>
<td>104,983</td>
<td>56,978</td>
<td>54%</td>
</tr>
<tr>
<td>Site D</td>
<td>122,220</td>
<td>80,125</td>
<td>39,741</td>
<td>50%</td>
</tr>
<tr>
<td>Site E</td>
<td>230,901</td>
<td>200,798</td>
<td>119,700</td>
<td>60%</td>
</tr>
<tr>
<td>Site F</td>
<td>286,572</td>
<td>197,965</td>
<td>116,633</td>
<td>59%</td>
</tr>
<tr>
<td>Site G</td>
<td>129,390</td>
<td>155,599</td>
<td>50,066</td>
<td>32%</td>
</tr>
<tr>
<td>Site H</td>
<td>181,893</td>
<td>144,900</td>
<td>87,964</td>
<td>61%</td>
</tr>
<tr>
<td>Site I</td>
<td>127,074</td>
<td>102,287</td>
<td>46,676</td>
<td>46%</td>
</tr>
<tr>
<td>Site J</td>
<td>215,541</td>
<td>182,542</td>
<td>89,896</td>
<td>49%</td>
</tr>
<tr>
<td>Site K</td>
<td>268,881</td>
<td>272,587</td>
<td>86,711</td>
<td>32%</td>
</tr>
<tr>
<td>Site L</td>
<td>326,724</td>
<td>208,888</td>
<td>146,180</td>
<td>70%</td>
</tr>
<tr>
<td>Site M</td>
<td>523,637</td>
<td>398,443</td>
<td>240,545</td>
<td>60%</td>
</tr>
<tr>
<td>Site N</td>
<td>272,840</td>
<td>225,536</td>
<td>111,340</td>
<td>49%</td>
</tr>
<tr>
<td>Site O</td>
<td>135,632</td>
<td>97,992</td>
<td>56,463</td>
<td>57%</td>
</tr>
<tr>
<td>Site P</td>
<td>55,595</td>
<td>43,345</td>
<td>30,658</td>
<td>71%</td>
</tr>
<tr>
<td>Site Q</td>
<td>228,063</td>
<td>193,633</td>
<td>98,285</td>
<td>51%</td>
</tr>
<tr>
<td>Site R</td>
<td>592,450</td>
<td>640,656</td>
<td>296,894</td>
<td>46%</td>
</tr>
<tr>
<td>Site S</td>
<td>426,925</td>
<td>362,416</td>
<td>227,910</td>
<td>63%</td>
</tr>
<tr>
<td>Site T</td>
<td>198,743</td>
<td>328,331</td>
<td>133,303</td>
<td>41%</td>
</tr>
<tr>
<td>Totals</td>
<td>4,889,519</td>
<td>4,327,560</td>
<td>2,248,082</td>
<td>52%</td>
</tr>
</tbody>
</table>
Table 6-7: Field shelterbelt classification accuracy

<table>
<thead>
<tr>
<th>Site</th>
<th>Classified Shelterbelt Areas m²</th>
<th>Manual Shelterbelt Area m²</th>
<th>Correctly Classified Areas m²</th>
<th>Classification Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>95,200</td>
<td>85,775</td>
<td>45,601</td>
<td>53%</td>
</tr>
<tr>
<td>Site B</td>
<td>280,866</td>
<td>304,923</td>
<td>113,462</td>
<td>37%</td>
</tr>
<tr>
<td>Site C</td>
<td>19,120</td>
<td>6,155</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Site D</td>
<td>281</td>
<td>5,281</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Site E</td>
<td>24,801</td>
<td>25,656</td>
<td>11,655</td>
<td>45%</td>
</tr>
<tr>
<td>Site F</td>
<td>284,414</td>
<td>439,819</td>
<td>161,599</td>
<td>37%</td>
</tr>
<tr>
<td>Site G</td>
<td>44,879</td>
<td>32,673</td>
<td>14,331</td>
<td>44%</td>
</tr>
<tr>
<td>Site H</td>
<td>25,375</td>
<td>31,675</td>
<td>7,522</td>
<td>24%</td>
</tr>
<tr>
<td>Site I</td>
<td>69,324</td>
<td>84,835</td>
<td>19,721</td>
<td>23%</td>
</tr>
<tr>
<td>Site J</td>
<td>284,039</td>
<td>380,969</td>
<td>134,555</td>
<td>35%</td>
</tr>
<tr>
<td>Site K</td>
<td>73,575</td>
<td>47,412</td>
<td>12,822</td>
<td>27%</td>
</tr>
<tr>
<td>Site L</td>
<td>249,345</td>
<td>228,821</td>
<td>89,051</td>
<td>39%</td>
</tr>
<tr>
<td>Site M</td>
<td>188,537</td>
<td>209,187</td>
<td>91,299</td>
<td>44%</td>
</tr>
<tr>
<td>Site N</td>
<td>2,233,682</td>
<td>3,280,304</td>
<td>1,699,853</td>
<td>52%</td>
</tr>
<tr>
<td>Site O</td>
<td>204,811</td>
<td>337,032</td>
<td>136,623</td>
<td>41%</td>
</tr>
<tr>
<td>Site P</td>
<td>252,109</td>
<td>356,610</td>
<td>203,672</td>
<td>57%</td>
</tr>
<tr>
<td>Site Q</td>
<td>1,288,369</td>
<td>1,289,583</td>
<td>773,807</td>
<td>60%</td>
</tr>
<tr>
<td>Site R</td>
<td>284,443</td>
<td>246,543</td>
<td>110,854</td>
<td>45%</td>
</tr>
<tr>
<td>Site S</td>
<td>1,277,431</td>
<td>1,272,874</td>
<td>576,009</td>
<td>45%</td>
</tr>
<tr>
<td>Site T</td>
<td>126,718</td>
<td>176,037</td>
<td>51,299</td>
<td>29%</td>
</tr>
<tr>
<td>Totals</td>
<td>7,337,319</td>
<td>8,842,164</td>
<td>4,253,735</td>
<td>48%</td>
</tr>
</tbody>
</table>
Table 6-8: Farmyard shelterbelt omission errors

<table>
<thead>
<tr>
<th>Site</th>
<th>Farmyard Shelterbelt Area m²</th>
<th>Omitted Areas m²</th>
<th>Omission Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>155,729</td>
<td>77,762</td>
<td>50%</td>
</tr>
<tr>
<td>Site B</td>
<td>230,805</td>
<td>96,633</td>
<td>42%</td>
</tr>
<tr>
<td>Site C</td>
<td>104,983</td>
<td>48,005</td>
<td>46%</td>
</tr>
<tr>
<td>Site D</td>
<td>80,125</td>
<td>40,384</td>
<td>50%</td>
</tr>
<tr>
<td>Site E</td>
<td>200,798</td>
<td>81,098</td>
<td>40%</td>
</tr>
<tr>
<td>Site F</td>
<td>197,965</td>
<td>81,332</td>
<td>41%</td>
</tr>
<tr>
<td>Site G</td>
<td>155,599</td>
<td>105,533</td>
<td>68%</td>
</tr>
<tr>
<td>Site H</td>
<td>144,900</td>
<td>56,936</td>
<td>40%</td>
</tr>
<tr>
<td>Site I</td>
<td>102,287</td>
<td>55,611</td>
<td>54%</td>
</tr>
<tr>
<td>Site J</td>
<td>182,542</td>
<td>92,646</td>
<td>51%</td>
</tr>
<tr>
<td>Site K</td>
<td>272,587</td>
<td>185,876</td>
<td>69%</td>
</tr>
<tr>
<td>Site L</td>
<td>208,888</td>
<td>62,708</td>
<td>30%</td>
</tr>
<tr>
<td>Site M</td>
<td>398,443</td>
<td>157,898</td>
<td>40%</td>
</tr>
<tr>
<td>Site N</td>
<td>225,536</td>
<td>114,196</td>
<td>51%</td>
</tr>
<tr>
<td>Site O</td>
<td>97,992</td>
<td>41,529</td>
<td>42%</td>
</tr>
<tr>
<td>Site P</td>
<td>43,345</td>
<td>12,687</td>
<td>30%</td>
</tr>
<tr>
<td>Site Q</td>
<td>193,633</td>
<td>95,348</td>
<td>50%</td>
</tr>
<tr>
<td>Site R</td>
<td>640,656</td>
<td>343,762</td>
<td>54%</td>
</tr>
<tr>
<td>Site S</td>
<td>362,416</td>
<td>134,506</td>
<td>38%</td>
</tr>
<tr>
<td>Site T</td>
<td>328,331</td>
<td>195,028</td>
<td>60%</td>
</tr>
<tr>
<td>Totals</td>
<td>4,327,560</td>
<td>2,079,478</td>
<td>48%</td>
</tr>
</tbody>
</table>
### Table 6-9: Field shelterbelt omission errors

<table>
<thead>
<tr>
<th>Site</th>
<th>Field Shelterbelt Area m²</th>
<th>Omitted Areas m²</th>
<th>Omission Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>85,775</td>
<td>40,174</td>
<td>47%</td>
</tr>
<tr>
<td>Site B</td>
<td>304,923</td>
<td>191,461</td>
<td>63%</td>
</tr>
<tr>
<td>Site C</td>
<td>6,155</td>
<td>6,155</td>
<td>100%</td>
</tr>
<tr>
<td>Site D</td>
<td>5,281</td>
<td>5,281</td>
<td>100%</td>
</tr>
<tr>
<td>Site E</td>
<td>25,656</td>
<td>14,001</td>
<td>54%</td>
</tr>
<tr>
<td>Site F</td>
<td>439,819</td>
<td>278,220</td>
<td>63%</td>
</tr>
<tr>
<td>Site G</td>
<td>32,673</td>
<td>18,342</td>
<td>56%</td>
</tr>
<tr>
<td>Site H</td>
<td>31,675</td>
<td>24,153</td>
<td>76%</td>
</tr>
<tr>
<td>Site I</td>
<td>84,835</td>
<td>65,114</td>
<td>77%</td>
</tr>
<tr>
<td>Site J</td>
<td>380,969</td>
<td>246,414</td>
<td>65%</td>
</tr>
<tr>
<td>Site K</td>
<td>47,412</td>
<td>34,590</td>
<td>73%</td>
</tr>
<tr>
<td>Site L</td>
<td>228,821</td>
<td>139,770</td>
<td>61%</td>
</tr>
<tr>
<td>Site M</td>
<td>209,187</td>
<td>117,888</td>
<td>56%</td>
</tr>
<tr>
<td>Site N</td>
<td>3,280,304</td>
<td>1,580,451</td>
<td>48%</td>
</tr>
<tr>
<td>Site O</td>
<td>337,032</td>
<td>200,409</td>
<td>59%</td>
</tr>
<tr>
<td>Site P</td>
<td>356,610</td>
<td>152,938</td>
<td>43%</td>
</tr>
<tr>
<td>Site Q</td>
<td>1,289,583</td>
<td>515,776</td>
<td>40%</td>
</tr>
<tr>
<td>Site R</td>
<td>246,543</td>
<td>135,689</td>
<td>55%</td>
</tr>
<tr>
<td>Site S</td>
<td>1,272,874.00</td>
<td>696,865</td>
<td>55%</td>
</tr>
<tr>
<td>Site T</td>
<td>176,037</td>
<td>124,738</td>
<td>71%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8,842,164</strong></td>
<td><strong>4,588,429</strong></td>
<td><strong>52%</strong></td>
</tr>
</tbody>
</table>
Most of the mis-classified areas were the result of errors of commission, where areas that were classified as shelterbelt objects but were, in fact, not shelterbelts. Commission errors were 55% (Tab. 6-11) for farmyard shelterbelts and 58% (Tab. 6-10) for field shelterbelts.

Table 6-10: Field shelterbelt area commission errors

<table>
<thead>
<tr>
<th>Site</th>
<th>Classified Field Shelterbelt Areas m²</th>
<th>Commission Areas m²</th>
<th>Commission Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>95,200</td>
<td>49,599</td>
<td>52%</td>
</tr>
<tr>
<td>Site B</td>
<td>280,866</td>
<td>167,404</td>
<td>56%</td>
</tr>
<tr>
<td>Site C</td>
<td>19,120</td>
<td>19,120</td>
<td>100%</td>
</tr>
<tr>
<td>Site D</td>
<td>281</td>
<td>281</td>
<td>100%</td>
</tr>
<tr>
<td>Site E</td>
<td>24,801</td>
<td>13,146</td>
<td>53%</td>
</tr>
<tr>
<td>Site F</td>
<td>284,414</td>
<td>122,815</td>
<td>43%</td>
</tr>
<tr>
<td>Site G</td>
<td>44,879</td>
<td>30,548</td>
<td>68%</td>
</tr>
<tr>
<td>Site H</td>
<td>25,375</td>
<td>17,853</td>
<td>70%</td>
</tr>
<tr>
<td>Site I</td>
<td>69,324</td>
<td>49,603</td>
<td>71%</td>
</tr>
<tr>
<td>Site J</td>
<td>284,039</td>
<td>149,484</td>
<td>53%</td>
</tr>
<tr>
<td>Site K</td>
<td>73,575</td>
<td>60,753</td>
<td>83%</td>
</tr>
<tr>
<td>Site L</td>
<td>249,345</td>
<td>160,294</td>
<td>65%</td>
</tr>
<tr>
<td>Site M</td>
<td>188,537</td>
<td>97,238</td>
<td>52%</td>
</tr>
<tr>
<td>Site N</td>
<td>2,263,682</td>
<td>563,829</td>
<td>25%</td>
</tr>
<tr>
<td>Site O</td>
<td>204,811</td>
<td>68,188</td>
<td>33%</td>
</tr>
<tr>
<td>Site P</td>
<td>252,109</td>
<td>48,437</td>
<td>19%</td>
</tr>
<tr>
<td>Site Q</td>
<td>1,288,369</td>
<td>514,562</td>
<td>40%</td>
</tr>
<tr>
<td>Site R</td>
<td>284,443</td>
<td>173,589</td>
<td>61%</td>
</tr>
<tr>
<td>Site S</td>
<td>1,277,431</td>
<td>701,422</td>
<td>55%</td>
</tr>
<tr>
<td>Site T</td>
<td>126,718</td>
<td>75,419</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>7,337,319</strong></td>
<td><strong>4,262,009</strong></td>
<td><strong>58%</strong></td>
</tr>
<tr>
<td>Site</td>
<td>Classified Farmyard Shelterbelt Areas m²</td>
<td>Commission Areas m²</td>
<td>Commission Errors</td>
</tr>
<tr>
<td>-------</td>
<td>------------------------------------------</td>
<td>---------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Site A</td>
<td>166,917</td>
<td>88,950</td>
<td>53%</td>
</tr>
<tr>
<td>Site B</td>
<td>266,694</td>
<td>132,522</td>
<td>50%</td>
</tr>
<tr>
<td>Site C</td>
<td>132,827</td>
<td>75,849</td>
<td>57%</td>
</tr>
<tr>
<td>Site D</td>
<td>122,220</td>
<td>82,479</td>
<td>67%</td>
</tr>
<tr>
<td>Site E</td>
<td>230,901</td>
<td>111,201</td>
<td>48%</td>
</tr>
<tr>
<td>Site F</td>
<td>286,572</td>
<td>169,939</td>
<td>59%</td>
</tr>
<tr>
<td>Site G</td>
<td>129,390</td>
<td>79,324</td>
<td>61%</td>
</tr>
<tr>
<td>Site H</td>
<td>181,893</td>
<td>93,929</td>
<td>52%</td>
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<tr>
<td>Site I</td>
<td>127,074</td>
<td>80,398</td>
<td>63%</td>
</tr>
<tr>
<td>Site J</td>
<td>215,541</td>
<td>125,645</td>
<td>58%</td>
</tr>
<tr>
<td>Site K</td>
<td>268,881</td>
<td>182,170</td>
<td>68%</td>
</tr>
<tr>
<td>Site L</td>
<td>326,724</td>
<td>180,544</td>
<td>55%</td>
</tr>
<tr>
<td>Site M</td>
<td>523,637</td>
<td>283,092</td>
<td>54%</td>
</tr>
<tr>
<td>Site N</td>
<td>272,840</td>
<td>161,500</td>
<td>59%</td>
</tr>
<tr>
<td>Site O</td>
<td>135,632</td>
<td>79,169</td>
<td>58%</td>
</tr>
<tr>
<td>Site P</td>
<td>55,595</td>
<td>24,937</td>
<td>45%</td>
</tr>
<tr>
<td>Site Q</td>
<td>228,063</td>
<td>129,778</td>
<td>57%</td>
</tr>
<tr>
<td>Site R</td>
<td>592,450</td>
<td>295,556</td>
<td>50%</td>
</tr>
<tr>
<td>Site S</td>
<td>426,925</td>
<td>199,015</td>
<td>47%</td>
</tr>
<tr>
<td>Site T</td>
<td>198,743</td>
<td>65,440</td>
<td>33%</td>
</tr>
<tr>
<td>Totals</td>
<td>4,889,519</td>
<td>2,641,437</td>
<td>54%</td>
</tr>
</tbody>
</table>
Rather than tallying the total shelterbelt area, another way to assess the accuracy of the shelterbelt inventory is to determine if the procedure could correctly locate known shelterbelts. Location accuracy was much higher than area accuracy. It was found that 83% (Tab. 6-12) of field shelterbelts found on the ground were totally or partially classified. For farmyard shelterbelts the accuracy was slightly less at 80% (Tab. 6-12).

<table>
<thead>
<tr>
<th>Site</th>
<th>Manually Digitized Field Shelterbelts</th>
<th>Field Shelterbelts Classified</th>
<th>Accuracy</th>
<th>Manually Digitized Farmyard Shelterbelts</th>
<th>Farmyard Shelterbelts Classified</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>106</td>
<td>66</td>
<td>62%</td>
<td>123</td>
<td>87</td>
<td>71%</td>
</tr>
<tr>
<td>Site B</td>
<td>160</td>
<td>111</td>
<td>69%</td>
<td>158</td>
<td>140</td>
<td>89%</td>
</tr>
<tr>
<td>Site C</td>
<td>2</td>
<td>0</td>
<td>0%</td>
<td>74</td>
<td>60</td>
<td>81%</td>
</tr>
<tr>
<td>Site D</td>
<td>3</td>
<td>0</td>
<td>0%</td>
<td>51</td>
<td>34</td>
<td>67%</td>
</tr>
<tr>
<td>Site E</td>
<td>15</td>
<td>8</td>
<td>53%</td>
<td>113</td>
<td>85</td>
<td>75%</td>
</tr>
<tr>
<td>Site F</td>
<td>179</td>
<td>117</td>
<td>65%</td>
<td>144</td>
<td>119</td>
<td>83%</td>
</tr>
<tr>
<td>Site G</td>
<td>12</td>
<td>9</td>
<td>75%</td>
<td>91</td>
<td>67</td>
<td>74%</td>
</tr>
<tr>
<td>Site H</td>
<td>17</td>
<td>10</td>
<td>59%</td>
<td>112</td>
<td>68</td>
<td>61%</td>
</tr>
<tr>
<td>Site I</td>
<td>54</td>
<td>24</td>
<td>44%</td>
<td>98</td>
<td>70</td>
<td>71%</td>
</tr>
<tr>
<td>Site J</td>
<td>198</td>
<td>144</td>
<td>73%</td>
<td>182</td>
<td>150</td>
<td>82%</td>
</tr>
<tr>
<td>Site K</td>
<td>14</td>
<td>8</td>
<td>57%</td>
<td>117</td>
<td>82</td>
<td>70%</td>
</tr>
<tr>
<td>Site L</td>
<td>132</td>
<td>100</td>
<td>76%</td>
<td>144</td>
<td>137</td>
<td>95%</td>
</tr>
<tr>
<td>Site M</td>
<td>63</td>
<td>44</td>
<td>70%</td>
<td>149</td>
<td>127</td>
<td>85%</td>
</tr>
<tr>
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<td>1,785</td>
<td>1,592</td>
<td>89%</td>
<td>165</td>
<td>127</td>
<td>77%</td>
</tr>
<tr>
<td>Site O</td>
<td>185</td>
<td>159</td>
<td>86%</td>
<td>98</td>
<td>83</td>
<td>85%</td>
</tr>
<tr>
<td>Site P</td>
<td>343</td>
<td>300</td>
<td>87%</td>
<td>60</td>
<td>53</td>
<td>88%</td>
</tr>
<tr>
<td>Site Q</td>
<td>612</td>
<td>570</td>
<td>93%</td>
<td>134</td>
<td>117</td>
<td>87%</td>
</tr>
<tr>
<td>Site R</td>
<td>64</td>
<td>52</td>
<td>81%</td>
<td>247</td>
<td>228</td>
<td>92%</td>
</tr>
<tr>
<td>Site S</td>
<td>622</td>
<td>503</td>
<td>81%</td>
<td>178</td>
<td>165</td>
<td>93%</td>
</tr>
<tr>
<td>Site T</td>
<td>57</td>
<td>32</td>
<td>56%</td>
<td>182</td>
<td>103</td>
<td>57%</td>
</tr>
<tr>
<td>Totals</td>
<td>4,623</td>
<td>3,849</td>
<td>83%</td>
<td>2,620</td>
<td>2,102</td>
<td>80%</td>
</tr>
</tbody>
</table>

6.3.1 Analysis of Omission Errors

While most of the shelterbelts that exist on the ground were found in the imagery (Tab. 6-12), there is little agreement on how the shelterbelt boundaries are defined.
Additional analyses show that those shelterbelt areas that were considered as errors of omission were, in fact, found to be in contact with areas that were correctly classified as field shelterbelts 71% of the time for field shelterbelts (Tab. 6-13) and 65% of the time for farmyard shelterbelts (Tab. 6-14).

Table 6-13: Location of field shelterbelt omission errors

<table>
<thead>
<tr>
<th>Site</th>
<th>Omission Area m²</th>
<th>Omission Area Adjacent to Classified Area m²</th>
<th>% Omission Area Adjacent to Classified Area</th>
<th>Omission Area Not Adjacent to Classified Area m²</th>
<th>% Omission Area Not Adjacent to Classified Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>40,174</td>
<td>28216</td>
<td>70%</td>
<td>11,958</td>
<td>30%</td>
</tr>
<tr>
<td>Site B</td>
<td>191,461</td>
<td>105,278</td>
<td>55%</td>
<td>86,183</td>
<td>45%</td>
</tr>
<tr>
<td>Site C</td>
<td>6,155</td>
<td>0</td>
<td>0%</td>
<td>6,155</td>
<td>100%</td>
</tr>
<tr>
<td>Site D</td>
<td>5,281</td>
<td>0</td>
<td>0%</td>
<td>5,281</td>
<td>100%</td>
</tr>
<tr>
<td>Site E</td>
<td>14,001</td>
<td>5,233</td>
<td>37%</td>
<td>8,768</td>
<td>63%</td>
</tr>
<tr>
<td>Site F</td>
<td>278,220</td>
<td>179,910</td>
<td>65%</td>
<td>98,310</td>
<td>35%</td>
</tr>
<tr>
<td>Site G</td>
<td>18,342</td>
<td>14,408</td>
<td>79%</td>
<td>3,934</td>
<td>21%</td>
</tr>
<tr>
<td>Site H</td>
<td>24,153</td>
<td>9,616</td>
<td>40%</td>
<td>14,537</td>
<td>60%</td>
</tr>
<tr>
<td>Site I</td>
<td>65,114</td>
<td>20,171</td>
<td>31%</td>
<td>44,943</td>
<td>69%</td>
</tr>
<tr>
<td>Site J</td>
<td>246,414</td>
<td>140,156</td>
<td>57%</td>
<td>106,258</td>
<td>43%</td>
</tr>
<tr>
<td>Site K</td>
<td>34,590</td>
<td>17,572</td>
<td>51%</td>
<td>17,018</td>
<td>49%</td>
</tr>
<tr>
<td>Site L</td>
<td>139,770</td>
<td>91,864</td>
<td>66%</td>
<td>47,906</td>
<td>34%</td>
</tr>
<tr>
<td>Site M</td>
<td>117,888</td>
<td>64,792</td>
<td>55%</td>
<td>53,096</td>
<td>45%</td>
</tr>
<tr>
<td>Site N</td>
<td>1,580,451</td>
<td>1,263,863</td>
<td>80%</td>
<td>316,588</td>
<td>20%</td>
</tr>
<tr>
<td>Site O</td>
<td>200,409</td>
<td>157,613</td>
<td>79%</td>
<td>42,796</td>
<td>21%</td>
</tr>
<tr>
<td>Site P</td>
<td>152,938</td>
<td>128,743</td>
<td>84%</td>
<td>24,195</td>
<td>16%</td>
</tr>
<tr>
<td>Site Q</td>
<td>515,776</td>
<td>438,300</td>
<td>85%</td>
<td>77,476</td>
<td>15%</td>
</tr>
<tr>
<td>Site R</td>
<td>135,689</td>
<td>94,838</td>
<td>70%</td>
<td>40,851</td>
<td>30%</td>
</tr>
<tr>
<td>Site S</td>
<td>696,865</td>
<td>458,398</td>
<td>66%</td>
<td>238,467</td>
<td>34%</td>
</tr>
<tr>
<td>Site T</td>
<td>124,738</td>
<td>37,889</td>
<td>30%</td>
<td>86,849</td>
<td>70%</td>
</tr>
<tr>
<td>Totals</td>
<td>4,588,429</td>
<td>3,256,860</td>
<td>71%</td>
<td>1,331,569</td>
<td>29%</td>
</tr>
</tbody>
</table>
A review of the omitted areas suggests several reasons why they were not included in the classification. First, the errors of omission were especially pronounced on images where there was inconsistent tonal variation. For example, the images for some sites were composed of a mosaic of different images, each acquired on a different date and to which a different contrast enhancement had been applied. These mosaics produced image regions containing values that were different from the values in the areas where the classification rules were established. While image mosaics were the dominant source of tonal variations, some scene brightness changes of natural origin

Table 6-14: Location of farmyard shelterbelt omission errors

<table>
<thead>
<tr>
<th>Site</th>
<th>Omission Area m²</th>
<th>Omission Area Adjacent to Classified Area m²</th>
<th>% Omission Area Adjacent to Classified Area</th>
<th>Omission Area Not Adjacent to Classified Area m²</th>
<th>% Omission Area Not Adjacent to Classified Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>77,762</td>
<td>42,186</td>
<td>54%</td>
<td>35,576</td>
<td>46%</td>
</tr>
<tr>
<td>Site B</td>
<td>96,633</td>
<td>81,316</td>
<td>84%</td>
<td>15,317</td>
<td>16%</td>
</tr>
<tr>
<td>Site C</td>
<td>48,005</td>
<td>34,682</td>
<td>72%</td>
<td>13,323</td>
<td>28%</td>
</tr>
<tr>
<td>Site D</td>
<td>40,384</td>
<td>24,165</td>
<td>60%</td>
<td>16,219</td>
<td>40%</td>
</tr>
<tr>
<td>Site E</td>
<td>81,098</td>
<td>30,928</td>
<td>38%</td>
<td>50,170</td>
<td>62%</td>
</tr>
<tr>
<td>Site F</td>
<td>81,332</td>
<td>64,681</td>
<td>80%</td>
<td>16,651</td>
<td>20%</td>
</tr>
<tr>
<td>Site G</td>
<td>105,533</td>
<td>71,811</td>
<td>68%</td>
<td>33,722</td>
<td>32%</td>
</tr>
<tr>
<td>Site H</td>
<td>56,936</td>
<td>20,259</td>
<td>36%</td>
<td>36,677</td>
<td>64%</td>
</tr>
<tr>
<td>Site I</td>
<td>55,611</td>
<td>20,660</td>
<td>37%</td>
<td>34,951</td>
<td>63%</td>
</tr>
<tr>
<td>Site J</td>
<td>92,646</td>
<td>5,6784</td>
<td>61%</td>
<td>35,862</td>
<td>39%</td>
</tr>
<tr>
<td>Site K</td>
<td>185,876</td>
<td>108,796</td>
<td>59%</td>
<td>77,080</td>
<td>41%</td>
</tr>
<tr>
<td>Site L</td>
<td>62,708</td>
<td>53,473</td>
<td>85%</td>
<td>9,235</td>
<td>15%</td>
</tr>
<tr>
<td>Site M</td>
<td>157,898</td>
<td>93,791</td>
<td>59%</td>
<td>64,107</td>
<td>41%</td>
</tr>
<tr>
<td>Site N</td>
<td>114,196</td>
<td>65,498</td>
<td>57%</td>
<td>48,698</td>
<td>43%</td>
</tr>
<tr>
<td>Site O</td>
<td>41,529</td>
<td>23,760</td>
<td>57%</td>
<td>17,769</td>
<td>43%</td>
</tr>
<tr>
<td>Site P</td>
<td>12,687</td>
<td>10,809</td>
<td>85%</td>
<td>1,878</td>
<td>15%</td>
</tr>
<tr>
<td>Site Q</td>
<td>95,348</td>
<td>74,229</td>
<td>78%</td>
<td>21,119</td>
<td>22%</td>
</tr>
<tr>
<td>Site R</td>
<td>343,762</td>
<td>289,335</td>
<td>84%</td>
<td>54,427</td>
<td>16%</td>
</tr>
<tr>
<td>Site S</td>
<td>134,339</td>
<td>107,713</td>
<td>80%</td>
<td>26,626</td>
<td>20%</td>
</tr>
<tr>
<td>Site T</td>
<td>196,236</td>
<td>72,880</td>
<td>37%</td>
<td>123,356</td>
<td>63%</td>
</tr>
<tr>
<td>Totals</td>
<td>2,080,519</td>
<td>134,7756</td>
<td>65%</td>
<td>732,763</td>
<td>35%</td>
</tr>
</tbody>
</table>
were also evident. At site T an area of high cloud caused the brightness values of the centre parts of the scene to be much higher than the other objects within the image (Fig. 6-6), leading to higher error rates in these areas.

Figure 6-6: High clouds found on site T

A second source of the omission errors came from inaccuracies in the ancillary data used in the classification. For example, the farmyard classification rule set depended largely on finding shelterbelts within 150 m of a building. However, most of the errors in farmyard shelterbelt identification arose when buildings were not present in
the topographic data set. This was common when the farmyard was too new to be included in the most recent edition of the National Topographic dataset (Fig. 6-7).

Site G Missing Building Points

![Image of Site G Missing Building Points]

**Figure 6-7: Site G missing building points**

Atypical shelterbelt configurations also caused many of the errors of omission. In some sites, for example, there were farmyards that were significantly larger than the 150 m buffer around farm buildings that was used to define these features. Parts of the shelterbelt that were beyond this buffer threshold were not included in the classification.
Another atypical configuration was created in situations where the shelterbelt was composed of a collection of disjoint stands rather than one continuous length of trees. Poor shelterbelt condition, as a result of shelterbelt age or improper planting, created areas where there were not enough trees to be recognized as a shelterbelt. It may be argued that these areas are not in fact shelterbelts anymore because they do not provide any of the functions. Still, they were at one time part of the shelterbelt and so should be recognized as such.

To test the extent to which omitted areas affected the overall classification accuracies buffers were added around the classified areas in an attempt to fill in small gaps. Buffers of 1 metre and 2.5 metres were used. While the buffers did increase the area accuracy for both field and farmyard shelterbelts, they did so at the cost of much higher commission errors.

6.3.2 Analysis of Commission Errors

Narrow strips of grass were often confused with shelterbelts because, like shelterbelts, they were narrow and long and had similar textural properties. The majority of these commission errors occurred along roads where grassy ditches could not be consistently removed due to poor georegistration between the road and image data.

The rate at which commission errors for field shelterbelts occurred was inversely proportional to the number of shelterbelts in the area. For example, sites C and D only had 2 or 3 real shelterbelts across their extents, and none of them were classified, resulting in 100% commission error. Other sites (e.g., E, G, H and K) that had less than twenty field shelterbelts in reality also had high commission errors (over 55%).
Conversely, the sites that had the most shelterbelts also had the lowest commission error rates. For example, over 180 actual shelterbelts were tabulated at each of sites N, O, P and Q and commission error rates were under 40%. These sites also had the highest accuracy in terms of both area and location.

Commission errors around field shelterbelts were mostly due to the inclusion of adjacent areas in the classification. For example, grassy areas were frequently included along the edges of true shelterbelts. (Fig. 6-8)

Figure 6-8: Commission errors found around edges of field shelterbelts
6.4 Shelterbelt Carbon Sequestration

The classification results were combined with seedling distribution records from the Agroforestry Development Centre in Indian Head to estimate the amount of above-ground carbon that is being sequestered by shelterbelts in Saskatchewan. Sequestration amounts were calculated based on the number of kilometres of shelterbelts for each of the species found in the classification.

The total length of shelterbelts classified within the twenty sites was 1575 kilometres of field shelterbelts and 1041 kilometres of farmyard shelterbelts (Tab. 6-15). Length was determined from the original value determined from the Definiens classification values. However, the total lengths determined from the manually digitized shelterbelts were 310 km longer for field shelterbelts and 122 km shorter for farmyard shelterbelts (Tab. 6:15). When comparing the total amount of shelterbelts classified and actual shelterbelts on the ground it was found that 7% fewer shelterbelts were classified than actual shelterbelts on the ground.

There was a large range of results for field shelterbelts. Three of the twenty sites in the study had over one hundred kilometres of shelterbelts. The site with the greatest length of shelterbelts was site N, at 442 km (Tab. 6-15). Site N is located near Conquest, Saskatchewan which has been used as research site for development of field shelterbelts (Howe, 1988). While a few sites had less than ten kilometres of field shelterbelts, the majority had between 10 and 100 km.
Many sites had between 30 and 70 km of farmyard shelterbelts. Extreme values ranged between 120 km at site R while at site P the total length was only 12 km (Tab. 6-15).

The difference between the actual length compared to that of the distance found using the classification procedures are not dissimilar. Using the numbers provided in the classification to estimate carbon sequestration would produce results that would be near to the actual shelterbelts found on the ground.

Table 6-15: Total length of shelterbelts

<table>
<thead>
<tr>
<th>Site</th>
<th>Manual Digitized Km. of Farmyard Shelterbelts</th>
<th>Km. of Farmyard Shelterbelts Classified</th>
<th>Manual Digitized Km of Field Shelterbelts</th>
<th>Km. of Field Shelterbelts Classified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>33.9</td>
<td>36.3</td>
<td>18.7</td>
<td>20.7</td>
</tr>
<tr>
<td>Site B</td>
<td>46.7</td>
<td>53.9</td>
<td>61.7</td>
<td>56.9</td>
</tr>
<tr>
<td>Site C</td>
<td>22.3</td>
<td>28.2</td>
<td>1.3</td>
<td>3.5</td>
</tr>
<tr>
<td>Site D</td>
<td>18.7</td>
<td>28.5</td>
<td>1.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Site E</td>
<td>37.8</td>
<td>43.4</td>
<td>4.9</td>
<td>4.7</td>
</tr>
<tr>
<td>Site F</td>
<td>42.5</td>
<td>61.5</td>
<td>94.4</td>
<td>61</td>
</tr>
<tr>
<td>Site G</td>
<td>42.7</td>
<td>35.5</td>
<td>8.9</td>
<td>12.3</td>
</tr>
<tr>
<td>Site H</td>
<td>30.9</td>
<td>38.9</td>
<td>6.8</td>
<td>5.4</td>
</tr>
<tr>
<td>Site I</td>
<td>22.2</td>
<td>27.6</td>
<td>18.4</td>
<td>15</td>
</tr>
<tr>
<td>Site J</td>
<td>46.3</td>
<td>54.66</td>
<td>96.6</td>
<td>72</td>
</tr>
<tr>
<td>Site K</td>
<td>51.6</td>
<td>50.9</td>
<td>8.9</td>
<td>13.9</td>
</tr>
<tr>
<td>Site L</td>
<td>43.5</td>
<td>68.3</td>
<td>47.6</td>
<td>51.9</td>
</tr>
<tr>
<td>Site M</td>
<td>818</td>
<td>107.5</td>
<td>42.9</td>
<td>38.7</td>
</tr>
<tr>
<td>Site N</td>
<td>44.1</td>
<td>53.35</td>
<td>641.4</td>
<td>442.6</td>
</tr>
<tr>
<td>Site O</td>
<td>22.4</td>
<td>31</td>
<td>77</td>
<td>46.8</td>
</tr>
<tr>
<td>Site P</td>
<td>9.8</td>
<td>12.6</td>
<td>80.8</td>
<td>57.1</td>
</tr>
<tr>
<td>Site Q</td>
<td>45.1</td>
<td>53.2</td>
<td>300.5</td>
<td>300.2</td>
</tr>
<tr>
<td>Site R</td>
<td>129.9</td>
<td>120.2</td>
<td>50.</td>
<td>57.7</td>
</tr>
<tr>
<td>Site S</td>
<td>82.1</td>
<td>96.7</td>
<td>288.2</td>
<td>289.1</td>
</tr>
<tr>
<td>Site T</td>
<td>65.6</td>
<td>39.7</td>
<td>35.2</td>
<td>25.3</td>
</tr>
<tr>
<td>Totals</td>
<td>919.8</td>
<td>1041.5</td>
<td>1885.52</td>
<td>1575.72</td>
</tr>
<tr>
<td>Per Sq km</td>
<td>.49</td>
<td>.56</td>
<td>1.01</td>
<td>.84</td>
</tr>
<tr>
<td>Estimate Provincial Total*</td>
<td>128,245</td>
<td>145,207</td>
<td>262,890</td>
<td>219,695</td>
</tr>
</tbody>
</table>
Carbon sequestered in the above-ground mass of the shelterbelts in the 20 study sites was calculated to be 99,110 t. It was estimate that 53 t of carbon per square kilometre of agricultural was being sequestered in shelterbelts. When applied across the entire agricultural area based on my results for the twenty sites, my estimate is 14 million t of carbon being stored within shelterbelts.

Table 6-16: Classification; total above-ground carbon sequestered

<table>
<thead>
<tr>
<th>Site</th>
<th>Field Shelterbelts</th>
<th>Farmyard Shelterbelts</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>840</td>
<td>1426</td>
<td>2267</td>
</tr>
<tr>
<td>Site B</td>
<td>2079</td>
<td>1974</td>
<td>4054</td>
</tr>
<tr>
<td>Site C</td>
<td>121</td>
<td>974</td>
<td>1096.</td>
</tr>
<tr>
<td>Site D</td>
<td>2</td>
<td>1130</td>
<td>1133</td>
</tr>
<tr>
<td>Site E</td>
<td>165</td>
<td>1539</td>
<td>1704</td>
</tr>
<tr>
<td>Site F</td>
<td>1711</td>
<td>1724</td>
<td>3437</td>
</tr>
<tr>
<td>Site G</td>
<td>485</td>
<td>1103</td>
<td>1589</td>
</tr>
<tr>
<td>Site H</td>
<td>174</td>
<td>1254</td>
<td>1429</td>
</tr>
<tr>
<td>Site I</td>
<td>459</td>
<td>842</td>
<td>1302</td>
</tr>
<tr>
<td>Site J</td>
<td>1744</td>
<td>1323</td>
<td>3068</td>
</tr>
<tr>
<td>Site K</td>
<td>464</td>
<td>1696</td>
<td>2161</td>
</tr>
<tr>
<td>Site L</td>
<td>1562</td>
<td>2047</td>
<td>3611</td>
</tr>
<tr>
<td>Site M</td>
<td>1749</td>
<td>4859</td>
<td>6609</td>
</tr>
<tr>
<td>Site N</td>
<td>17134</td>
<td>2065</td>
<td>19199</td>
</tr>
<tr>
<td>Site O</td>
<td>1344</td>
<td>890</td>
<td>2235</td>
</tr>
<tr>
<td>Site P</td>
<td>1555</td>
<td>342</td>
<td>1898</td>
</tr>
<tr>
<td>Site Q</td>
<td>9590</td>
<td>1697</td>
<td>11288</td>
</tr>
<tr>
<td>Site R</td>
<td>2524</td>
<td>5257</td>
<td>7782</td>
</tr>
<tr>
<td>Site S</td>
<td>15475</td>
<td>5172</td>
<td>20648</td>
</tr>
<tr>
<td>Site T</td>
<td>1011</td>
<td>1587</td>
<td>2599</td>
</tr>
<tr>
<td>Total</td>
<td>60199</td>
<td>38911</td>
<td>99110</td>
</tr>
<tr>
<td>Per Sq Km</td>
<td>32.26</td>
<td>20.85</td>
<td>53.10</td>
</tr>
<tr>
<td>Provincial Total*</td>
<td>8,393,306</td>
<td>5,425,231</td>
<td>13,818,537</td>
</tr>
<tr>
<td>Yearly Total†</td>
<td>209,892</td>
<td>135,630</td>
<td>345,463</td>
</tr>
</tbody>
</table>

* Per Sq Km x Agricultural Regions Area
† Provincial Total / Tree Life Span (40 years)
The results are based on the total amount of carbon stored during the lifespan of a tree. To determine the amount of carbon that is being sequestered each year the sequestration values were divided by the average lifespan of a shelterbelt. Kort and Turnock (1999) estimated the average lifespan of a tree in a shelterbelt to be about 40 years. Thus, approximately 345,000 t of carbon are being sequestered by shelterbelts in Saskatchewan annually.

### Table 6-17: Total actual above-ground carbon sequestered

<table>
<thead>
<tr>
<th>Site</th>
<th>Field Shelterbelts</th>
<th>Farmyard Shelterbelts</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>733</td>
<td>1331</td>
<td>2064</td>
</tr>
<tr>
<td>Site B</td>
<td>2257</td>
<td>1709</td>
<td>3967</td>
</tr>
<tr>
<td>Site C</td>
<td>45</td>
<td>770</td>
<td>815</td>
</tr>
<tr>
<td>Site D</td>
<td>48</td>
<td>741</td>
<td>790</td>
</tr>
<tr>
<td>Site E</td>
<td>171</td>
<td>1338</td>
<td>1510</td>
</tr>
<tr>
<td>Site F</td>
<td>2647</td>
<td>1191</td>
<td>3839</td>
</tr>
<tr>
<td>Site G</td>
<td>246</td>
<td>1174</td>
<td>1421</td>
</tr>
<tr>
<td>Site H</td>
<td>218</td>
<td>99</td>
<td>318</td>
</tr>
<tr>
<td>Site I</td>
<td>562</td>
<td>678</td>
<td>1241</td>
</tr>
<tr>
<td>Site J</td>
<td>2339</td>
<td>1121</td>
<td>3460</td>
</tr>
<tr>
<td>Site K</td>
<td>299</td>
<td>1720</td>
<td>2019</td>
</tr>
<tr>
<td>Site L</td>
<td>1434</td>
<td>1309</td>
<td>2743</td>
</tr>
<tr>
<td>Site M</td>
<td>1941</td>
<td>3697</td>
<td>5638</td>
</tr>
<tr>
<td>Site N</td>
<td>24829</td>
<td>1707</td>
<td>26536</td>
</tr>
<tr>
<td>Site O</td>
<td>2213</td>
<td>104</td>
<td>2317</td>
</tr>
<tr>
<td>Site P</td>
<td>2199</td>
<td>267</td>
<td>2467</td>
</tr>
<tr>
<td>Site Q</td>
<td>9599</td>
<td>1441</td>
<td>11041</td>
</tr>
<tr>
<td>Site R</td>
<td>2187</td>
<td>5686</td>
<td>7874</td>
</tr>
<tr>
<td>Site S</td>
<td>15420</td>
<td>4391</td>
<td>19811</td>
</tr>
<tr>
<td>Site T</td>
<td>1405</td>
<td>2622</td>
<td>4028</td>
</tr>
<tr>
<td>Total</td>
<td>70800</td>
<td>33098</td>
<td>103898</td>
</tr>
<tr>
<td>Per Sq Km</td>
<td>37.94</td>
<td>17.73</td>
<td>55.67</td>
</tr>
<tr>
<td>Provincial Total*</td>
<td>9,871,384</td>
<td>4,614,726</td>
<td>14,486,110</td>
</tr>
<tr>
<td>Yearly Total†</td>
<td>246,784.60</td>
<td>115,368</td>
<td>362,152</td>
</tr>
</tbody>
</table>

* Per Sq Km x Agricultural Regions Area
† Provincial Total / Tree Life Span (40 years)
From all activities, the Province of Saskatchewan emitted 71.8 million tonnes of carbon into the atmosphere during 2006 (Environment Canada, 2010). Thus 0.67% of yearly emissions are being sequestered by shelterbelts within the province. However, when this analysis is restricted to Saskatchewan’s agricultural and forestry activities the estimated amount of carbon sequestered by shelterbelts is greater than the amount of carbon being emitted. The agriculture and forest industries in Saskatchewan emitted 245,000 tonnes of carbon in 2006 (Environment Canada, 2010). This is less than 51% of the carbon being sequestered by shelterbelts in Saskatchewan.
CHAPTER 7 – Discussion

7.1 Image Data

When identifying the presence of shelterbelts on the landscape, the effectiveness of the classification procedure hinged on the limitations of the SPOT-5 2.5 metre panchromatic imagery. While this imagery proved to be useful in locating both field and farmyard shelterbelts, the data could not be used to define shelterbelt boundaries within a reasonable accuracy of 80%. As a result, area measurements derived from the shelterbelt boundaries sometimes differed from the actual values by as much as 50%.

The lack of area accuracy of the classified shelterbelts can be attributed to the lack of spectral data within the imagery. Without spectral data, the ability to discriminate between different types of vegetation is difficult. For example, in the panchromatic imagery used in this research, grassy areas frequently had brightness values similar to those of trees and it became difficult to classify these features separately. Consequently, the classifications had high errors of commission and omission.

The best way to increase the area measurement accuracy is to use multispectral imagery when available. In particular, near-infrared imagery would enhance the ability to distinguish different types of vegetation on the landscape. For example, Wiseman et al., (2007) were able to use multispectral imagery to determine individual shelterbelt species. However, at the present time, a low-cost, high resolution, multispectral image data source that has complete provincial coverage does not exist.
High spatial resolution imagery would also improve the classification accuracy. The 2.5 metre resolution of the imagery used here should be considered the lowest resolution that could be used with panchromatic images. While these data were used to successfully locate shelterbelts, they lack clarity and create confusion when trying to determine the exact boundaries. The use of panchromatic imagery with 1 metre resolution would enhance the visibility of the shelterbelt borders. However, this method is presently not practical due to the high cost of the data. When higher resolution panchromatic becomes available at a low cost and with complete provincial coverage, it is recommended that this type of imagery be used.

Consequently, there is a need for balance between the cost of acquiring imagery, the purpose of their use, and the effectiveness of the imagery to classify shelterbelts. At the present time, the SPOT-5 2.5 metre panchromatic imagery is the most effective in terms of the cost and purpose because they are available for the entire Prairie region at minimal cost. Cost was the determining factor for use in this study.

7.2 Object-Based Classification

Although one of the original motivations was to devise an object-based classification scheme that could be applied over large areas, this experiment has shown that there is not one simple variable that contributes to the feature values used to classify the image. Rather, there is a complex relationship between a variety of feature values and how each reacts to the conditions of a region during a particular time of the year. As result it is difficult, based on the available imagery, to make a comprehensive generalized classification rule set for the entire province.
A consistent set of imagery, if available, would greatly reduce the variation of some of the features used in the rule set. It would not however reduce all variation from site to site. Features such as texture would still vary from site to site due to changes in the landscape and land use characteristics.

Shape features were the most consistent rules, even when applied to the variable imagery used here. Features such as asymmetry and main direction had consistent values across most sites, probably due to the fact they capture the intentionally design of shelterbelt plantings. Other shape features, such as differences in shelterbelt widths, may change slightly from site to site. These are not artefacts of the imagery, however, but they may change due to the type of species that dominate that site.

Texture features for both farmyard and field shelterbelts are not generalizable over large areas because these parameters varied considerably between sites. Texture variation arises from the different landscapes and land uses found within each site. For example, different land uses such as crop lands and ranch lands produce different GLCM contrast and GLCM homogeneity values.

Nonetheless, if higher resolution multispectral imagery were to become offered at a reasonable cost, it is conceivable that three rule sets could be used to inventory the shelterbelts for the entire agricultural region. The first rule set would cover the south-western part of the province where there are more areas of grasslands and ranch activities. The second rule set would be developed to characterize the shelterbelts in the aspen parkland region where the croplands and ranch lands are interspersed with

90
island forests. The third rule set would be used to inventory the shelterbelts in the remaining areas between the southwestern part of the province and the aspen parkland region. The crop lands that dominate this region would require different texture thresholds than those of the other two areas.

7.3 Shelterbelt Design

The methods developed may be useful for monitoring the impact of new farming techniques on shelterbelts. As farming becomes more mechanized, shelterbelts are increasingly making farming with large machines more awkward. For example, the design guidelines for field shelterbelts recommend that they be planted 200 metres apart (Agroforestry Development Centre, 2010). However, implements, such as sprayers and deep tillers, are 9-36.5 m wide; measurements that require an extra pass by the cultivator or sprayer. As a result, many farmers are removing shelterbelts to facilitate the use of new larger machinery. In addition, centre-pivot irrigation has also led to the removal of many shelterbelts throughout the Prairie Provinces because the circular pivot pattern doesn't match the typical linear shelterbelt arrangement. Clearly, there is a need to impose shelterbelt planting designs that match modern farming practices.

7.4 Carbon Sequestration

The removal of shelterbelts affects carbon sequestration in two ways. First, it reduces the number of trees available to remove carbon from the atmosphere. Secondly, carbon that was being stored in the shelterbelt biomass is released back into the atmosphere as the trees are burned or decompose.
An inventory of shelterbelts is a necessary first step in our ability to manage sequestered carbon resources. Such an inventory would establish a baseline of carbon sequestration that could be compared against future classifications so that effective policies could be implemented to adapt to changes in farming practices.
CHAPTER 8 – Conclusion

The main purpose was to develop object-based classification techniques to identify field and farmyard shelterbelts on satellite imagery of the Province of Saskatchewan with the intent of determining the amount of carbon that they could sequester. The object-based classification techniques used are a potentially viable option to classify shelterbelts on the prairies.

However, general application of object-based classification techniques were limited by deficiencies in the image data. For example, the lack of spectral data created confusion between objects that have similar composition, such as between thin strips of grass or crops and shelterbelts. Texture did provide a means to partially separate grassy areas and croplands from shelterbelt areas; however it did so with marginal accuracy. Also, the images used in the study were acquired over a time frame from April to September, during which many different shelterbelt growing conditions are present that complicate any automated process. Lastly, the contrast of images had been independently enhanced, producing sharp changes at image borders that were difficult to model with a single rule set. This inconsistent image data made it impossible to create rule sets that could be used for classifying shelterbelts over the entire province. These consistency issues need to be considered in future shelterbelt classifications.

The image deficiencies are reflected in low classification accuracies, largely arising from shelterbelt boundary mis-matches. It was determined that only 48% of field
shelterbelts and 52% of farmyard shelterbelt areas had been correctly classified. The procedure detected many features which, due to the poor imagery, were incorrectly classified as shelterbelts. The high commission error rate of 50% that this produced is. Notably, however, 70% of the errors of omission (actual shelterbelts that were not detected) were found to be located next to correctly classified shelterbelt areas. This suggests that although the classifier could find most shelterbelts – in fact, 80% of all actual shelterbelts were overlapped by the classified shelterbelts – experienced difficulties in finding adjacent areas.

It is expected that the classification accuracies could be improved substantially with imagery having a higher spatial resolution and multiple spectral bands. An increase in resolution, to 1 metre for example, would make the borders of the shelterbelts more identifiable from that of the surrounding landscape. The inclusion of additional spectral bands, particularly one in the near-infrared, would facilitate the correct discrimination of different types of vegetation that were found to be the source of the high commission error rates.

A procedure was developed to use the classified shelterbelt data in conjunction with distribution records from the Agroforestry Development Centre and published carbon storage data for a variety of tree species to estimate the amount of carbon that is being sequestered. It estimated that there were 1,576 kilometres of field shelterbelts and 1,041 kilometres of farm shelterbelts in the twenty sites evaluated. The distribution records were used to calculate the proportion of each tree species that could be expected at each site. When these data were combined with the species-specific carbon storage data the amount of above-ground carbon sequestered per kilometre of
shelterbelt was estimated. The amount of carbon sequestered was estimated to be a combined 99,000 tonnes for all sites, or 50 tonnes per square kilometre. When applied to all agricultural areas of the province it is estimated that 345,000 tonnes of above-ground carbon are sequestered by shelterbelts yearly.

The amount of carbon being sequestered by shelterbelts is a small fraction of the total amount being emitted in the Province of Saskatchewan. However for agriculture specifically, the amount carbon being sequestered by shelterbelts offsets that being emitted by agricultural activities.

In conclusion, while the results were hampered by inconsistent image data, the procedures developed and tested should have broad application when improved data become available.
CHAPTER 9 – References


Pankiw, J., Kort, J. and Piwowar, J. 2008. The Use of Definiens (eCognition) for Shelterbelt Inventories. Indian Head: Agroforestry Development Centre, Agriculture and Agri-Food Canada.


Appendix: Site Rule Sets/Classification

Site A

Process: Main:
Shelterbelt Inventory
Segmentation
multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating ‘Farmyard Shelterbelts’
Thematic Layers
assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
assign class: unclassified with ID: Rivers > 0 at Farmyard Shelterbelts: Water
assign class: unclassified with ID: Water 1 > 0 at Farmyard Shelterbelts: Water
Reduction of Candidate Areas: Classification
assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.2 at Farmyard Shelterbelts: Open areas
assign class: unclassified with Mean Layer 1 > 140 at Farmyard Shelterbelts: Open areas
assign class: unclassified at Farmyard Shelterbelts: Possible Trees
Classification of Shelterbelts
Classification of Farmyard Shelterbelts
assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
assign class: Farmyard Shelterbelt with Brightness > 90 at Farmyard Shelterbelts: Open areas
Classification of Field Shelterbelts
assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
assign class: Rows of Trees with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
assign class: Rows of Trees with Main direction > 175 at Farmyard Shelterbelts: Field Shelterbelts
classification: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts
assign class: Field Shelterbelts with Area < 250 m² at Farmyard Shelterbelts: Open areas
assign class: Field Shelterbelts with Brightness < 50 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Shape index < 2 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Brightness > 130 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 400 at Farmyard Shelterbelts: Possible Trees
export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to Site_A_Farm_Def
export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteA_Field_Def

Figure A1-1: Site A rule set

Figure A1-2: Site A classification
Site B

Process: Main:
Shelterbelt Inventory
Segmentation
multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Shelterbelts'

Thematic Layers
assign class: unclassified with ID: Buildings > 0 at Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads > 0 at Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads > 0 at Shelterbelts: Roads
assign class: unclassified with ID: Rivers > 0 at Shelterbelts: Water
assign class: unclassified with ID: Water 1 > 0 at Shelterbelts: Water
assign class: unclassified with ID: Natural Vegetation (V4.0) > 0 at Shelterbelts: Vegetation

Reduction of Candidate Areas: Classification
assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.22 at Shelterbelts: Open areas
assign class: unclassified with Mean Layer 1 > 130 at Shelterbelts: Open areas
assign class: unclassified at Shelterbelts: Possible Trees

Classification of Shelterbelts
Classification of Farmyard Shelterbelts
assign class: Possible Trees with Distance to Buildings < 150 at Shelterbelts: Farmyard Shelterbelt
assign class: Farmyard Shelterbelt with Brightness > 115 at Shelterbelts: Open areas
assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 150 at Shelterbelts: Possible Trees

Classification of Field Shelterbelts
assign class: Possible Trees with Asymmetry > 0.8 at Shelterbelts: Rows of Trees
assign class: Rows of Trees with Rel. border to Water > 0 at Shelterbelts: Possible Trees
assign class: Rows of Trees with Main direction <= 5 at Shelterbelts: Field Shelterbelts
assign class: Rows of Trees with Main direction >= 175 at Shelterbelts: Field Shelterbelts
classification: Rows of Trees at Shelterbelts: Field Shelterbelts
assign class: Field Shelterbelts with Brightness > 110 at Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Width > 30 at Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Rel. border to Vegetation > 0 at Shelterbelts: Vegetation
assign class: Field Shelterbelts with Rel. border to Roads > 0 at Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Rel. border to Limited Use Roads > 0 at Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Area < 250 at Shelterbelts: Possible Trees
assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 125 at Shelterbelts: Open areas
export vector layers: Field Shelterbelts at Shelterbelts: export object shapes to Site B field
export vector layers: Farmyard Shelterbelt at Shelterbelts: export object shapes to Site B farm

Figure A1-3: Site B rule set

Figure A1-4: Site B classification
Process: Main:

Shelterbelt Inventory

Segmentation

multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'

Thematic Layers

assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
assign class: unclassified with ID: Rivers and Streams > 0 at Farmyard Shelterbelts: Water
assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water

Reduction of Candidate Areas: Classification

assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.2 at Farmyard Shelterbelts: Open areas
assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
assign class: unclassified at Farmyard Shelterbelts: Possible Trees

Classification of Shelterbelts

Classification of Farmyard Shelterbelts

assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
assign class: Farmyard Shelterbelt with Brightness > 125 at Farmyard Shelterbelts: Open areas
assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 300 at Farmyard Shelterbelts: Possible Trees

Classification of Field Shelterbelts

assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
assign class: Rows of Trees with Distance to Water < 100 at Farmyard Shelterbelts: Possible Trees
assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
assign class: Rows of Trees with Main direction >= 175 at Farmyard Shelterbelts: Field Shelterbelts
classification: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts
assign class: Field Shelterbelts with Brightness < 50 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Shape index < 2 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Brightness > 125 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Width > 20 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Distance to Roads < 25 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Rel. border to Possible Trees > 0 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Distance to Limited Use Roads < 25 m at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 400 at Farmyard Shelterbelts: Possible Trees

export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteC_farm

Figure A1-5: Site C ruleset

Figure A1-6: Site C classification
Site D

Process: Main:
  Shelterbelt Inventory
    Segmentation
      multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'
    Thematic Layers
      assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
      assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
      assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
      assign class: unclassified with ID: Streams and Rivers > 0 at Farmyard Shelterbelts: Water
      assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water
      assign class: with ID: Vegetation > 0 at Farmyard Shelterbelts: Vegetation
    Reduction of Candidate Areas: Classification
      assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.15 at Farmyard Shelterbelts: Open areas
      assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
      assign class: unclassified at Farmyard Shelterbelts: Possible Trees
    Classification of Shelterbelts
      Classification of Farmyard Shelterbelts
        assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
        assign class: Farmyard Shelterbelt with Brightness > 120 at Farmyard Shelterbelts: Possible Trees
        assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 225 at Farmyard Shelterbelts: Possible Trees
        assign class: Farmyard Shelterbelt with Rel. border to Vegetation > 0 at Farmyard Shelterbelts: Vegetation
        assign class: Farmyard Shelterbelt with Brightness < 50 at Farmyard Shelterbelts: Possible Trees
      Classification of Field Shelterbelts
        assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
        assign class: Rows of Trees with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
        assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
        assign class: Rows of Trees with Main direction >= 175 at Farmyard Shelterbelts: Field Shelterbelts
        assign class: Field Shelterbelts with Shape index < 2 at Farmyard Shelterbelts: Possible Trees
        assign class: Field Shelterbelts with Brightness > 100 at Farmyard Shelterbelts: Possible Trees
        assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
        assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 500 at Farmyard Shelterbelts: Possible Trees
        assign class: Field Shelterbelts with Distance to Roads < 50 m at Farmyard Shelterbelts: Possible Trees
        assign class: Field Shelterbelts with Distance to Limited Use Roads < 50 m at Farmyard Shelterbelts: Possible Trees
      Export
        export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteD_FarmShelterbelts
        export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteD_FieldShelterbelts

Figure A1-7: Site D rule set

![Site D Classified Shelterbelts](image)

Figure A1-8: Site D classification
Site E

Process: Main:
  Shelterbelt Inventory
  Segmentation
  multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'
  Themetic Layers
    assign class: unclassified with ID: Buildings > 0  at Farmyard Shelterbelts: Buildings
    assign class: unclassified with ID: Limited Use Roads > 0  at Farmyard Shelterbelts: Limited Use Roads
    assign class: unclassified with ID: Roads > 0  at Farmyard Shelterbelts: Roads
    assign class: unclassified with ID: Streams and Rivers > 0  at Farmyard Shelterbelts: Water
    assign class: unclassified with ID: Lakes and Ponds > 0  at Farmyard Shelterbelts: Water
    assign class: with ID: Vegetation > 0  at Farmyard Shelterbelts: Vegetation
  Reduction of Candidate Areas: Classification
    assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.15  at Farmyard Shelterbelts: Open areas
    assign class: unclassified with Mean Layer 1 > 130  at Farmyard Shelterbelts: Open areas
    assign class: unclassified at Farmyard Shelterbelts: Possible Trees
  Classification of Shelterbelts
    Classification of Farmyard Shelterbelts
      assign class: Possible Trees with Distance to Buildings < 150  at Farmyard Shelterbelts: Farmyard Shelterbelt
      assign class: Farmyard Shelterbelt with Brightness > 120  at Farmyard Shelterbelts: Possible Trees
      assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 225  at Farmyard Shelterbelts: Possible Trees
      assign class: Farmyard Shelterbelt with Rel. border to Vegetation > 0  at Farmyard Shelterbelts: Vegetation
      assign class: Farmyard Shelterbelt with Brightness < 50  at Farmyard Shelterbelts: Possible Trees
    Classification of Field Shelterbelts
      assign class: Possible Trees with Asymmetry > 0.9  at Farmyard Shelterbelts: Rows of Trees
      assign class: Rows of Trees with Rel. border to Water > 0  at Farmyard Shelterbelts: Possible Trees
      assign class: Rows of Trees with Main direction <= 5  at Farmyard Shelterbelts: Field Shelterbelts
      assign class: Rows of Trees with Main direction >= 175  at Farmyard Shelterbelts: Field Shelterbelts
      assign class: Field Shelterbelts with Shape index < 2  at Farmyard Shelterbelts: Possible Trees
      assign class: Field Shelterbelts with Brightness > 100  at Farmyard Shelterbelts: Possible Trees
      assign class: Field Shelterbelts with Width > 30  at Farmyard Shelterbelts: Possible Trees
      assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 500  at Farmyard Shelterbelts: Possible Trees
      assign class: Field Shelterbelts with Distance to Roads < 50  at Farmyard Shelterbelts: Possible Trees
      assign class: Field Shelterbelts with Distance to Limited Use Roads < 50 m at Farmyard Shelterbelts: Possible Trees
  Export
    export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteD_FarmShelterbelts
    export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteD_FieldShelterbelts

Figure A1-9: Site E rule set

Figure A1-10: Site E classification
Site F

Process: Main:
Shelterbelt Inventory
  Segmentation
    multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'

  Thematic Layers
    assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
    assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
    assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
    assign class: unclassified with ID: Streams and Rivers > 0 at Farmyard Shelterbelts: Water
    assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water
    assign class: with Object ID (V4.0): Railways > 0 at Farmyard Shelterbelts: Railways

  Reduction of Candidate Areas: Classification
    assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.25 at Farmyard Shelterbelts: Open areas
    assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
    assign class: unclassified at Farmyard Shelterbelts: Possible Trees

Classification of Shelterbelts

  Classification of Farmyard Shelterbelts
    assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
    assign class: Farmyard Shelterbelt with Brightness > 100 at Farmyard Shelterbelts: Possible Trees
    assign class: Farmyard Shelterbelt with Brightness = 0 at Farmyard Shelterbelts: Open areas

  Classification of Field Shelterbelts
    assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
    assign class: Rows of Trees with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
    assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
    assign class: Field Shelterbelts classification: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts
    assign class: Field Shelterbelts with Area < 250 m² at Farmyard Shelterbelts: Open areas
    assign class: Field Shelterbelts with Shape index < 2 at Farmyard Shelterbelts: Possible Trees
    assign class: Field Shelterbelts with Brightness > 115 at Farmyard Shelterbelts: Possible Trees
    assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
    assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 250 at Farmyard Shelterbelts: Possible Trees
    assign class: Field Shelterbelts with Distance to Railways < 60 m at Farmyard Shelterbelts: unclassified
    assign class: Field Shelterbelts with Distance to Limited Use Roads < 25 m at Farmyard Shelterbelts: unclassified

Export
  export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteF_Field
  export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteF_Farmyard

Figure A1-11: Site F rule set

![Site F Classified Shelterbelts](image)

Figure A1-12: Site D classification
Site G

Process: Main:
Shelterbelt Inventory
Segmentation
multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'
Thematic Layers
assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
assign class: unclassified with ID: Streams and Rivers > 0 at Farmyard Shelterbelts: Water
assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water
assign class: with ID: Wetlands > 0 at Farmyard Shelterbelts: Wetlands
Reduction of Candidate Areas: Classification
assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.2 at Farmyard Shelterbelts: Open areas
assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
assign class: unclassified at Farmyard Shelterbelts: Possible Trees
Classification of Shelterbelts
Classification of Farmyard Shelterbelts
assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
assign class: Farmyard Shelterbelt with Brightness > 90 at Farmyard Shelterbelts: Possible Trees
assign class: Farmyard Shelterbelt, Possible Trees with Brightness <= 0.2 at Farmyard Shelterbelts: Open areas
Classification of Field Shelterbelts
assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
assign class: Rows of Trees with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
assign class: Rows of Trees with Main direction >= 175 at Farmyard Shelterbelts: Field Shelterbelts
classification: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts
assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 500 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Shape index < 2 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Brightness > 122 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Distance to Roads < 50 at Farmyard Shelterbelts: Possible Trees
Exports
export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteG_Farmyard
export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteG_Field

Figure A1-13: Site G rule set

Figure A1-14: Site G classification
Site H

Process: Main:
Shelterbelt Inventory
Segmentation
multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating ‘Farmyard Shelterbelts’
Thematic Layers
assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
assign class: unclassified with ID: Streams and Rivers > 0 at Farmyard Shelterbelts: Water
assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water
assign class: with ID: Wetlands > 0 at Farmyard Shelterbelts: Wetlands
Reduction of Candidate Areas: Classification
assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.2 at Farmyard Shelterbelts: Open areas
assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
assign class: Open areas with Brightness < 25 at Farmyard Shelterbelts: Possible Trees
assign class: unclassified at Farmyard Shelterbelts: Possible Trees
Classification of Shelterbelts
Classification of Farmyard Shelterbelts
assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
assign class: Farmyard Shelterbelt with Brightness > 90 at Farmyard Shelterbelts: Possible Trees
assign class: Farmyard Shelterbelt with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 300 at Farmyard Shelterbelts: Possible Trees
Classification of Field Shelterbelts
assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
assign class: Rows of Trees with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
assign class: Rows of Trees with Main direction >= 175 at Farmyard Shelterbelts: Field Shelterbelts
assign class: Field Shelterbelts with Shape index < 1.5 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Brightness > 125 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 3000 at Farmyard Shelterbelts: Possible Trees
Export
export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteH_Farmyards
export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteH_Field

Figure A1-15: Site H rule set

Figure A1-16: Site H classification
Site I

Process: Main:
  Shelterbelt Inventory
  Segmentation
  multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'

Thematic Layers
assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
assign class: with ID: Buildings 2 > 0 at Farmyard Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: with ID: Limited Use Roads 2 > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
assign class: with ID: Roads 2 > 0 at Farmyard Shelterbelts: Roads
assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water
assign class: with ID: Lakes and Ponds 2 > 0 at Farmyard Shelterbelts: Water

Reduction of Candidate Areas: Classification
assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.2 at Farmyard Shelterbelts: Open areas
assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
assign class: unclassified at Farmyard Shelterbelts: Possible Trees

Classification of Shelterbelts
Classification of Farmyard Shelterbelts
  assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
  assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 150 at Farmyard Shelterbelts: Possible Trees
  assign class: Farmyard Shelterbelt with Brightness > 100 at Farmyard Shelterbelts: Possible Trees

Classification of Field Shelterbelts
  assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
  assign class: Rows of Trees with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
  assign class: Rows of Trees with Main direction <= 6 at Farmyard Shelterbelts: Field Shelterbelts
  assign class: Rows of Trees with Main direction >= 175 at Farmyard Shelterbelts: Field Shelterbelts
  assign class: Field Shelterbelts with Shape index < 1.5 at Farmyard Shelterbelts: Possible Trees
  assign class: Field Shelterbelts with Brightness > 100 at Farmyard Shelterbelts: Possible Trees
  assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
  assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 100 at Farmyard Shelterbelts: Possible Trees
  assign class: Field Shelterbelts with Distance to Limited Use Roads < 50 m at Farmyard Shelterbelts: Possible Trees
  assign class: Field Shelterbelts with Distance to Roads < 50 at Farmyard Shelterbelts: Possible Trees

Export
  export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to Sitel_Farmyard
  export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to Sitel_Field

Figure A1-17: Site I rule set

![Site I Classified Shelterbelts](image1)

Figure A1-18: Site D classification
Site J

Process: Main:
Shelterbelt Inventory
Segmentation
- multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'

Thematic Layers
- assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
- assign class: with ID: Buildings2 > 0 at Farmyard Shelterbelts: Buildings
- assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
- assign class: with ID: Limited Use Roads 2 > 0 at Farmyard Shelterbelts: Limited Use Roads
- assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
- assign class: with ID: Roads 2 > 0 at Farmyard Shelterbelts: Roads
- assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water
- assign class: with ID: Lakes and Ponds 2 > 0 at Farmyard Shelterbelts: Water

Reduction of Candidate Areas: Classification
- assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.22 at Farmyard Shelterbelts: Open areas
- assign class: unclassified with Mean Layer 1 > 150 at Farmyard Shelterbelts: Open areas
- assign class: unclassified at Farmyard Shelterbelts: Possible Trees

Classification of Shelterbelts
- Classification of Farmyard Shelterbelts
  - assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
  - assign class: Farmyard Shelterbelt, Possible Trees with Brightness < 2 at Farmyard Shelterbelts: Possible Trees
  - assign class: Farmyard Shelterbelt with Brightness > 100 at Farmyard Shelterbelts: Open areas
  - assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 400 at Farmyard Shelterbelts: Possible Trees
  - assign class: Possible Trees with Brightness < 2 at Farmyard Shelterbelts: Temp Farm
  - assign class: Temp Farm with GLCM Contrast (all dir.) < 300 at Farmyard Shelterbelts: Farmyard Shelterbelt

- Classification of Field Shelterbelts
  - assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
  - assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
  - assign class: Rows of Trees with Main direction >= 175 at Farmyard Shelterbelts: Field Shelterbelts
  - classification: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts
  - assign class: Field Shelterbelts with Shape index < 2 at Farmyard Shelterbelts: Possible Trees
  - assign class: Field Shelterbelts with Brightness > 150 at Farmyard Shelterbelts: Possible Trees
  - assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
  - assign class: Possible Trees with Asymmetry > 0.989 at Farmyard Shelterbelts: Field Shelterbelts
  - assign class: Field Shelterbelts with Distance to Roads < 100 at Farmyard Shelterbelts: Possible Trees
  - assign class: Field Shelterbelts with Distance to Limited Use Roads < 100 m at Farmyard Shelterbelts: Possible Trees

export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteJ_farm
export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteJ_fiel

Figure A1-19: Site J rule set

Figure A1-20: Site J classification
Site K

Process: Main:
Shelterbelt Inventory
Segmentation
  multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'
Thematic Layers
  assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
  assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
  assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
  assign class: unclassified with ID: Streams and Rivers > 0 at Farmyard Shelterbelts: Water
  assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water
  assign class: with ID: Vegetation > 0 at Farmyard Shelterbelts: Vegetation
Reduction of Candidate Areas: Classification
  assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.2 at Farmyard Shelterbelts: Open areas
  assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
  assign class: unclassified at Farmyard Shelterbelts: Possible Trees
Classification of Shelterbelts
  Classification of Farmyard Shelterbelts
    assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
    assign class: Farmyard Shelterbelt with Brightness > 120 at Farmyard Shelterbelts: Possible Trees
    assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 100 at Farmyard Shelterbelts: Possible Trees
    assign class: Farmyard Shelterbelt with Brightness < 70 at Farmyard Shelterbelts: Possible Trees
    assign class: Farmyard Shelterbelt with Area > 5000 at Farmyard Shelterbelts: unclassified
  Classification of Field Shelterbelts
    assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
    assign class: Rows of Trees with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
    assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
    assign class: Rows of Trees with Main direction >= 175 at Farmyard Shelterbelts: Field Shelterbelts
    classification: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts
    assign class: Field Shelterbelts with Area < 250 m² at Farmyard Shelterbelts: Open areas
    assign class: Field Shelterbelts with Shape index < 2 at Farmyard Shelterbelts: Possible Trees
    assign class: Field Shelterbelts with Brightness > 125 at Farmyard Shelterbelts: Possible Trees
    assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
    assign class: Field Shelterbelts with Distance to Roads < 50 at Farmyard Shelterbelts: Possible Trees
    assign class: Field Shelterbelts with Distance to Limited Use Roads < 50 m at Farmyard Shelterbelts: Possible Trees
    assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 100 at Farmyard Shelterbelts: Possible Trees
Export
  export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteK_Farmyard
  export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteK_Field

Figure A1-21: Site K rule set

Figure A1-22: Site K classification
Site L

Process: Main:
Shelterbelt Inventory
Segmentation
  multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'
Thematic Layers
  assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
  assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
  assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
  assign class: unclassified with ID: Streams and Rivers > 0 at Farmyard Shelterbelts: Water
  assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water
  assign class: with ID: Vegetation > 0 at Farmyard Shelterbelts: Vegetation
  assign class: with ID: Wetlands > 0 at Farmyard Shelterbelts: Wetlands
  assign class: Water with TYPE: Lakes and Ponds = 2 at Farmyard Shelterbelts: Lakes

Reduction of Candidate Areas: Classification
  assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.22 at Farmyard Shelterbelts: Open areas
  assign class: unclassified with Mean Layer 1 > 150 at Farmyard Shelterbelts: Open areas
  assign class: unclassified at Farmyard Shelterbelts: Possible Trees
Classification of Shelterbelts
  Classification of Farmyard Shelterbelts
    assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
    assign class: Farmyard Shelterbelt with Brightness > 110 at Farmyard Shelterbelts: Possible Trees
    assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 150 at Farmyard Shelterbelts: Possible Trees
    assign class: Farmyard Shelterbelt with Distance to Lakes < 200 m at Farmyard Shelterbelts: Possible Trees
  Classification of Field Shelterbelts
    assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
    assign class: Rows of Trees with Ref. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
    assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
    assign class: Rows of Trees with Main direction >= 175 at Farmyard Shelterbelts: Field Shelterbelts
    assign class: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts: Classification
    assign class: Field Shelterbelts with Area < 250 m² at Farmyard Shelterbelts: Open areas
    assign class: Field Shelterbelts with Shape index < 2 at Farmyard Shelterbelts: Possible Trees
    assign class: Field Shelterbelts with Brightness > 130 at Farmyard Shelterbelts: Possible Trees
    assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
    assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 300 at Farmyard Shelterbelts: Possible Trees

Export
  export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteL_Farmyard
  export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteL_Field

Figure A1-23: Site L rule set

![Site L Classified Shelterbelts](image)

Figure A1-24: Site L classification
Site M

Process: Main:
  Shelterbelt Inventory
    Segmentation
      multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'

Thematic Layers
  assign class: unclassified with ID: Buildings > 0  at Farmyard Shelterbelts: Buildings
  assign class: unclassified with ID: Limited Use Roads > 0  at Farmyard Shelterbelts: Limited Use Roads
  assign class: unclassified with ID: Roads > 0  at Farmyard Shelterbelts: Roads
  assign class: unclassified with ID: Streams and Rivers > 0  at Farmyard Shelterbelts: Water
  assign class: unclassified with ID: Lakes and Ponds > 0  at Farmyard Shelterbelts: Water

Reduction of Candidate Areas: Classification
  assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.2  at Farmyard Shelterbelts: Open areas
  assign class: unclassified with Mean Layer 1 > 130  at Farmyard Shelterbelts: Open areas
  assign class: unclassified at Farmyard Shelterbelts: Possible Trees

Classification of Shelterbelts
  Classification of Farmyard Shelterbelts
    assign class: Possible Trees with Distance to Buildings < 150  at Farmyard Shelterbelts: Farmyard Shelterbelt
    assign class: Farmyard Shelterbelt with Brightness > 110  at Farmyard Shelterbelts: Open areas
    assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 50  at Farmyard Shelterbelts: Possible Trees

Classification of Field Shelterbelts
  assign class: Possible Trees with Asymmetry > 0.9  at Farmyard Shelterbelts: Rows of Trees
  assign class: Rows of Trees with Rel. border to Water > 0  at Farmyard Shelterbelts: Possible Trees
  assign class: Rows of Trees with Main direction <= 5  at Farmyard Shelterbelts: Field Shelterbelts
  assign class: Rows of Trees with Main direction >= 175  at Farmyard Shelterbelts: Field Shelterbelts
  classification: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts
  assign class: Field Shelterbelts with Area < 250 m² at Farmyard Shelterbelts: Open areas
  assign class: Field Shelterbelts with Shape index < 1.75  at Farmyard Shelterbelts: Possible Trees
  assign class: Field Shelterbelts with Brightness > 125  at Farmyard Shelterbelts: Possible Trees
  assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 100  at Farmyard Shelterbelts: Possible Trees
  assign class: Field Shelterbelts with Distance to Roads < 100  at Farmyard Shelterbelts: Possible Trees
  assign class: Field Shelterbelts with Distance to Limited Use Roads < 100 m at Farmyard Shelterbelts: Possible Trees

Export
  export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteM_Farmyard
  export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteM_Field

Figure A1-25: Site M rule set

Figure A1-26: Site M classification

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Site N

Process: Main:
Shelterbelt Inventory
Segmentation
multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'
Thematic Layers
assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
assign class: unclassified with ID: Streams and Rivers > 0 at Farmyard Shelterbelts: Water
assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water
assign class: with ID: Buildings2 > 0 at Farmyard Shelterbelts: Buildings
assign class: with ID: Limited Use Roads2 > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: with ID: Roads2 > 0 at Farmyard Shelterbelts: Roads
assign class: with ID: Lakes and Ponds2 > 0 at Farmyard Shelterbelts: Water
assign class: with ID: Built Up Area > 0 at Farmyard Shelterbelts: Built Up Areas
assign class: with ID: Railways > 0 at Farmyard Shelterbelts: Railways
assign class: with ID: Railways2 > 0 at Farmyard Shelterbelts: Railways
Reduction of Candidate Areas: Classification
assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.22 at Farmyard Shelterbelts: Open areas
assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
assign class: unclassified at Farmyard Shelterbelts: Possible Trees
Classification of Shelterbelts
Classification of Farmyard Shelterbelts
assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
assign class: Farmyard Shelterbelt with Brightness > 100 at Farmyard Shelterbelts: Possible Trees
assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 100 at Farmyard Shelterbelts: Possible Trees
Classification of Field Shelterbelts
assign class: Possible Trees with Asymmetry > 0.8 at Farmyard Shelterbelts: Rows of Trees
assign class: Rows of Trees with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
assign class: Rows of Trees with Main direction <= 6 at Farmyard Shelterbelts: Field Shelterbelts
assign class: Rows of Trees with Main direction >= 176 at Farmyard Shelterbelts: Field Shelterbelts
classification: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts
assign class: Field Shelterbelts with Area < 250 m² at Farmyard Shelterbelts: Open areas
assign class: Field Shelterbelts with Shape index < 1.75 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Brightness > 120 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Distance to Roads < 50 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Distance to Limited Use Roads < 50 at Farmyard Shelterbelts: Possible Trees
Export
export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteN_Farmyard
export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteN_Field

Figure A1-27: Site N rule set

Figure A1-28: Site N classification
Site O

Process: Main:
Shelterbelt Inventory
Segmentation
multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'

Thematic Layers
assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
assign class: unclassified with ID: Streams and Rivers > 0 at Farmyard Shelterbelts: Water
assign class: with ID: Vegetation > 0 at Farmyard Shelterbelts: Vegetation
assign class: with ID: Buildings2 > 0 at Farmyard Shelterbelts: Buildings
assign class: with ID: Limited Use Roads 2 > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: with ID: Roads 2 > 0 at Farmyard Shelterbelts: Roads
assign class: with ID: Vegetation 2 > 0 at Farmyard Shelterbelts: Vegetation
assign class: with ID: Lakes and Ponds 2 > 0 at Farmyard Shelterbelts: Water
assign class: with ID: Streams and Rivers 2 > 0 at Farmyard Shelterbelts: Water
assign class: unclassified with ID: Buildings2 > 0 at Farmyard Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads 2 > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads 2 > 0 at Farmyard Shelterbelts: Roads
assign class: unclassified with ID: Vegetation 2 > 0 at Farmyard Shelterbelts: Vegetation
assign class: unclassified with ID: Lakes and Ponds 2 > 0 at Farmyard Shelterbelts: Water
assign class: unclassified with ID: Streams and Rivers 2 > 0 at Farmyard Shelterbelts: Water
assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.22 at Farmyard Shelterbelts: Open areas
assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
assign class: unclassified at Farmyard Shelterbelts: Possible Trees

Classification of Shelterbelts
Classification of Farmyard Shelterbelts
assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
assign class: Farmyard Shelterbelt with Brightness > 100 at Farmyard Shelterbelts: Possible Trees
assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 100 at Farmyard Shelterbelts: Possible Trees

Classification of Field Shelterbelts
assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
assign class: Rows of Trees with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
assign class: Rows of Trees with Main direction <= 6 at Farmyard Shelterbelts: Field Shelterbelts
assign class: Rows of Trees with Main direction >= 174 at Farmyard Shelterbelts: Field Shelterbelts
classification: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts
assign class: Field Shelterbelts with Area < 250 m² at Farmyard Shelterbelts: Open areas
assign class: Field Shelterbelts with Shape index < 1.75 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Brightness > 125 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 300 at Farmyard Shelterbelts: Possible Trees

Export
export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteO_Farmyard
export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteO_Field

Figure A1-29: Site O rule set

Figure A1-30: Site O classification
Site P

Process: Main:
  Shelterbelt Inventory
    Segmentation
      multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'
    Thematic Layers
      assign class: unclassified with ID: Buildings > 0  at Farmyard Shelterbelts: Buildings
      assign class: unclassified with ID: Limited Use Roads > 0  at Farmyard Shelterbelts: Limited Use Roads
      assign class: unclassified with ID: Roads > 0  at Farmyard Shelterbelts: Roads
      assign class: unclassified with ID: Streams and Rivers > 0  at Farmyard Shelterbelts: Water
      assign class: unclassified with ID: Lakes and Ponds > 0  at Farmyard Shelterbelts: Water
    Reduction of Candidate Areas: Classification
      assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.22  at Farmyard Shelterbelts: Open areas
      assign class: unclassified with Mean Layer 1 > 120  at Farmyard Shelterbelts: Open areas
      assign class: unclassified at Farmyard Shelterbelts: Possible Trees
    Classification of Shelterbelts
      Classification of Farmyard Shelterbelts
        assign class: Possible Trees with Distance to Buildings < 150  at Farmyard Shelterbelts: Farmyard Shelterbelt
        assign class: Farmyard Shelterbelt with Brightness > 110  at Farmyard Shelterbelts: Open areas
        assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 300  at Farmyard Shelterbelts: Open areas
      Classification of Field Shelterbelts
        assign class: Possible Trees with Asymmetry > 0.9  at Farmyard Shelterbelts: Rows of Trees
        assign class: Rows of Trees with Rel. border to Water > 0  at Farmyard Shelterbelts: Possible Trees
        assign class: Rows of Trees with Main direction <= 6  at Farmyard Shelterbelts: Field Shelterbelts
        assign class: Rows of Trees with Main direction >= 175  at Farmyard Shelterbelts: Field Shelterbelts
        assign class: Field Shelterbelts with Distance to Roads < 50  at Farmyard Shelterbelts: Open areas
        assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 400  at Farmyard Shelterbelts: Open areas
        assign class: Possible Trees with Rel. border to Field Shelterbelts > 0  at Farmyard Shelterbelts: Field Shelterbelts
        export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to site p field
        export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to site p farm

Figure A1-30: Site P rule set

Figure A1-32: Site P classification
Site Q

Process: Main:
Shelterbelt Inventory
Segmentation
multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating ‘Farmyard Shelterbelts’
Thematic Layers
assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
assign class: unclassified with ID: Streams and Rivers > 0 at Farmyard Shelterbelts: Water
assign class: unclassified with ID: Wetlands > 0 at Farmyard Shelterbelts: Water
grow region: Vegetation with Brightness < 110 at Farmyard Shelterbelts: Vegetation
assign class: unclassified with ID: Vegetation > 0 at Farmyard Shelterbelts: Vegetation
Reduction of Candidate Areas: Classification
assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.28 at Farmyard Shelterbelts: Open areas
assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
assign class: unclassified at Farmyard Shelterbelts: Possible Trees
Classification of Shelterbelts
Classification of Farmyard Shelterbelts
assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
assign class: Farmyard Shelterbelt with Brightness > 100 at Farmyard Shelterbelts: Possible Trees
Classification of Field Shelterbelts
assign class: Possible Trees with Asymmetry > 0.8 at Farmyard Shelterbelts: Rows of Trees
assign class: Rows of Trees with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
assign class: Rows of Trees with Main direction >= 175 at Farmyard Shelterbelts: Field Shelterbelts
classification: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts
assign class: Field Shelterbelts with Area < 250 m² at Farmyard Shelterbelts: Open areas
assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 50 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Rel. border to Vegetation > 0 at Farmyard Shelterbelts: Vegetation
Export
export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteQ_Farmyard
export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteQ_Field

Figure A1-33: Site Q rule set

Figure A1-34: Site Q classification
Site R

Process: Main:
Shelterbelt Inventory
Segmentation
multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'
Thematic Layers
assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
assign class: unclassified with ID: Streams and Rivers > 0 at Farmyard Shelterbelts: Water
assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water
assign class: with ID: Vegetation > 0 at Farmyard Shelterbelts: Vegetation
assign class: with ID: Built Up Areas > 0 at Farmyard Shelterbelts: Town
Reduction of Candidate Areas: Classification
assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.2 at Farmyard Shelterbelts: Open areas
assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
assign class: unclassified at Farmyard Shelterbelts: Possible Trees
Classification of Shelterbelts
Classification of Farmyard Shelterbelts
assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
assign class: Farmyard Shelterbelt with Brightness > 120 at Farmyard Shelterbelts: Possible Trees
assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 150 at Farmyard Shelterbelts: Possible Trees
assign class: Vegetation with Distance to Buildings < 50 at Farmyard Shelterbelts: Farmyard Shelterbelt
assign class: Farmyard Shelterbelt with Area > 5500 at Farmyard Shelterbelts: Possible Trees
Classification of Field Shelterbelts
assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
assign class: Rows of Trees with Ref. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
assign class: Field Shelterbelts with Shape index < 2 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Brightness > 125 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 100 at Farmyard Shelterbelts: Possible Trees
Export
export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteR_Farmyard
export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteR_Field

Figure A1-35: Site R rule set

Figure A1-36: Site R classification
Site S

Process: Main:
Shelterbelt Inventory
Segmentation
multiresolution segmentation: 25 [shape:0.5 compct.:0.5] creating 'Farmyard Shelterbelts'
Thematic Layers
assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
assign class: unclassified with ID: Streams and Rivers > 0 at Farmyard Shelterbelts: Water
assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water
assign class: with ID: Vegetation > 0 at Farmyard Shelterbelts: Vegetation
Reduction of Candidate Areas: Classification
assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.28 at Farmyard Shelterbelts: Open areas
assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
assign class: unclassified at Farmyard Shelterbelts: Possible Trees
Classification of Shelterbelts
Classification of Farmyard Shelterbelts
assign class: Possible Trees with Distance to Buildings < 175 at Farmyard Shelterbelts: Farmyard Shelterbelt
assign class: Farmyard Shelterbelt with Brightness > 90 at Farmyard Shelterbelts: Possible Trees
assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) > 500 at Farmyard Shelterbelts: Possible Trees
assign class: Farmyard Shelterbelt with Area > 5000 at Farmyard Shelterbelts: Possible Trees
Classification of Field Shelterbelts
assign class: Possible Trees with Asymmetry > 0.8 at Farmyard Shelterbelts: Rows of Trees
assign class: Rows of Trees with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
assign class: Rows of Trees with Main direction >= 175 at Farmyard Shelterbelts: Field Shelterbelts
classification: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts
assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Brightness > 125 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Distance to Roads < 150 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Distance to Limited Use Roads < 150 m at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Rel. border to Vegetation > 0.25 at Farmyard Shelterbelts: Vegetation
Export
export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteS_Farmyard
export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export object shapes to SiteS_Field

Figure A1-37: Site S rule set

Figure A1-38: Site S classification
Site T

Process: Main:
Shelterbelt Inventory
Segmentation
multiresolution segmentation: 25 [shape:0.5 compct:.0.5] creating 'Farmyard Shelterbelts'
Thematic Layers
assign class: unclassified with ID: Buildings > 0 at Farmyard Shelterbelts: Buildings
assign class: unclassified with ID: Limited Use Roads > 0 at Farmyard Shelterbelts: Limited Use Roads
assign class: unclassified with ID: Roads > 0 at Farmyard Shelterbelts: Roads
assign class: unclassified with ID: Streams and Rivers > 0 at Farmyard Shelterbelts: Water
assign class: unclassified with ID: Lakes and Ponds > 0 at Farmyard Shelterbelts: Water
assign class: with Object ID (V4.0): Railways > 0 at Farmyard Shelterbelts: Railways
Reduction of Candidate Areas: Classification
assign class: unclassified with GLCM Homogeneity Layer 1 (all dir.) >= 0.22 at Farmyard Shelterbelts: Open areas
assign class: unclassified with Mean Layer 1 > 130 at Farmyard Shelterbelts: Open areas
assign class: unclassified at Farmyard Shelterbelts: Possible Trees
assign class: with ID: Vegetation > 0 at Farmyard Shelterbelts: Vegetation
Classification of Shelterbelts
Classification of Farmyard Shelterbelts
assign class: Possible Trees with Distance to Buildings < 150 at Farmyard Shelterbelts: Farmyard Shelterbelt
assign class: Farmyard Shelterbelt with Brightness > 110 at Farmyard Shelterbelts: Possible Trees
assign class: Farmyard Shelterbelt with GLCM Homogeneity (all dir.) > 0.14 at Farmyard Shelterbelts: Possible Trees
assign class: Farmyard Shelterbelt with Area > 5000 at Farmyard Shelterbelts: Possible Trees
assign class: Farmyard Shelterbelt with GLCM Contrast (all dir.) < 250 at Farmyard Shelterbelts: Possible Trees
Classification of Field Shelterbelts
assign class: Possible Trees with Asymmetry > 0.9 at Farmyard Shelterbelts: Rows of Trees
assign class: Rows of Trees with Rel. border to Water > 0 at Farmyard Shelterbelts: Possible Trees
assign class: Rows of Trees with Main direction <= 5 at Farmyard Shelterbelts: Field Shelterbelts
classification: Rows of Trees at Farmyard Shelterbelts: Field Shelterbelts
assign class: Field Shelterbelts with Area < 250 m² at Farmyard Shelterbelts: Open areas
assign class: Field Shelterbelts with Shape index < 2 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Brightness > 125 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with Width > 30 at Farmyard Shelterbelts: Possible Trees
assign class: Field Shelterbelts with GLCM Contrast (all dir.) < 250 at Farmyard Shelterbelts: Possible Trees
Export
export vector layers: Farmyard Shelterbelt at Farmyard Shelterbelts: export object shapes to SiteT_Farmyard
export vector layers: Field Shelterbelts at Farmyard Shelterbelts: export obje

Figure A1-39: Site T rule set

Figure A1-40: Site T classification