

How are greening and browning trends associated with topography in the boreal forests of the Athabasca Plains Ecoregion?

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Highlights:

- Annual Landsat data used to derive yearly NDVI for each pixel throughout study area
- NDVI trend significance and direction assessed with Mann-Kendall test and Sen's slope
- 42.8% of unmasked pixels exhibited a significant monotonic NDVI trend
- 86.9% of pixels with a significant NDVI trend were greening, only 13.1% were browning
- Areas with higher slope had a greater proportion of greening pixels
- Increased elevation, more southerly aspect displayed a weaker association with greening

Abstract:

Satellite time-series have revealed that vast areas of Canada's boreal forests have been experiencing long term greening and browning trends. Climate change has been identified as the primary factor causing these changes in vegetation productivity, excluding disturbances like fire and harvest. Non-climate factors like topography might also influence where greening and browning occur, but these associations have not been thoroughly studied. The relationship between topographical variables and forest greening and browning was examined in this study within the Athabasca Plains ecoregion in northern Canada. Annual Landsat composites were acquired for each year from 1984 to 2015. The normalized difference vegetation index (NDVI) was then derived for each pixel in each yearly dataset. The NDVI time series were used to determine which pixels had a significant monotonic NDVI trend and the trend direction using the nonparametric Mann-Kendall test and Sen's slope respectively. Pixels that were greening, browning, or exhibiting no significant NDVI trend were grouped into topographical classes based on landscape slope, elevation, and aspect to examine association. 42.8% of unmasked pixels showed a significant NDVI trend, and 86.9% of these pixels were greening whereas only 13.1% were browning. Slope displayed the greatest association with greening and browning out of the three topographical variables, with higher slopes having greater proportions of greening pixels. Increased elevation and south facing slopes were also associated with increased greening, but less strongly than slope. These associations between topographical variables and vegetation productivity trend suggest that their relationship should be studied in finer detail and in more of Canada's boreal. Understanding how the landscape influences greening and browning may aid in refining predictions of future boreal forest changes.

Key Words: NDVI, Landsat, Topography, Boreal forest, Vegetation greening, Mann-Kendall

Introduction:

Significance of Boreal Forests

Boreal forest covers much of the northerly latitudes of the northern hemisphere and consists primarily of coniferous trees like spruce, fir, and pine as well as large areas of wetlands. In addition to facing increasing disturbances such as wildfires and logging, boreal forests are experiencing substantial greening and browning trends even in undisturbed areas due to climate change. The world's boreal forests are an enormous carbon sink, storing over 30% of global forest carbon, and provide a large proportion of global primary productivity (Pan et al, 2011). Understanding how greening and browning occurs in these forests may be important for climate regulation and natural resources management. In this study I examined if physical landscape characteristics are related to greening and browning trends in a region primarily covered by boreal forest.

Canada's Boreal Forests and Their Vegetation Productivity Trends

Canada's boreal forests are found in nearly every province and make up the largest vegetation region in the country. In recent decades, time series of satellite imagery have been used to reveal significant patterns of greening (increases in vegetation productivity) and browning (decreases in vegetation productivity) in regions of Canada's boreal forest (Ju and Masek, 2016). I assessed greening and browning using the Normalized Difference Vegetation Index (NDVI), which has been widely used for assessing vegetation productivity change in boreal forests using remote sensing data. Eastern Canada has experienced more greening of boreal forests than Western Canada, which has experienced more browning (Sulla-Menashe, Woodcock, and Freidl, 2018). The strongest greening trends in Canada's boreal forests have been in northerly ecotones, which are regions where boreal forests transition into tundra (Bonney, Danby, and Treitz 2018). In general, more greening has occurred in higher latitudes of boreal forests. A larger area of forests in Canada has experienced greening trends than browning trends (Ju and Masek, 2016). Conclusions regarding vegetation productivity trends have varied depending on what datasets (e.g. Landsat vs AVHRR) were used to quantify vegetation metrics (Sulla-Menashe, Freidl, and Woodcock, 2016, Alcaraz-Segura et al, 2010).

Known Influencers of Vegetation Greening and Browning

Both greening and browning trends in Canada's boreal forests have been associated with changes in regional climate (Alcaraz-Segura et al, 2010). Increasing temperatures contribute to greening in many areas as the growing season increases. However, in some boreal forest regions climate change has led to decreased moisture which has contributed to browning trends. Another major factor that influences greening and browning is forest disturbance, such as fire or shifts in caribou grazing patterns. Disturbance-recovery dynamics are most responsible for greening and browning trends in regions of boreal forest outside of ecotones (Bonney, Danby, and Treitz, 2018). Climate and disturbance recovery are responsible for much of the greening and browning

trends in Canada's boreal forests, but other variables may potentially be correlated with this change in vegetation productivity.

Topographical Variables as Potential Predictors for Greening and Browning

In this study, I used the Mann-Kendall test and Sen's slope to determine where significant greening and browning were occurring in the Athabasca Plains ecoregion. This region is located in northern Saskatchewan and Alberta within the boreal shield ecozone and is mostly covered by boreal forests. I then classified the greening, browning, and no trend pixels based on the physical landscape variables of elevation, slope to examine the possible association between topography and NDVI trend. Topographical variables such as elevation and slope have been identified as possibly being related to productivity trends in boreal forests, but this has not been widely studied (Bonney, Danby, and Treitz, 2018). Plant species like grasses have been found to be more tolerant to climatic stresses when located on steeper slopes and at higher elevations, so I hypothesized that higher slope and elevation areas in boreal forests might experience less browning than lower and flatter regions (Liancourt et al, 2013) I derived NDVI from annual mosaics of Landsat data between 1984 and 2015. Areas covered by water as well as areas that were affected by disturbances such as fires were masked out for analysis, to better isolate the effects of other variables within forested pixels. I expected that climatic changes would be fairly uniform within the ecoregion during this study period, which should aid in revealing the association of greening and browning with topography if they are in fact related. Identifying other predictors for greening and browning in Canadian boreal forests besides climate change and disturbance may allow us to refine existing models and better understand how changes will occur across this vast region.

Study Area Description

This study will take place within the Athabasca Plains ecoregion. This area lies primarily within northern Saskatchewan, although a small portion extends into northern Alberta around the southern shore of Lake Athabasca. This places the region within the heart of Canada's boreal forests, making it well suited for studying changes in boreal forest productivity. This ecoregion is a subset of the Boreal Shield ecozone, an area defined by the overlap of boreal forest and shield rock (Ecological Framework 1995). The total area of the ecoregion, which will be used for analysis in this study, is 283,078.46 square kilometers. The Athabasca Plains ecoregion is suitable for analysis using 30 meter Landsat data due to its small but still sub-provincial scale. While the region largely consists of flat plains, it also has numerous ridges deposited by glacial movement, and the entire area has a gentle slope towards Lake Athabasca in the northwest (Ecological Framework 1995). This topographic variation should make the area satisfactory for testing the association of physical variables (slope, elevation, and aspect) with forest productivity change. The region experiences long and cold winters with relatively brief summers, and has a mean annual temperature of around -3.5 degrees Celsius. Due to its remote location in the central Canadian provinces, it is sparsely populated, and frequently experiences large fires.

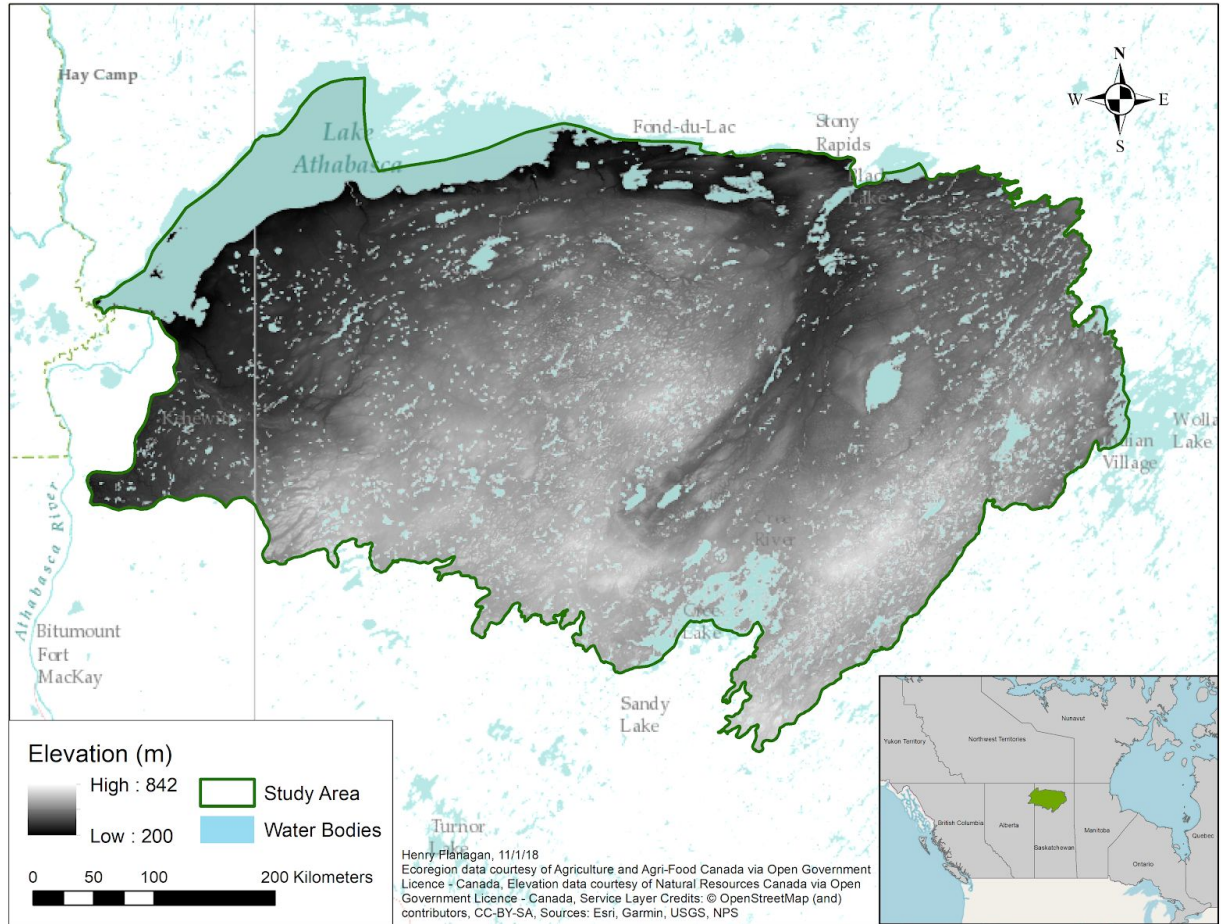


Figure 1: Reference map of the Athabasca Plains ecoregion

Methods

Methods Overview

I acquired a digital elevation model of the study region from the Canadian Digital Elevation Model (CDEM) data made publicly available by Natural Resources Canada. I then obtained Landsat composite best available pixel (BAP) and disturbance data for each year from 1984 to 2015, which was both produced by and acquired from Hermosilla et al (2016). I derived slope and aspect in ArcMap from the study area DEM. For each annual BAP raster, I masked out all of the disturbed areas and water and then generated an NDVI raster. I used the Mann Kendall test to determine which pixels had a significant NDVI trend throughout the study period, and derived the NDVI trend for significant pixels by calculating Sen's slope for each pixel.

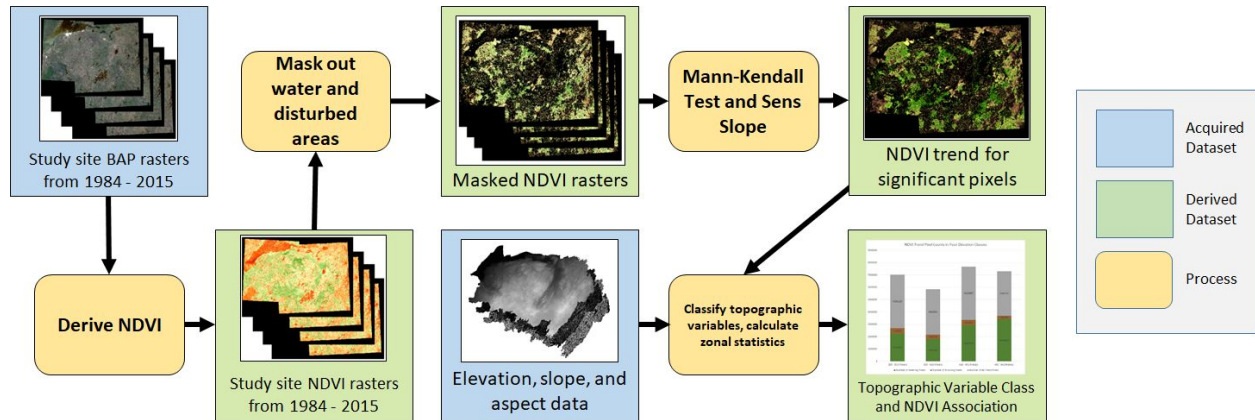


Figure 2: Workflow Diagram

Data Acquisition

Digital Elevation Model

To obtain elevation, slope, and aspect data for the study site, I acquired a digital elevation model before deriving the next two datasets. I used the Government of Canada Geospatial Data Extraction tool to download a subset of the Canadian Digital Elevation Model in TIFF format. This tool allowed me to enter a shapefile of the study area as an input to determine where elevation data would be extracted. Because the size of my study area exceeded the maximum area for which data could be extracted, I had to split the study area shapefile into two sub-regions, download each half of the DEM separately, and then mosaic them together. The resulting dataset had a 1:50,000 scale, with a pixel size of around 19.1 by 19.1 meters. The complete CDEM dataset was last updated in 2016.

Landsat Best Available Pixel Time Series

The Canada BAP Landsat dataset provided a source of spectral time series data for my entire study area. This dataset currently contains preprocessed annual composites of Landsat imagery for each year from 1984-2016. In each composite every pixel across all of Canada has values taken from the best available images for that area (Hermosilla et al 2016). All images in this dataset were captured during peak growing season (August 1st +/- 30 days). The dataset also contains data about where and what type of disturbance occurred. I obtained this data for each year between 1984 and 2015 directly from the creator, clipped to the study area boundaries. The obtained data was in TIFF format, with a pixel size of 30 by 30 meters.

Auxiliary Datasets

I acquired a shapefile of all of Canada's terrestrial ecoregions from Agriculture and Agri-Food Canada through Canada's open data portal. From this, I extracted the Athabasca Plains ecoregion boundaries to use as a standalone shapefile for clipping data and for making a study area map. Additionally, in my study area map I used ESRI's World Terrain Basemap with labels which is available through ArcMap.

Geoprocessing

Landsat BAP Data Processing

I first reprojected the data into a custom UTM "Zone 12.5" coordinate system, with a central meridian of -108 which is halfway between UTM zones 12 and 13. I chose this projection due to the study area lying evenly between these two UTM zones. For each annual BAP composite, I identified the pixels of all areas that underwent disturbance such as fire or harvesting using the BAP disturbance data. I created a masked dataset with all disturbed areas set to NoData. I then calculated the Normalized Difference Vegetation Index (NDVI) for each of the disturbance-masked annual BAP composites using Rstudio. NDVI is representative of vegetation productivity, with a decrease in NDVI representing browning, and an increase in NDVI representing greening. The equation for NDVI is as follows: $NDVI = \frac{(NIR - R)}{(NIR + R)}$, where NIR is Landsat band 4 (near infrared) and R is Landsat band 3 (red). This outputs values ranging from -1 to 1, where 1 represents maximum productivity / vegetation density.

I also used the BAP data to determine where water bodies were located, in order to exclude them from my NDVI trend analysis. Using the first BAP composite from 1984, I performed an iso cluster unsupervised classification in ArcMap to produce two classes. One of these generated classes consisted of lakes, rivers, and other water bodies since water has very different spectral properties from all other land classes. I confirmed the accuracy of the classification by comparing it to the visual imagery and a water features shapefile acquired from the Atlas of Canada waterbodies dataset. I extracted the water class to use as a masking layer.

Topographical Data Processing

After I acquired the DEM for the study area, I reprojected the data into UTM "Zone 12.5" coordinates and then used ArcMap to derive the other two topographical datasets. I used the "Slope" tool with the DEM as an input to generate a new raster for slope within the study region, which creates an output with pixel values ranging from 0 to 90 degrees. I

also used the “Aspect” tool to generate a raster for aspect, where the resulting pixel values range from 0 to 360 degrees (0 and 360 degrees being exact North). I then resampled each of the three topographical datasets using bilinear interpolation to align them with the 30 by 30 meter NDVI data. I classified each of these datasets in order to assess how NDVI trends varied across the landscape. I classified slope into four classes using Agriculture and Agri-Food Canada’s National Soil Database Slope Gradient classes (AAFC, 2013). These classes consisted of little/no slope (0 - 3 degrees), gentle slopes (3 - 9 degrees), moderate slopes (9 - 15 degrees), and steep slopes and above (>15 degrees). I classified elevation into four general classes using Jenks natural breaks after masking out water areas. I classified aspect into five classes: flat (no slope), north facing (315 - 45 degrees), east facing (45 - 135), south facing (135 - 225), and west facing (225 - 315).

Statistical Analysis

Mann-Kendall Test

The Mann-Kendall test is used to assess if values from a time series have a monotonic (consistent) upward or downward trend. It is a nonparametric test, which makes it suited for data that may not be normally distributed. The null hypothesis of this test is that there is no monotonic trend, whereas the alternative hypothesis is that a monotonic trend exists. I performed this test on the stacked annual NDVI rasters in Rstudio using the ‘MannKendall’ tool within the Kendall Package developed by A.I. McLeod. Using this function, I input a vector containing time series of NDVI values from each year for each pixel (excluding masked water and disturbed areas) to determine if there was a monotonic trend in vegetation productivity. The output of this test included a p-value for each pixel that was used for hypothesis testing given a significance level of 0.05. This test was used to determine which pixels in the study area had a monotonic NDVI trend.

Sen’s Slope

To estimate the NDVI trend slopes of pixels that exhibited a monotonic trend, I determined the Sen’s slope in R using the ‘sens.slope’ tool in the trend package developed by Thorsten Pohler. The Sen’s slope function calculates the slope between each yearly set of measurements and then outputs the median slope for all of the data. Like the Mann-Kendall test, deriving Sen’s slope is also a nonparametric method. In Rstudio, each slope calculation was performed using a vector of NDVI values from each year for each pixel. Among eligible pixels, Sen slope was reclassified using ArcMap into positive slopes (greening) and negative slopes (browning) where the pixel was

determined to have a significant NDVI trend by the Mann Kendall test and classified as no trend where there was not a significant trend.

Comparing NDVI Trend with Topographical Variables

In order to assess how NDVI trend was associated with elevation, slope, and aspect, the count of each trend type of eligible pixel (greening, browning, no significant trend) was calculated for each class of each classified topographical variable. To find these values, rasters containing exclusively greening, browning, and no trend pixels were extracted from the full classified sen's slope raster. Using the Zonal Statistics tool in ArcMap, I determined the pixel count of each trend type within each class for the three topographic variables.

Results:

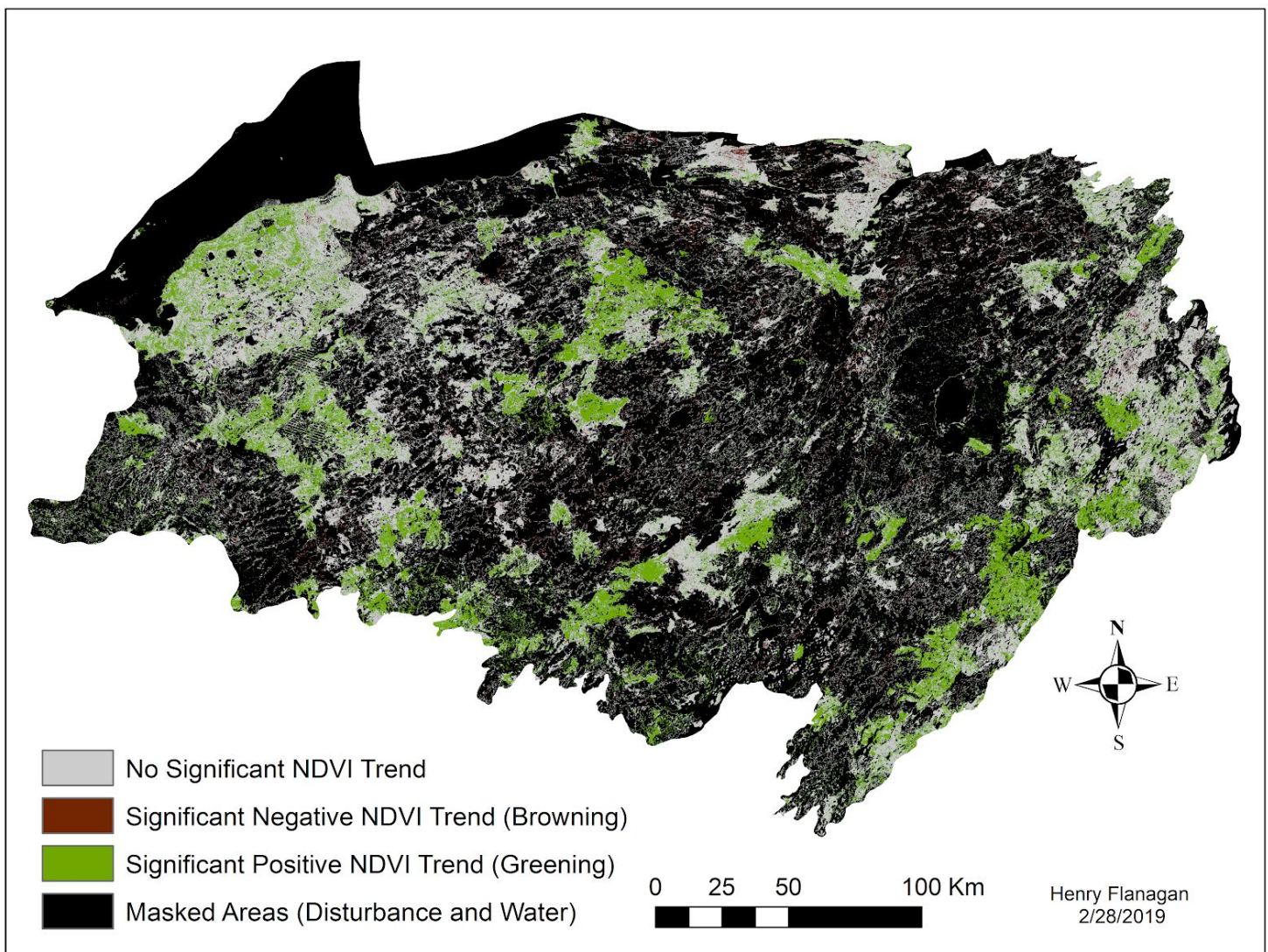


Figure 3: Pixels within the study area that had a positive significant NDVI trend during the study period as determined by the Mann-Kendall test and Sen’s slope are shown in green. Pixels with a negative significant trend in NDVI are shown in brown. A total of 11,930,224 pixels were found to display a monotonic trend in NDVI (i.e. a p-value less than 0.05). Of the pixels with a significant NDVI trend, 1,557,677 or 13.06% were browning whereas were 10,372,547 or 86.94% were greening.

A majority of the eligible pixels within the study area did not display a significant NDVI trend using a significance level of 0.05, as seen in Figure 3. The results from the Mann-Kendall test showed that nearly 12 million out of the roughly 86.7 million total pixels within the study area did exhibit a significant trend in NDVI. This constitutes about 13.8% of the total Athabasca Plains Ecoregion, with a combined area of around 10,755 square kilometers. Within the eligible, unmasked areas (which were not covered by water and had not experienced any disturbance during the study period), 42.8% of pixels displayed a significant NDVI trend. Within the study area, there was much more statistically significant greening than browning. Over 86.9% of the pixels with a significant NDVI trend were greening, and around 13.1% were browning.

Figures 4 through 6 show where pixels are greening and browning in regards to elevation, slope, and aspect within the study region. For each topographical variable, the raw counts of greening pixels, browning pixels, and pixels with no trend are provided for every class. These values are also displayed as percents of all eligible pixels within each class.

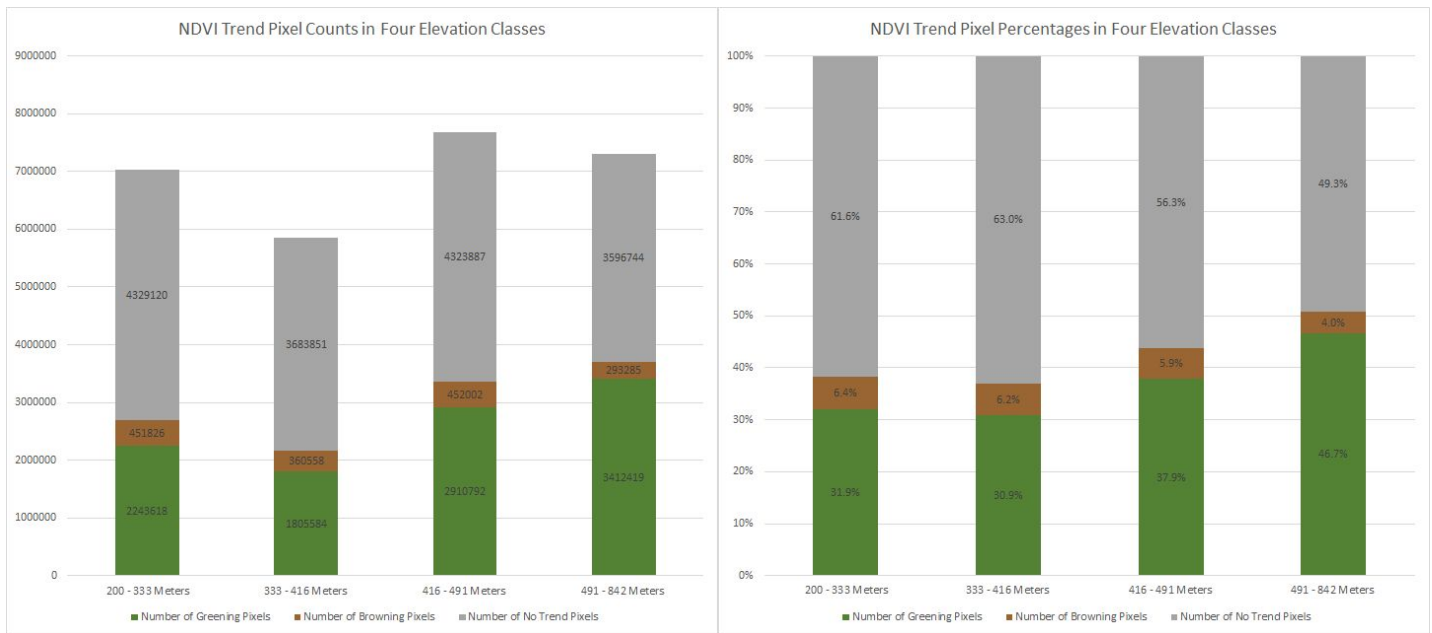


Figure 4: Raw counts and percentages of pixels in the 3 NDVI trend types (browning, greening, or none) within 4 elevation classes

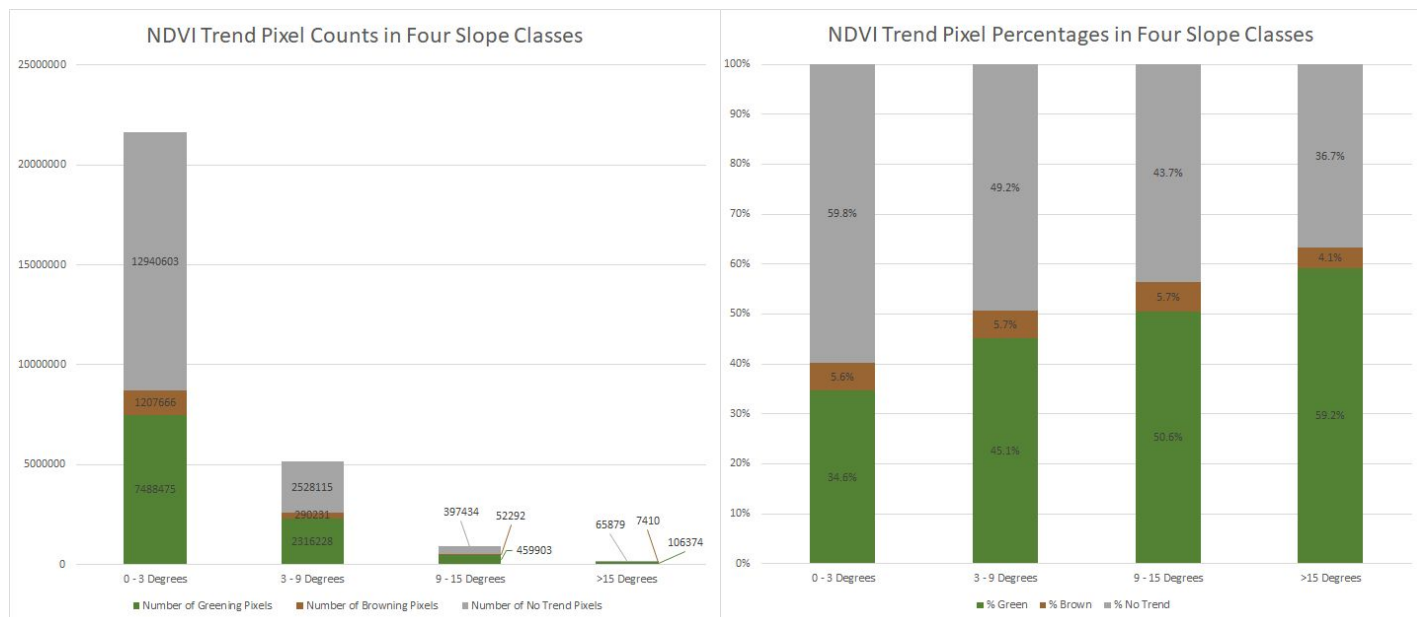


Figure 5: Raw counts and percentages of pixels in the 3 NDVI trend types (browning, greening, or none) within 4 slope classes

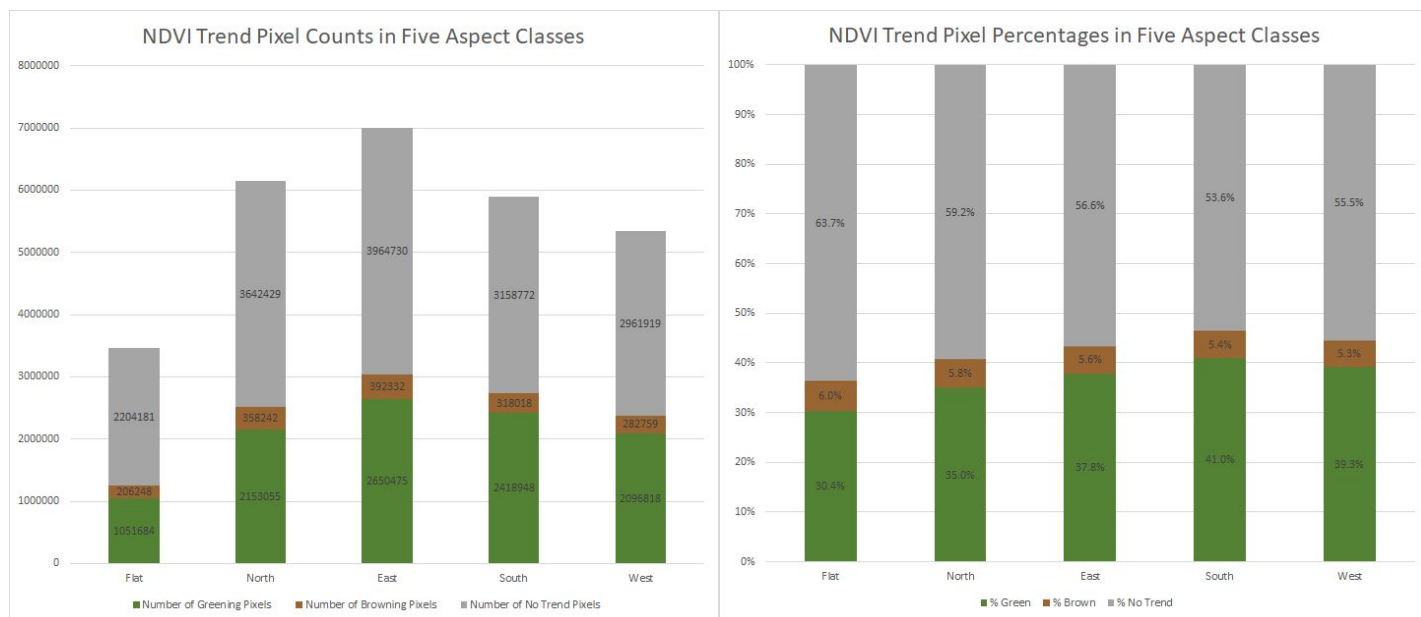


Figure 6: Raw counts and percentages of pixels in the 3 trend types (browning, greening, or none) within 5 aspect classes

Discussion

NDVI Trend Association with Topography

There is evidently an association between topography and NDVI trend in the boreal forests of the Athabasca plains ecoregion. Previous studies of boreal vegetation productivity change have identified topography as a potential variable that influences greening and browning over time (Ju and Masek 2016, Myers-Smith et al 2011, Ropars and Boudreau 2012). Slope had the greatest association with greening and browning out of the three topographical variables. Areas with higher slopes experienced proportionally more greening than areas with lesser slopes. The percent of eligible pixels that experienced greening increased notably in each increasing slope class (Figure 5). Higher elevation and more southerly aspect seemed to also be associated with increased greening, but less strongly than slope. The highest height class did contain the greatest proportion of greening pixels, but the lowest height did not contain the smallest proportion of greening pixels. Browning percentages did not vary as strongly as greening between the different classes in each classified variable. Unlike with greening pixels, the proportion of browning pixels did not steadily increase or decrease as topographical variable class increased. Parent and Verbyla (2010) studied browning in Alaska's Boreal forest during a similar time period with Landsat and MODIS Data and found that the most browning occurred in lower elevation areas. This pattern was also seen in the height classes from this study. The lowest elevation class had the greatest proportion of browning pixels at 6.4%, whereas the highest elevation class had the lowest proportion of browning pixels at 4.0%.

Assessing the Amount of Greening vs Browning in the Study Area

This analysis also showed that a much greater area of boreal forest in this ecoregion experienced greening than experienced browning. During the study, period 87% of unmasked pixels with a significant NDVI trend were greening, whereas only 13% were browning (Figure 3). This pattern of mixed greening and browning with more widespread greening has been seen in other remote sensing studies of boreal forest productivity change (Ju and Masek 2016, Guay et al 2014). Guay et al (2014) assessed greening and browning with NDVI in worldwide northerly latitudes using several different remote sensing datasets for comparison. Using the GIMMS3 dataset, which was derived from AVHRR data, they found that 15% of their total study area experienced significant greening whereas less than 3% experienced significant browning. NDVI, which has been the primary vegetation index used in similar studies, was also used to study boreal forest productivity by Ropars and Boudreau (2012), Sulla-Menashe et al (2018), and Myers-Smith et al (2011).

Many types of remote sensing data have been used to study greening and browning in boreal forests using time series analysis. These include datasets derived from AVHRR, MODIS, Landsat, and aerial photography (Guay et al 2014, Parent and Verbyla 2010, Ropars and Boudreau 2012, Ju and Masek 2016). Using Landsat data, Bonney, Danby, and Traitz (2018) found that around 27% of the non-masked pixels in Canadian tundra/forest transition zones had a significant NDVI trend, with over 99% of these trending pixels greening rather than browning. Ju and Masek (2016) also used Landsat data to derive NDVI per-pixel time series to assess greening and browning in northerly latitudes. They too found that more greening was occurring than browning, with a majority of the greening occurred in areas in or near tundra. There appears to be much more browning occurring in more southerly boreal forests that are not adjacent to the northern Canadian tundra. Ju and Masek's (2016) results differed from the results of this study in that they found that browning rather than greening trends dominated throughout northern Saskatchewan and Alberta from 1984 to 2012. This may have been due to differences in the Landsat images used, the length of the study period, or statistical methods used for analysis as they determined the NDVI trend using simple linear regression and assessed trend significance with a Student's t-test.

The Mann-Kendall test and Sen's slope have been employed by several authors for studying boreal forest change. Guay et al (2014) previously used the Mann-Kendall test to test the significance of NDVI trend in per-pixel time series and calculated Sen's slope to estimate the trend. de Jong et al (2011) used a seasonal Mann-Kendall test to determine NDVI trend significance on a global scale. The use of the nonparametric Mann-Kendall test and Sen's slope is advantageous compared to other statistical methods because they require fewer assumptions (e.g. normality) to be met and are generally less affected by outliers in data. This is valuable when performing time-series analysis because there is often some noise present in large remote sensing datasets and because reflectance values are often not distributed normally (Olson, 2009).

Importance of Studying Non-Climate Variables Affecting Greening and Browning in Canadian Boreal Forests

Productivity in boreal forests is increasing in many areas and decreasing in some others due to climate change (Sulla-Menashe et al 2018, Guay et al 2014, Ropars and Boudreau 2012), but other local factors may play a part in where greening and browning occurs. Time series of vegetation indices like NDVI generated from Landsat provide a way to monitor these changes and make predictions about how forests will change in the future. Understanding if and how much topography affects boreal forest greening and browning trends may aid in refining models of forest productivity change over time. The apparent association between topographical variables like slope, elevation, and aspect and vegetation productivity trend in these regions makes these relationships worth studying in more detail and in more areas of Canada's boreal

forests. For instance, regression analysis can be used to quantitatively estimate how the annual NDVI trend varies based on slope and elevation. This information could then be used to supplement climate data to create models that predict vegetation productivity trends on a pixel by pixel basis. Improving localized predictions of greening and browning may provide value to many groups such as foresters, climate scientists (e.g. through better forecasts of carbon stocks), and local residents who rely on resources from forests.

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Appendix 1: Quantitative Data Review

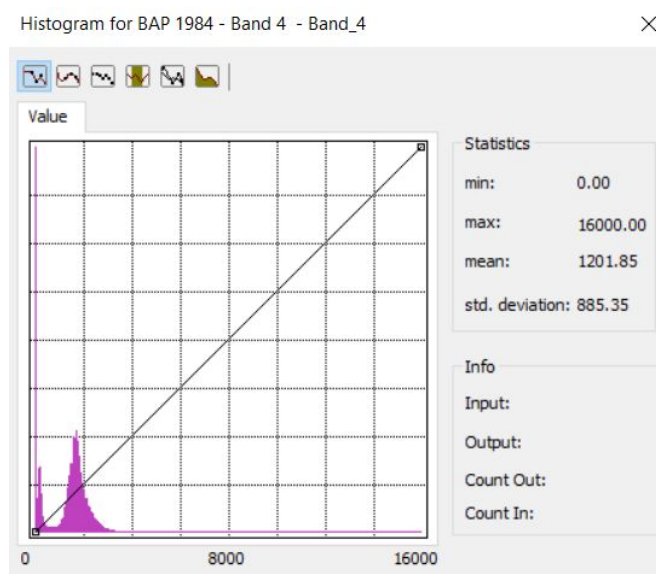
Primary Datasets

1. Landsat annual best available pixel (BAP) data from 1984 - 2015

- Data Format: 32 TIFF files with 6 bands
- Purpose: Determine spectral reflectance values for the entire study area in each year in the study period. This preprocessed dataset produced by Hermosilla et al (2016) provides the best Landsat pixel available (i.e. no cloud cover or other obstruction) for every location taken from images from the peak growing season, which was defined as August 1st +/- 30 days.
- Statistics (for 1984 file, Band 4 - NIR):

| <i>Statistic</i> | <i>Value</i> |
|------------------|---------------------------------------|
| n (pixel count) | 172,694,976 (study area bounding box) |
| Min | 0 |
| Max | 16,000 |
| Mode | n/a |
| Mean | 1201.85 |
| Std Dev | 885.35 |

- Histogram (for 1984 file, Band 4 - NIR):



- Map (for 1984 file - true color RGB):

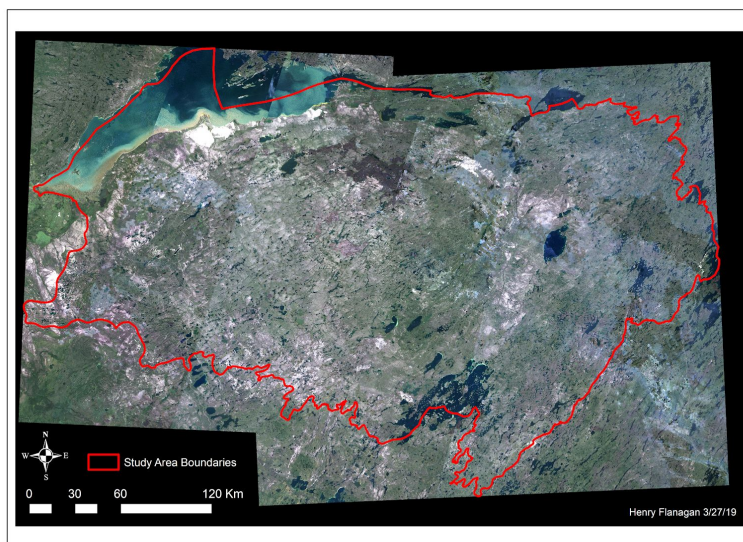


Figure 7: Map showing the 1984 BAP data and the study area, with true color bands displayed

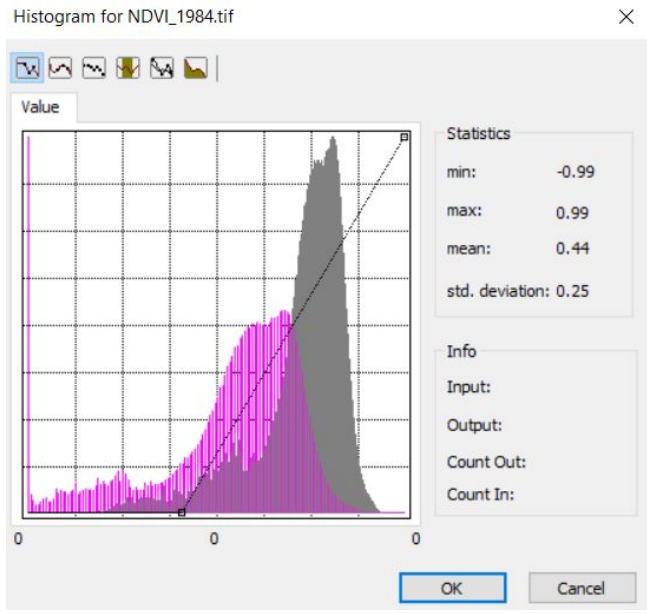
- Metadata Summary:
 - Data creation: This data was originally acquired from Landsat images from July-September 1984, which were then composited in 2016-2017.
 - Originator: The BAP datasets were produced by Hermosilla et al (2016), I acquired a portion of the data clipped to my study area from the UBC Integrated Remote Sensing Studio during November of 2018.
 - Last date of update: N/A, updated annually to add the previous year

2. Annual NDVI Data 1984 - 2015 (derived from BAP data)

- Data Format: 32 TIFF files
- Purpose: Derived NDVI (normalized difference vegetation index) for each pixel in each of the annual Landsat BAP files to assess the vegetation productivity trend over time. The following formula is used to calculate NDVI using the spectral values for each pixel: $\text{Band 4 (NIR)} - \text{Band 3 (Red)} / \text{Band 4} + \text{Band 3}$.
- Statistics (1984 File):

| <i>Statistic</i> | <i>Value</i> |
|------------------|--------------|
| n (pixel count) | 172,694,976 |
| Min | -0.9941 |
| Max | 0.9942 |
| Mode | n/a |
| Mean | 0.4419 |
| Std Dev | 0.2516 |

- Histogram (1984 File):



- Map (1984 File):

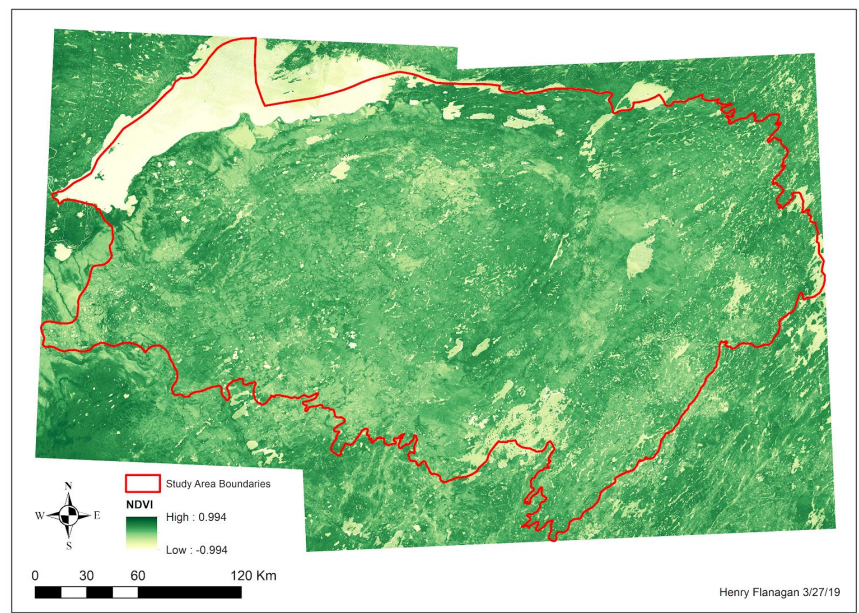


Figure 8: Map showing the derived NDVI values for the 1984 BAP Data

- Metadata Summary:

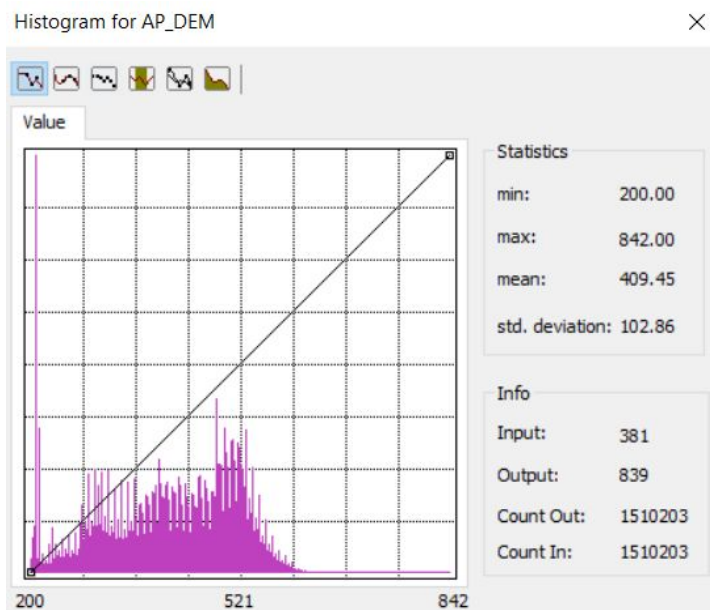
- Data creation: 10/24/18
- Originator: I derived this dataset using the NDVI Image Analysis tool in ArcMap 10.6
- Last date of update: 10/24/18

3. Elevation data for study area

- Data Format: TIFF file
- Purpose: Testing if there is an association between NDVI trend and elevation
- Statistics:

| <i>Statistic</i> | <i>Value</i> |
|------------------|--------------|
| n (pixel count) | 213,778,212 |
| Min | 200 |
| Max | 842 |
| Mode | 209 |
| Mean | 409.45 |
| Std Dev | 102.86 |

- Histogram:



- Map:

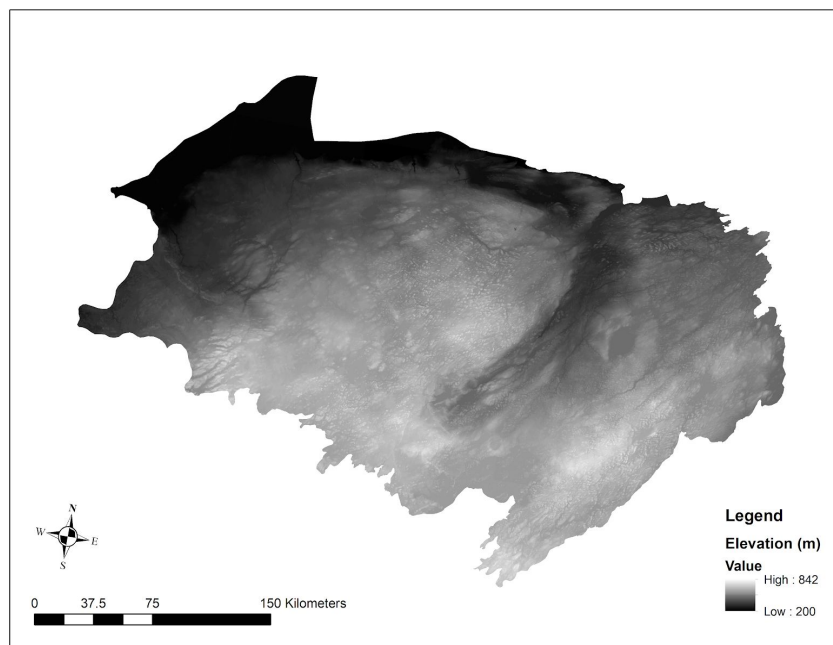


Figure 9: Map showing the elevation (DEM) dataset for the study area

- Metadata Summary:
 - Data creation: The CDEM data was created from Canadian Digital Elevation Data (CDED). The CDED was extracted from the hypsographic and hydrographic elements of the National Topographic Data Base (NTDB) at the scale of 1:50 000, the Geospatial Database (GDB), various scaled positional data acquired by the provinces and territories, or remotely sensed imagery
 - Originator: This data was acquired using the Government of Canada Geospatial Data Extraction tool. It was originally produced by Natural Resources Canada.
 - Last date of update: The data was last updated in 2016

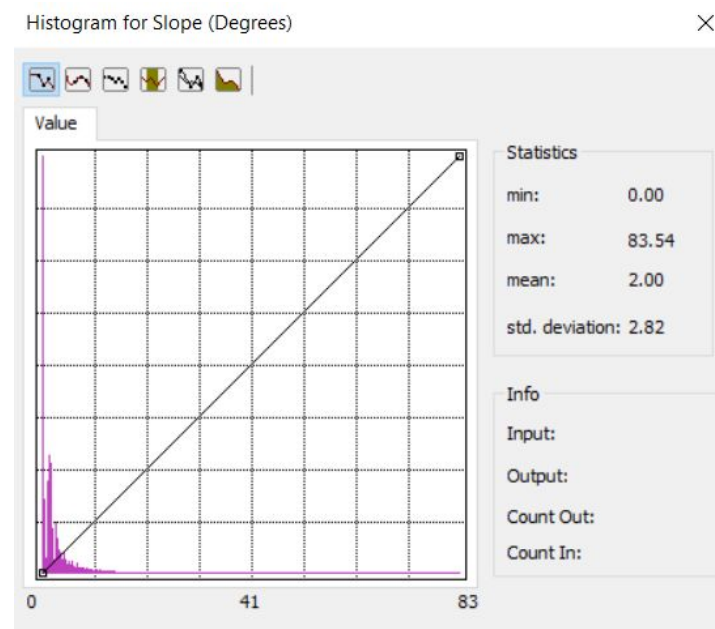
4. Slope data for study area

- Data Format: TIFF file
- Purpose: Testing if there is an association between NDVI trend and slope
- Statistics:

| <i>Statistic</i> | <i>Value</i> |
|------------------|--------------|
| n (pixel count) | 213,778,212 |
| Min | 0 |
| Max | 83.5417 |

| | |
|---------|--------|
| Mode | n/a |
| Mean | 1.9969 |
| Std Dev | 2.8177 |

- Histogram:



- Map:

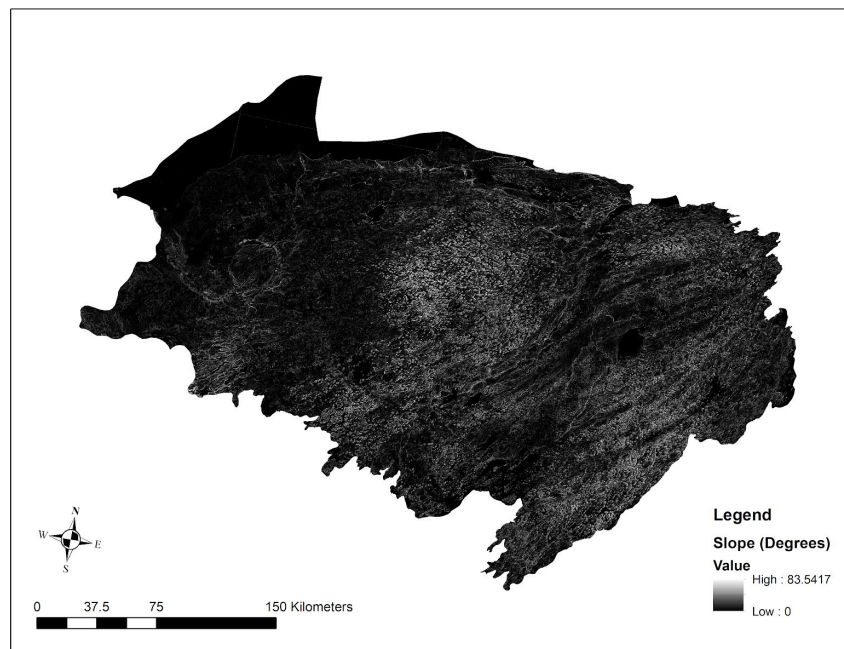


Figure 10: Map showing the slope dataset for the study area

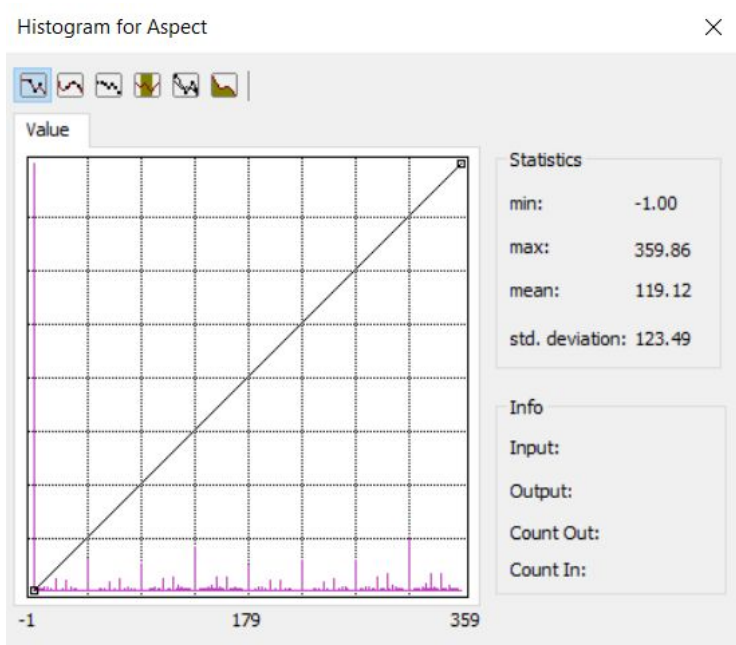
- Metadata Summary:
 - Data creation: This data was derived from the previously described study area DEM, using the ‘Slope’ Tool in ArcMap 10.6
 - Originator: I derived this dataset using ArcMap
 - Last date of update: 10/23/18

5. Aspect data for study area

- Data Format: TIFF file
- Purpose: Testing if there is an association between NDVI trend and aspect
- Statistics:

| <i>Statistic</i> | <i>Value</i> |
|------------------|--------------|
| n (pixel count) | 213,778,212 |
| Min | -1 |
| Max | 359.864 |
| Mode | n/a |
| Mean | 119.1159 |
| Std Dev | 123.4901 |

- Histogram:



- Map:

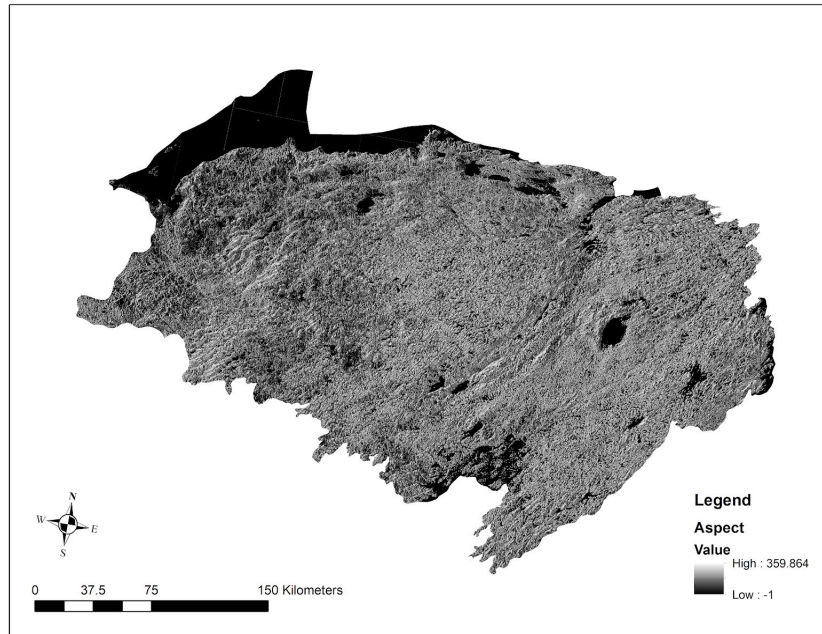


Figure 11: Map showing the aspect dataset for the study area

- **Metadata Summary:**
 - Data creation: This data was derived from the previously described study area DEM, using the ‘Aspect’ Tool in ArcMap 10.6
 - Originator: I derived this dataset using ArcMap
 - Last date of update: 10/23/18

Secondary Datasets

1. Study area / ecoregion boundaries
 - Data Format: Shapefile (.shp)
 - Map:

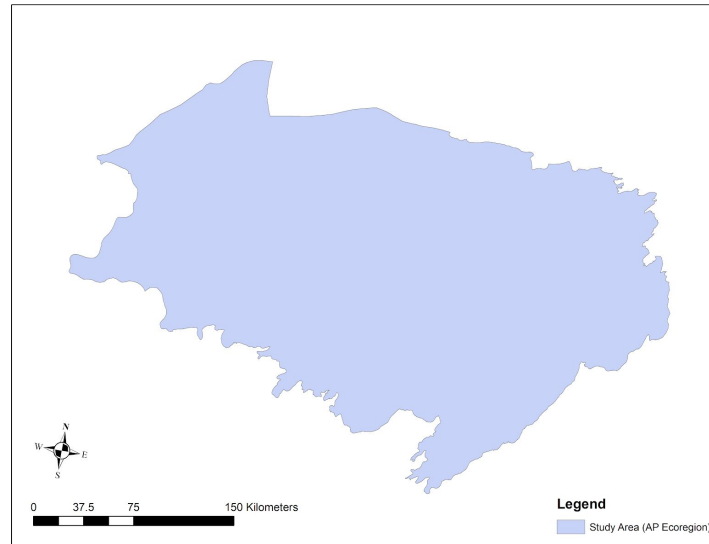


Figure 12: Map showing the Study Area boundaries dataset

- Metadata Summary
 - Data creation: The polygon features in this dataset were created to represent Canada's 194 ecoregions
 - Originator: The ecoregions dataset was created by Agriculture and Agri-Food Canada
 - Last Date of Update: 5/21/2013

2. Features within study area

- Data Format: ArcMap basemap
- Map:

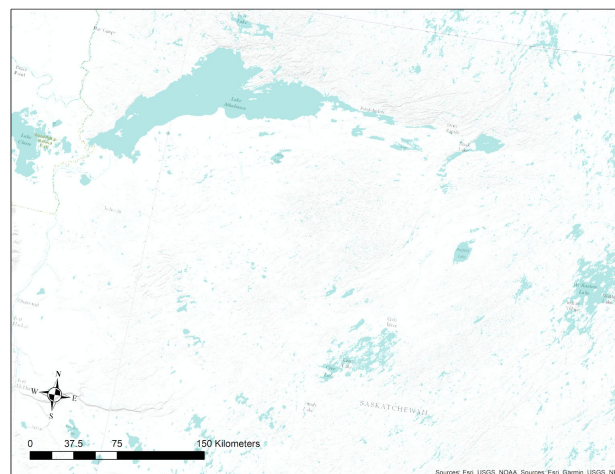


Figure 13: Map showing the terrain basemap layer in the study region

- Metadata Summary
 - Data creation and Originator: The World Terrain Base + Reference basemap was created by a number of data providers, including the U.S. Geological Survey, NOAA, and Esri
 - Last Date of Update: Feb 9, 2017