Remote Sensing Analysis of Woody Species Succession in the Carden Alvar

Collaborative Project Final Report

Project Number: 2308

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Abstract

The Carden Alvar is an extensive landscape consisting of multiple types of alvar communities, including pavement alvars which are being threatened by woody species encroachment. The shift in alvar composition could prove to be detrimental for the many unique, and possibly threatened or endangered species that thrive in pavement alvars. The Nature Conservancy of Canada would like to protect and restore the pavement alvars on the properties that they own and manage, by creating a time series going back approximately 50 years. With the use of Landsat imagery, a land cover change analysis of how woody species encroachment has altered the alvar extent in the natural area. Using Geographic Information Systems software, such as PCI's CATALYST and ArcGIS Pro, the results of a per-pixel supervised classification provide insight into the loss of alvars. In 50 years, the Carden Alvar has lost approximately 28 km^2 of it's open alvar land cover. To assist the client, identify where there has been a shift in the alvar composition, an interactive web map has been created. This deliverable provides valuable insight to areas of concern throughout the Carden Alvar and will facilitate the decision-making process of where conservation and restoration efforts should prioritize or if encroachment in some areas is appropriate.

Keywords: Carden Alvar, Remote Sensing, Species At-Risk, Woody Species Encroachment

Terms of Reference

NCC – Nature Conservancy of Canada

Alvar - flat landscapes that only occur on limestone or dolostone bedrock with little to no soil

Endangered - the species lives in the wild in Ontario but is facing imminent extinction or extirpation (Ontario, 2023).

Threatened - the species lives in the wild in Ontario, is not endangered, but is likely to become endangered if steps are not taken to address factors threatening it (Ontario, 2023).

Special Concern - the species lives in the wild in Ontario, is not endangered or threatened, but may become threatened or endangered due to a combination of biological characteristics and identified threats (Ontario, 2023).

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1. Introduction

Alvar communities in North America are becoming increasingly compromised due to woody species encroachment (Nature Conservancy of Canada, 2020). Alvar environments are areas of shallow soils on either limestone or dolostone bedrock (Nature Conservancy of Canada, 2020). These areas are naturally occurring habitats that offer unique characteristics that allow for species to inhabit that cannot exist anywhere else in the world. Due to the significance of these natural areas and the ongoing threat of an increased abundance of woody plant species, the Nature Conservancy of Canada (NCC) has focused their conservation efforts on the Carden Alvar, located in Central Ontario. The Carden Alvar is one of the largest and most significant collection of alvar communities in the world, with an area totalling just over 17,000 hectares of natural area. (Nature Conservancy of Canada, 2020). It supports many threatened and endangered species such as the Blanding's turtle, Eastern Loggerhead Shrike and Monarch butterfly (Nature Conservancy of Canada, 2023). Historically, this area has been prosperous because of agricultural practices and natural disturbances that maintained the ecological cycles. However, these have been suppressed by colonization of invasive species and human interference with the natural cycles which have influenced the woody species succession rates (Nature Conservancy of Canada, 2023).

To gain a better understanding of where woody species succession has occurred within the natural area, the NCC has identified that they would like a solution designed that provides the staff without a geographic information system (GIS) background, a visualization of where woody species succession is occurring through the Carden Alvar. The primary focus of this analysis is to gain a better understanding of where there has been a significant loss of alvar communities so that the client can be better informed for decision making processes that will influence future restoration projects in the Carden Alvar.

1.1 Client

The client for this project is the NCC which is a private, non-profit, conservation organization based in Canada. The proposition for the collaborative project was submitted to Fleming College by Tessa Strickland, GIS coordinator at NCC. Additional input and support were provided by Jordan Howard, Conservation Biology Coordinator, and Rick Simpson, Project Director for Central Ontario West.

1.2 Study Area

The Carden Alvar is located in Central Ontario and is designated as an Ecotone because it consists of two ecoregions, the Georgian Bay (5E) and the Lake Simcoe-Rideau (6E) (Crins et al., 2009), that come together to form a geological and physically unique environment. Figure 1 below provides a visualization of the natural area boundary of Carden Alvar as well as the NCC owned and managed properties, outlined in green.

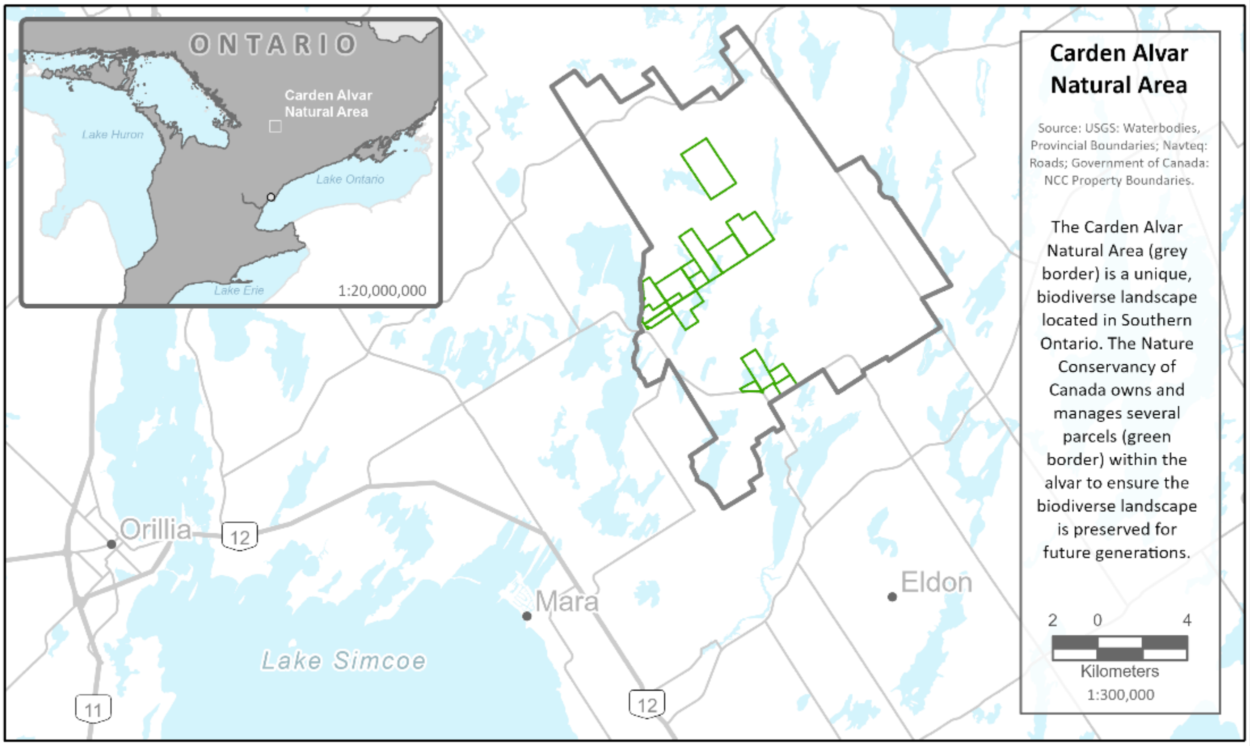

Figure 1: Map of the Carden Alvar Natural Area and the NCC parcel boundaries.

1.3 Problem Definition

Over the past several decades, woody species succession has been determined to have had detrimental effects on historic pavement alvars throughout the Carden Alvar. Pavement alvars are open areas with a significant amount of exposed bedrock and are sparsely vegetated (Reschke, C., et al., 1999). The Carden Alvar is a unique environment that provides habitat for many threatened and endangered species that cannot live anywhere else. The shift in alvar composition is posing significant threats to the success of these species.

Based on the identified threats to pavement alvars, the NCC is seeking a visualization solution that can be used by the non-GIS staff within the organization to help prioritize restoration efforts. Combining detailed information about the changes to alvar composition and the different species of importance will assist in the decision-making processes that will determine where restoration is required.

1.4 Literature Review

During the planning phases of this project, a literature review was conducted to gain a better understanding of topics that were to be explored throughout the process. Several articles were reviewed that provided the necessary knowledge regarding species of importance that inhabit the Carden Alvar, natural and human disturbances, woody species succession and the different types of Alvars along with their importance.

1.4.1 Species of importance

The Carden Alvar is important globally due to its large size and rich biodiversity (Nature Conservancy of Canada, 2023). The natural area has been designated as an Important Bird Area as it supports several threatened (Bobolink, Barn Swallow, Eastern Meadowlark, Eastern Whip-poor-will) and endangered (Eastern Loggerhead Shrike) bird species (Chabot et al., 2001; Nature Conservancy of Canada, 2023). The open landscape and grasslands are crucial nesting habitat for several of the threatened bird species, however, the endangered Eastern Loggerhead Shrike prefers Hawthorn, a shrubby species, for nesting (Chabot et al., 2001). Hawthorn is a native woody species encroaching on the open pavement alvars and grasslands converting the pavement alvars into shrubby alvars (Jones and Reschke 2005). The threat of woody species encroachment poses a unique challenge as it is crucial to both conserve the pavement alvars to support ground nesting birds while also protecting the endangered Eastern Loggerhead Shrike which relies on woody species for nesting (Nature Conservancy of Canada, 2023).

1.4.2 Woody Species Encroachment

Woody encroachment has become a global threat around the World for alvar communities (Mairota et al., 2014). Woody species encroachment of an area can be influenced by several factors including climatic trends, interferences with the natural regimes, and anthropogenic influences (Cohen, 2022). Changes in fire regimes have been the most cited cause of woody species encroachment in alvars. Prior to settlement of Europeans in North America, Indigenous peoples would participate in burning practices to clear land and promote production and growth of grass (Cohen, 2022). However, human activities have begun to supress fire burning practices as well as created preventative measures to ensure severe wildfires do not occur. This can prove to be detrimental to environments like alvars because by eliminating a natural cycle that maintained the open landscape, there is a higher chance of increase in woody species encroachment (Cohen, 2022). Woody encroachment has negative consequences on environments like alvars because it alters water, light and nutrient availability for the plant species (Ratajczak, 2012), which then impacts the species that rely on the diverse and unique ecosystem.

1.4.3 Alvar importance, types

An alvar is a unique, flat landscape that only occurs on limestone or dolostone bedrock with little to no soil (Albert, D.A, 2006). There are five types of alvars classified based on their species composition and soil thickness. They are classified as grassland, pavement, shrubland, savannah and woodlands (Reschke, C., et al., 1999). These different types of alvars may evolve into another type of alvar over time due to hydrologic and fire cycles or human interference (Reschke, C., et al., 1999). Alvars are known to form grykes, fissures, ruts and experience flooding and droughts which all contribute to how an alvar behaves and can turn into more of a forest over time (Reschke, C., et al., 1999). Alvars are important from a conservation perspective due to their rarity and genetic diversity and important research potential as they are home to many unique and endangered species (Reschke, C., et al., 1999).

1.4.4 Literature Summary

The sources that were examined during the literature review provided crucial information to better understanding woody species encroachment and how it negatively impacts alvar communities around the world. It provided insight to support remote sensing approaches as well as made it obvious that examining the at-risk species within the natural area would be crucial to a successful representation of the area.

2. Objectives

The NCC has prioritized managing and restoring the Carden Alvar since 1998 (Nature Conservancy of Canada 2020). It is an extremely diverse natural area that is made up of several types of alvars. Each type is of importance as it supports different wildlife and vegetation communities. The NCC has identified woody species succession as a threat to the historic pavement alvars within the area and required an analysis of remotely sensed data to determine the extent of damage caused by the woody species encroachment. This analysis investigates woody species encroachment, historical pavement alvar extents, current vegetation communities and the presence and/or absence of species at risk. This data will be used to help the non-GIS staff at the NCC move forward in managing the alvar, ensuring the unique biodiversity is preserved. The primary objectives to accomplish the task were to:

1. **Collect and analyze time series remote sensing data to identify areas where woody species succession has occurred in the Carden Alvar.** There are several types of alvars within the natural area, however, the pavement alvars are at the most risk for woody species encroachment. The primary focus of this project was to determine areas where woody species have encroached on

pavement alvars by looking at the time series of remotely sensed data. The client had requested the data to span as many years as possible to determine the historic extent of the pavement alvars and to inform restoration decisions moving forward.

2. **Collect existing flora and fauna data for the Carden Alvar and design a geodatabase.** The client required a geodatabase containing all data used and developed during the extent of the project. Although the client had some data on the vegetation communities within the Carden Alvar, it was requested that additional open-source data, including vegetation communities and species of importance, were collected. This data has all been incorporated into a geodatabase as a deliverable for the client.
3. **Ensure the web map and analysis is accessible and user friendly for all non-GIS staff at the NCC.** The primary deliverable for this project is an interactive map that can be easily used by non-GIS staff at NCC. This map displays areas where woody species have encroached on pavement alvars (displayed as polygons). Each area with encroachment has interactive pop-up windows that display the vegetation community information and identifies any species at-risk. This deliverable will be used by NCC staff to help visualize which areas of the Carden Alvar need prioritization for conservation.
4. **Create a poster highlighting the land cover changes, primarily focusing on the historic alvar extents.** The cartographic output was not requested by the client but will be used primarily to present the research during the Fleming College Open House in June of 2023.

3. Methodology

Using a time series of remotely sensed imagery, an analysis of the woody species succession in the Carden Alvar explores the change to the natural area spanning 50 years, from 1972 to 2022. The following sections elaborate on the process of how the deliverables were accomplished and the steps taken to discover the changes on the landscape over time and the species composition in an area. The results and conclusions of the project are elaborated on in subsequent sections following the methodology.

3.1 Project Workflow

The workflow for the project is illustrated in figure 2 below. During the initial stages of project planning, there were several discussions between the group and the client to best create the overall scope and requirements for the project. The workflow starts with data acquisition and pre-processing and then visualizes how the projects' requirements culminated over the course of the semester. The stages of the workflow are further discussed in subsequent sections.

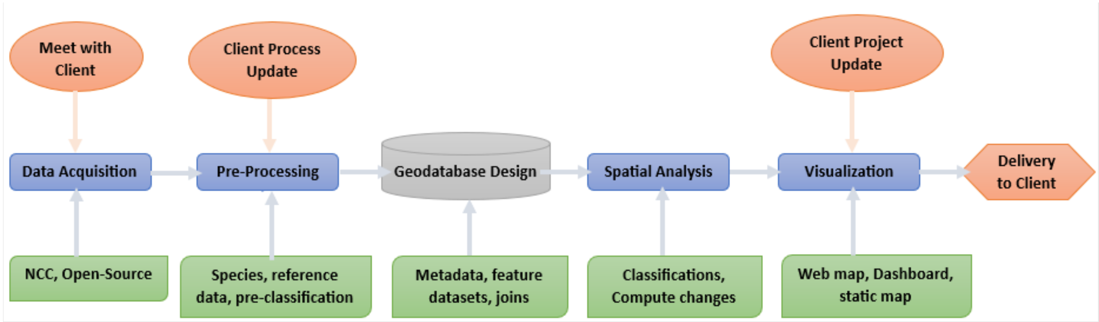

Figure 2: Project workflow to complete deliverables.

3.2 Data Acquisition

The client requested that the analysis span as many years as possible to determine the historic extent of pavement alvars. Prior to data collection, several potential sources of remote sensing imagery were explored and presented to the client. To be able to provide an in-depth examination of the pros and cons of different programs, the following were explored; South Central Ontario Orthophotography (SCOOP), aerial photography, and Landsat. The client decided that Landsat imagery would best suit their analysis needs and would provide them with more analytical opportunities for future analysis.

The initial data acquisition plan was to collect one image every five years, starting at 1972. The images were to be collected during the spring months to facilitate classification processes. However, it was quickly determined that the spring months were not suitable to acquire images because there was too much cloud cover over the study area. In order to acquire a complete time series for every five years, Landsat imagery was collected in the summer months ranging from June to August, see table 1 below, where there was significantly less cloud cover.

The most recent Landsat imagery is from Landsat 8 and 9 OLI, and those images were acquired from the United States Geological Survey (USGS). The rest of the Landsat imagery, missions 1-5, were acquired from Google Earth Engine (GEE), which can be seen in table 1. Please see *Appendix 1* for additional information on GEE data acquisition.

Table 1: Data acquisition of Landsat imagery from 1972 to 2022

Year	Source	Scale	Date	Mission
1972	GEE	60m	August 21, 1972	Landsat 1 MSS
1977	GEE	60m	June 11, 1977	Landsat 2 MSS
1982	GEE	60m	June 30, 1982	Landsat 3 MSS
1987	GEE	30m	June 15, 1987	Landsat 5 TM
1992	GEE	30m	August 06, 1992	Landsat 5 TM
1997	GEE	30m	August 04, 1997	Landsat 5 TM
2002	GEE	30m	July 01, 2002	Landsat 5 TM
2007	GEE	30m	June 29, 2007	Landsat 5 TM
***2013**	USGS	30m	July 15, 203	Landsat 8 OLI
2017	USGS	30m	June 08, 2017	Landsat 8 OLI
2022	USGS	30m	June 14, 2022	Landsat 9 OLI

To fulfil the second objective for geodatabase design and processing, open-sourced flora and fauna data from both iNaturalist and eBird were acquired to provide an in-depth analysis of species at-risk that inhabit the natural area of the Carden Alvar. The data from eBird was acquired by selecting the location where the study area was located, in this case the Kawartha Lakes region. The species data from iNaturalist was acquired by locating the project named “Carden Alvar Natural Area”, which is frequently used by NCC staff when they are in the field to collect species information. To ensure that the more accurate species data was acquired, the filter for ‘research grade observations only’ was selected. This filter ensures that there is data, photos, and coordinates of where a particular species was observed.

The remaining pertinent data was acquired from NCC that included shapefiles of the Carden Alvar Natural Area, an Ecological Land Classification (ELC) of the study area, NCC property boundaries within the Carden Alvar as well as two reference maps for NCC owned properties to assist with classification efforts. Please see *Appendix 2* for more information about the reference maps.

3.3 Pre-Processing

Pre-processing was completed in two main phases. One was to test and define which classification process would be most appropriate for analysis of the Landsat imagery. The second phase was to clip and reproject all the reference data going in the geodatabase and prepare the species data.

3.3.1. Testing Classification Methods

Several preliminary tests were conducted on Landsat 8 OLI imagery from September 18, 2013, to determine the most suitable classification method for the Carden Alvar Natural Area. Each Landsat image was imported into PCI's CATALYST software and clipped using a shapefile of the test study area extent (222 km^2) centered in the middle of the Carden Alvar Natural Area. Each clipped image was displayed as a false colour composite (5,4,3).

For the classification testing, there were seven training sites established. These classes were: industrial, emergent vegetation, bare ground, wetland, water, deciduous forest, and coniferous forest. Please see *Appendix 3* to view full descriptions of the classes used to generate the classifications.

The two major multispectral classification strategies were tested, supervised and unsupervised, in order to determine the most appropriate method for identifying land cover changes throughout the time series. An object-based classification was completed using the supervised approach. This approach used a support vector machine (SVM) classifier and radial-basis SVM kernel. This is useful when analyzing the edge of training sites because it helps to find the optimal boundaries between different training classes (Hsu et al., 2016). A per-pixel approach was then done using both a supervised and an unsupervised classification. The per-pixel supervised classification was tested using both a minimum distance and a maximum likelihood approach. The minimum distance approach forces every pixel in the image to be classed into one of the designated training sites whereas the maximum likelihood allows for a null class to be generated (PCI Geomatics Enterprises, 2023).

Once each test was completed, the classified imagery was exported as a TIFF and opened into ArcGIS Pro. Each method was visually inspected, comparing the accuracy of the classification method to raw 2013 SCOOP imagery. Emphasis was placed on correct emergent crop and open area classification to ensure open alvars were accurately classified. After visually inspecting the results, it was determined that the per-pixel supervised classification using the maximum likelihood method was the most appropriate for this analysis as it had highest accuracy when classifying emergent vegetation and open areas. Once this was determined, each group member classified the September 18, 2013, and June 11, 2018, Landsat imagery following the same per-pixel supervised classification methodology. The results were exported and visually compared to the 2013 and 2018 SCOOP imagery. The results were also compared between group members to determine whether it would introduce additional errors into the analysis if multiple group members participated in the time series Landsat classification and analysis. Once the analysis was complete, one group member was chosen to classify the time series imagery to reduce introduced errors in the analysis.

3.3.2 Species & Reference Data Pre-processing

The species data was acquired from iNaturalist and eBird. These tables were then brought into ArcGIS Pro to clip and set the projection. The clipping extent was created to surround the Carden Alvar Natural Area Boundary provided by the NCC. These tables were then exported and brought into Microsoft Access to clean the fields desired to be kept with SQL queries and have the formatting across both tables conform. More detail about how this process was achieved can be found in *Appendix 4*. Once complete they were merged into a new table and exported back into ArcGIS Pro. The reference data consists of all shapefiles provided by NCC and was clipped and reprojected to the Carden Alvar study area.

3.4 Geodatabase Design and Processing

The client requested a geodatabase to be designed using ArcGIS Pro that would be used to compile all pertinent data that had been used for the project. For the geodatabase, the projection was set to NAD 1983 UTM Zone 17N which is the regionally focused projection that the Carden Alvar falls within. This was set up as the default for the environments. The clipping extent created was also set up as the default. The geodatabase contains 7 feature classes, 4 rasters and 2 feature datasets. To limit the size of the geodatabase, only the classified raster layers for the years 1972, 1997, and 2022 and the compute change for 1972-2022 were included in the geodatabase. A separate folder was provided to the NCC which contained all the Landsat imagery, classification rasters and compute change rasters that were used and generated throughout the process of this project. The compute changes were also converted to polygon using raster to polygon so that they could be used in the AGOL Dashboard. Please see *Appendix 5* to view the full metadata report for all data that was utilized in this project.

3.4.1 Species Data processing

The previously merged species data table required a new field to be generated in order to provide the status of the at-risk species located in the study area. The resultant categories were determined to be endangered, threatened, special concern or not at-risk. The at-risk status information was sourced from the Species at Risk Ontario list (Ontario, 2023) as well as information from the NCC's documentation (Nature Conservancy of Canada, 2023). Two joins were made on the merged species data, one with the NCC properties to include the name of the property and one with the ELC to include the land classification type and parcel name. These spatial joins were both one to one and a match option of 'completely within' was selected. This was designed to ensure the data can be appropriately queried to make restoration decisions quickly. A table of all the species at-risk found in the Carden Alvar natural area and surroundings can be found in *Appendix 6*.

3.4.2 Reference Data processing

The ELC feature class that was provided by the NCC was corrected into a new feature class name Carden_ELC_Corrected. This was done as it showed some faulty data when trying to join it to the species data. A join type of one to one and match type of 'completely within' was selected. However, there was a count of 2 in the generated Join_count column from the join for some of the records. This should only be a count of 1 as there should only 1 parcel for it to join in with. It was later discovered that some older polygon lines were not removed in two of the parcels. Visually it was identical to the provided ELC map (*Appendix 2*, Figure 13) when setting the symbology to unique values for the vegetation code. However, when clicking on it, the highlighted portion did not match the polygon shape. The lines that did not match were deleted manually, please see figure 3 below. For classification purposes only, land use data from Geofabrik was clipped and queried to only display industrial and quarry polygons within the study area. This was to help with the classification process as it was difficult to distinguish between some of the quarry areas and pavement/open alvars. A roads data class from GeoGratis was also clipped down to the study area, and it was to help with the classification process.

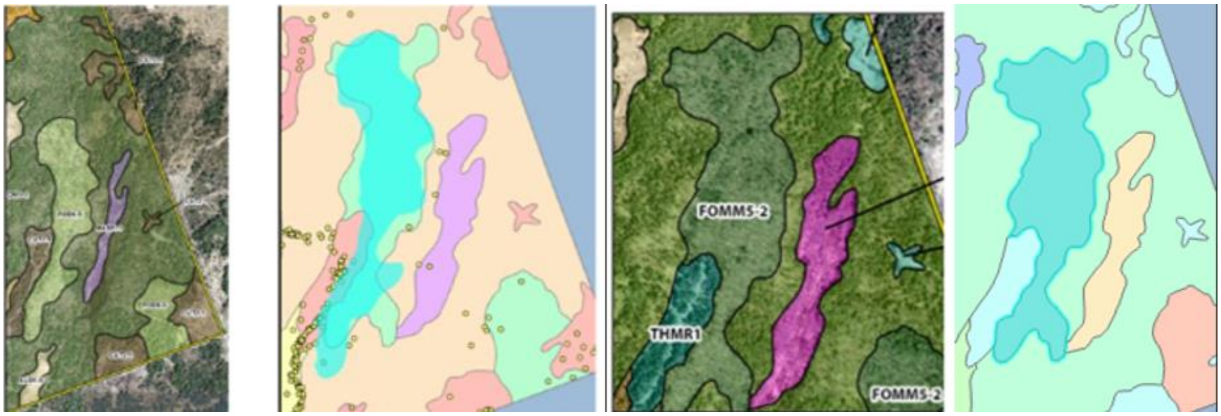

Figure 3: ELC from 2017 on the left and ELC from 2023 is on the right with the correction made to delete the older polygon line and now highlights the proper 2023 polygon.

3.5 Spatial and Statistical Analysis

To fulfil the first objective and project course requirements, spatial and statistical analysis was integrated. A variety of different GIS analysis techniques were performed to identify changes in land cover in the Carden Alvar. Upon finalization of classification techniques, as discussed section 4.3.1, the following methods were taken to get the information about landscape change from 1972-2022.

3.5.1 Time Series Landsat

The Landsat time series data was downloaded from USGS and GEE. All Landsat 8-9 OLI imagery was downloaded from USGS while all other imagery was downloaded from GEE (see *Appendix 3*, table 4). To ensure analysis could be completed within the designated time frame, it was decided to use an interval of one Landsat image for every 5 years starting in 1972 and ending in 2022. The Landsat imagery for the first 3 years (1972, 1977 and 1982) of the study is 60m spatial resolution with the remaining imagery at a resolution of 30m, with the notable exception of 2012. The Landsat 7 imagery in 2012 was determined to be unusable for the scope of this project due to the malfunctioning satellite that led to the stripping effect in the imagery. The only other imagery available for 2012 was from Landsat 5 however, that would interfere with the time series and the resolution would dip back down to a spatial resolution of 60m. After discussion with the client, it was decided it was acceptable to use 2013 Landsat 8-9 OLI imagery instead of 2012 imagery to ensure the consistency of resolution.

Each time series Landsat image was imported into PCI's CATALYST software and clipped to the Carden Alvar natural area. The supervised per-pixel classification was set up with seven training classes (Deciduous Forest, Coniferous Forest, Emergent vegetation, Open, Wetland, Water and Industrial). Training sites were established for each, ensuring minimal overlap between pixel classification, with particular emphasis on reducing overlap between the open class and all other classes. A separability of greater than 1.7 was required prior to classifying the imagery. Once the training sites were established and the separability was analyzed, a maximum likelihood classification was run. The produced classification was visually compared to the base Landsat imagery to determine overall accuracy. As necessary, training sites were fine-tuned until classifications were suitable. Classifications were then exported as a TIFF file and imported into ArcGIS Pro where the imagery was cleaned through pixel reclassification using pixel editor. The only areas that were cleaned within the classification were clouds, cloud shadows and misclassified industrial pixels. Secondary Landsat imagery was downloaded for each year that had clouds within the study area and used to reclassify clouds and cloud shadows appropriately. Geogratis road layers and raw imagery were used to correctly classify the roads for all imagery.

After all imagery was cleaned, the compute change raster function was used on each pair of Landsat images to compare land cover changes over time. Additional classification was completed on resampled 1997 and 2022 imagery to have landcover classifications at the halfway point and at the end of the time series that could be directly compared to 1972 imagery's spatial resolution. Imagery was resampled in CATALYST using a bilinear interpolation to decrease the sample from a 30m resolution to a 60m resolution. Imagery was then classified, processed and analyzed using the same methods.

3.6 Cartographic Visualization

There are three cartographic outputs for this project to effectively communicate the theme and to fulfil course requirements. The outputs are (1) ArcGIS Online web map, (2) ArcGIS Dashboard and (3) a static map. The rationalization for different aspects of the design are discussed in this section and the output results are presented in subsequent sections of the report.

3.6.1 AGOL Web Map

The primary cartographic output is a web map displaying historic and current pavement Alvar extents within the study area. The layers that have been imported into the web map for visualization are: Carden Alvar natural area, NCC owned properties, three classified Landsat images (1972, 1997 and 2022), total isolated alvar cover for 1972, 1997 and 2022, and the compute change results for 1972 to 1997, 1997 to 2022 and 1972 to 2022. The final version of the species table from the geodatabase was also imported into the web map so that it could be used in the subsequent deliverable of creating a dashboard.

3.6.2 AGOL Dashboard

To add more information and functionality to help with visualization and restoration planning, an AGOL dashboard was created using the layers that were prepared in the AGOL web map. At the top of the dashboard there is a link to a pdf webpage that explains all dashboard functionality and key features. The colour scheme of the dashboard is a dark theme and the data that is being visualized has more vibrant colours to draw the attention to certain aspects. The colour of the bar graph matches the colour of the data layer they are depicting, for example green was used for the species since species points are green and grey was used for alvar since the alvar cover polygon was grey.

All of the layers that were previously mentioned in the AGOL web map are togglable to allow the user to visualize different changes to the landscape of the extent of the study. There are many other functionalities in the dashboard that have been enabled to allow the user to customize different aspects for accessibility. On the right side of the dashboard, there is a list of at-risk species that includes their common name, status and the property that they were observed. The list also provides the capability to search for particular species. When a species is selected from the list, the point at which it was observed is highlighted on the map and a pop-window is opened providing the user with more information. At the bottom left of the dashboard, there is a bar graph showing the total open alvar land cover in square kilometers (km^2) for each year that was classified during the project. The user also has the capability to increase or decrease the width and height of the species and the alvar land cover sections.

3.6.3 Static Map

A static map was designed for the NCC and will serve as a visual aid that will be utilized within the organization and during future presentations. The static map will also be used for partial fulfilment of the visualization requirements of the collaborative project, outlined in the objectives section above. It will be on display at Fleming College's open house on June 23, 2023, to provide illustration of the study area and the results for attendees to view and facilitate discussions.

There is a side-by-side comparison of the 1972 and the 2022 classified imagery of the Carden Alvar natural area. To help add context to the maps, a generalized base map was created using layers from Statistics Canada Provincial Boundary layer from 2021 (Statistics Canada, 2021) for the Province of Ontario. This was then overlaid by Water and Waterway layers from Geofabrik's OpenStreetMap website (Geofabrik downloads, 2018). The base map was designed to be a simple representation of the surrounding area in the Kawartha Lakes to help users gain a better understanding of the study area. By using different tones of grey, it helped to emphasize the study area and not draw the attention of the user away from the primary focus. Prior to completing the final layout of the static map, the group consulted with the client for additional insight into different aspects that would assist them visualize the topic. The client was presented with several different layouts, which included different orientations, design, and colour schemes. The input was then implemented into the final design of the static map. The final map is vertically oriented on the 24”x36" “Architectural D” page size using ArcGIS Pro. To produce a physical map that would print well and be accessible to users, the Colour Brewer 2.0 “Color advice for cartography” application was used with the print friendly option selected. The colour scheme was chosen by selecting 4 classes and a qualitative theme to facilitate creating visual differences between classes, see figure 4 for the colour HEX colour scheme that was selected. To best visualize the results on the map and to focus on the open alvar changes, the deciduous and coniferous forest classes were grouped together using ArcGIS Pro to that it was only one shade of green. The Carden Alvar natural area is outlined in a dark grey and the NCC properties in a black to help them stand out. There were no fills assigned to the boundaries because the classifications were to be visible.

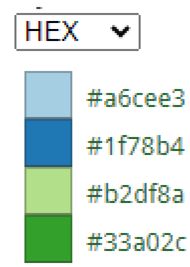

Figure 4:Color Brewer colour scheme. Qualitative colours with the 'print friendly' method selected for the static map.

4. Results

This section of the report demonstrates how the results of the project accurately reflect the main objectives that were discussed previously in section 2.

4.1 Data Acquisition, Pre-Processing and Database Design

Objective 2 stated that the client desired a geodatabase that contains all pertinent data that was used and also generated in the process of completing the project. Due to the sheer quantity of the imagery, classifications and compute change results, a separate folder was requested by the client to include those files and to only include the more relevant ones in the geodatabase design. Please see figure 5 for a screenshot of the geodatabase design that includes the relevant data that was used for the extent of the project. The geodatabase contains two feature datasets in which contains the 7 feature classes and there are also three raster datasets located within the geodatabase. The feature classes in the reference data feature dataset were used to support the creation of the cartographic outputs. The feature classes in the Species data contain two feature classes and contain the species for the entire study area as well as a clipped and joined species feature class to only display species found on the ELC's with joins made with the ELC and NCC properties. Four raster datasets include the 1972 –2022 compute change, and the 1972, 1997, and the 2022 supervised per-pixel classifications.

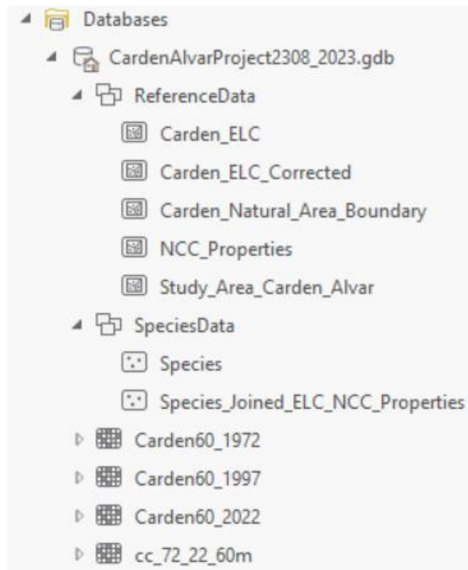

Figure 5: Snapshot of the finalized components of the geodatabase

A table highlighting the status of at-risk species was created to facilitate the creation of the species tables in the geodatabase along with providing simplified information for the ArcGIS Dashboard. This table was done to aid the client quickly see the status of each species on the Carden Alvar and aid in restoration decisions. The at-risk species table can be found in Appendix 4.

4.2 Woody Species Encroachment

Objective 1 highlighted that the main objective was to locate woody species encroachment on the open alvar extent throughout the Carden Alvar. Through the process of per-pixel supervised classification, discussed in section 4.5, it was confirmed that there has been a decrease in the open alvar communities over the past few decades. Figure 6 below, showcases the classification results from the beginning of the time series (1972), the middle (1997) and the final year (2022). It was immediately observed that the historic open alvar extents has been altered.

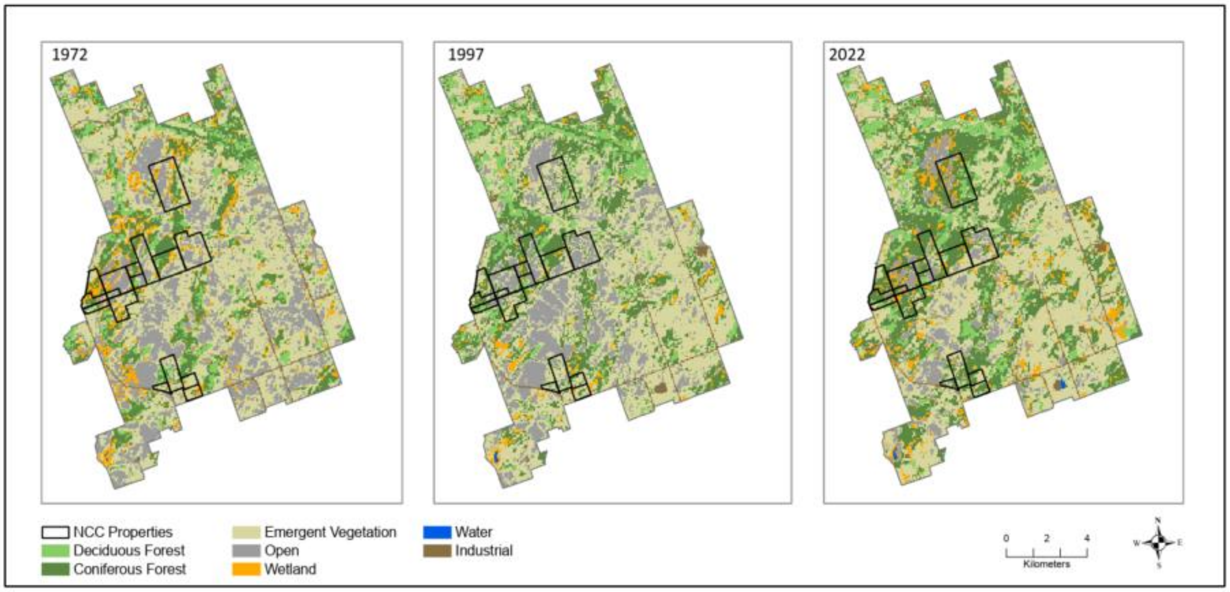

Figure 6: Land cover change results from 1972 to 2022 using a supervised per-pixel classification

Figures 7 below, summarizes the results of the classifications and the visualizes the trends of open alvar land cover in square kilometers (km^2). It is evident that there have been several changes to the open alvar extent from 1972 to 2022. Please see *Appendix 7* to view the total counts of pixels for each of the seven classes that were used to classify the Landsat imagery. It can be observed, see figure 6 above, that there has been a large amount of open alvar has been lost due to the emergence of vegetation. Figure 7 below shows the percent of landcover for each classified year. Figure 8 encompasses the total land cover for each year for each of the seven landcover categories.

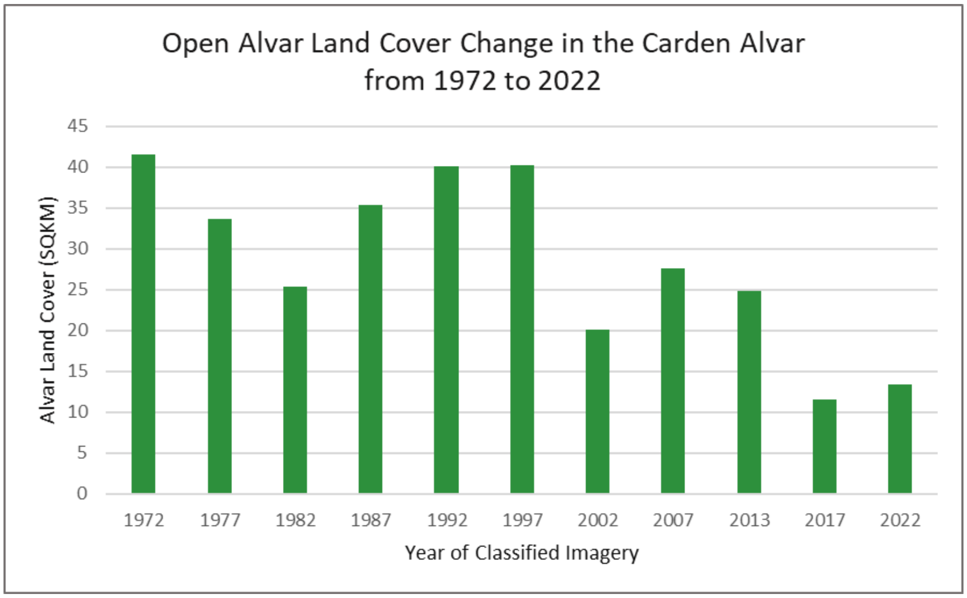

Figure 7: Total Land Cover (km2) from 1972 to 2022

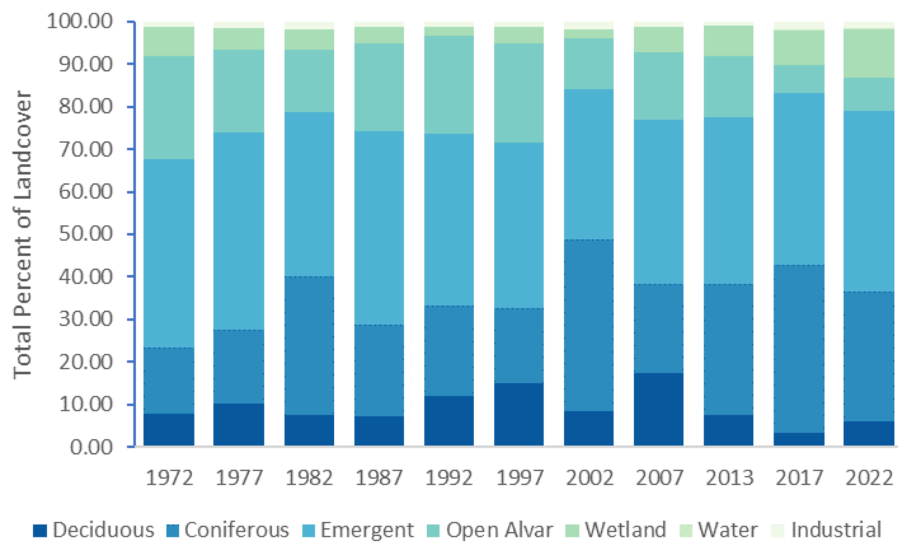

Figure 8: Percent of landcover type by classification year

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4.3 Visualization

There were three primary cartographic outputs for this project, which were outlined in section 3.6. The AGOL web map and AGOL Dashboard fulfil objective 3 and the static map supports objective 5. All aspects of visualization of the results considered the user operability and customization. The web solutions provide an interactive experience and are easy to use.

4.3.1 AGOL Web Map Results

ArcGIS Online (AGOL) was used primarily for importing the data layers from ArcGIS Pro into an online environment to later be used in the creation of a dashboard to visualize the results. Figure 9 and 10 below visualize the different layers and symbology for those layers that have been imported into AGOL. These layers are first stylized in AGOL before the creation and implementation of the dashboard.

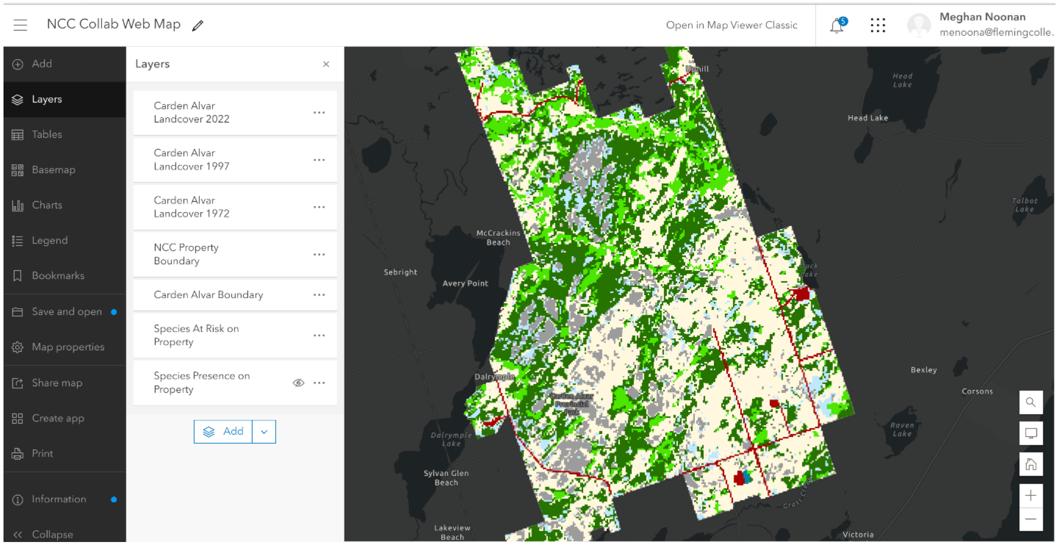

Figure 9: Layers imported into AGOL for visualization requirements.

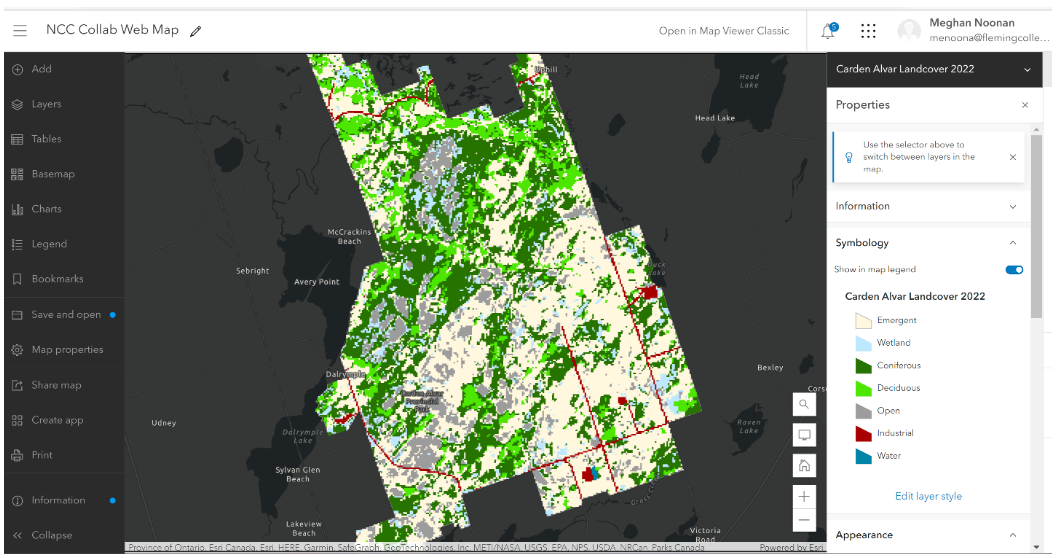

Figure 10: Symbology of the layers in AGOL for visualization purposes.

4.3.2 AGOL Dashboard Results

The ArcGIS Dashboard was designed for user accessibility in mind to ensure all staff within the organization can easily access the data that has been incorporated into it. As discussed in section 3.6.2, the dashboard is customizable for the benefit of the user by allowing them to be able to change sizes of the panels as well as the ability to change the base map to facilitate visualization purposes. Please see figure 119elow shows the Dashboard's final design. To create the most effective experience for the clients purpose, the following features were enable and created: (1) a link to an external pdf to explain how to use the dashboard (2) a legend to display the description of the various layer (3) the layers tab that is togglable (4) base map selection (5) species at-risk information and search bar (6) the alvar cover (squared kilometers) for each of the classified Landsat images and (7) an species observations graph to show total at risk species observed on NCC properties by map extent.

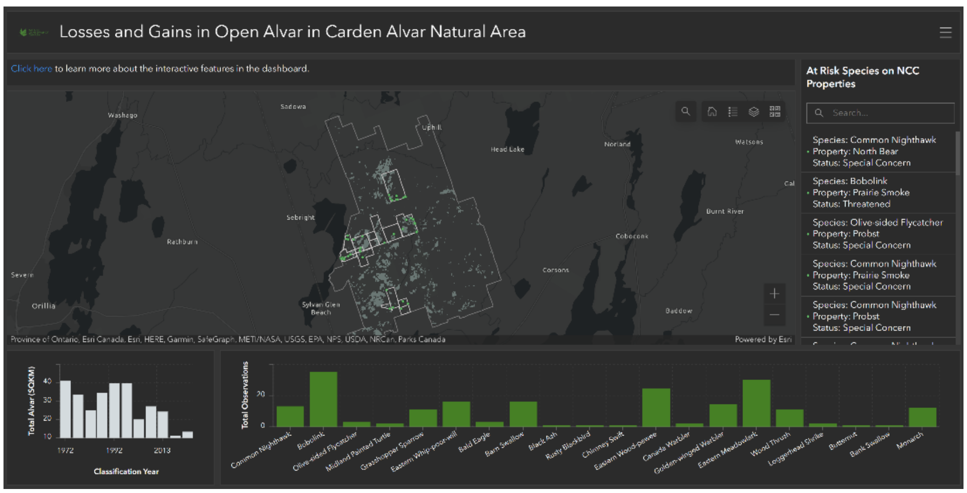

Figure 11: AGOL Dashboard final design, includes all layers that were initially imported into AGOL web map.

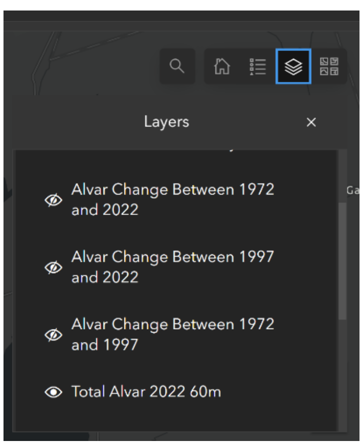

Figure 12: Layers that can be toggled between in the AGOL Dashboard

The user has been provided the capability to be able to toggle between different layers, as seen in figure 12 above, so that there is a more in-depth experience provided. By toggling between different classification layers, it becomes easier to understand and visualize where changes in the landscape have occurred over 50 years. To further facilitate understanding the land cover changes, the compute change results have been imported as well. This layer highlights both the loss and gains of open alvar extents in the Carden Alvar.

4.3.3 Static Map Results

Project objective 4 explained that a static map was not initially required by the client but would be created for fulfilment of the visualization project requirement as well as provide visual aid during the Open House at Fleming College. After discussion with the client regarding the design plans for a static map, they had decided that they would like a copy of the map so that it may be used for use within the organization as a visual aid as well as for future presentations regarding woody species encroachment in the Carden Alvar. The map has a side-by-side comparison of the 1972 and 2022 final per-pixel classification results. As discussed earlier, the colour scheme was selected from the Color Brewer application to allow for accessibility and print safe designs. The deciduous and coniferous forest classes were combined into one 'Forest Area' class. The primary focus of this map is to visualize the land cover changes in open alvar and therefore the design strategy was to emphasize these areas. The 2022 map is overlaid by the compute change results that shows both the gains and the losses to the open alvar extent. This helps to visualize that there has been a significant decrease in open alvar land cover from 1972 to 2022. In 1972, the open alvar covered approximately 41km^2 of the Carden Alvar and by 2022 it has decreased to around 15 km^2.

To finalize the overall layout of the map, important map surrounds were added including the title, legend, text, scale bar, north arrow, NCC disclaimer, spatial reference, source statement, and authorship. These features ensure the allow for full functionality of the static map for use by the NCC. The final result is shown in figure 13 below.

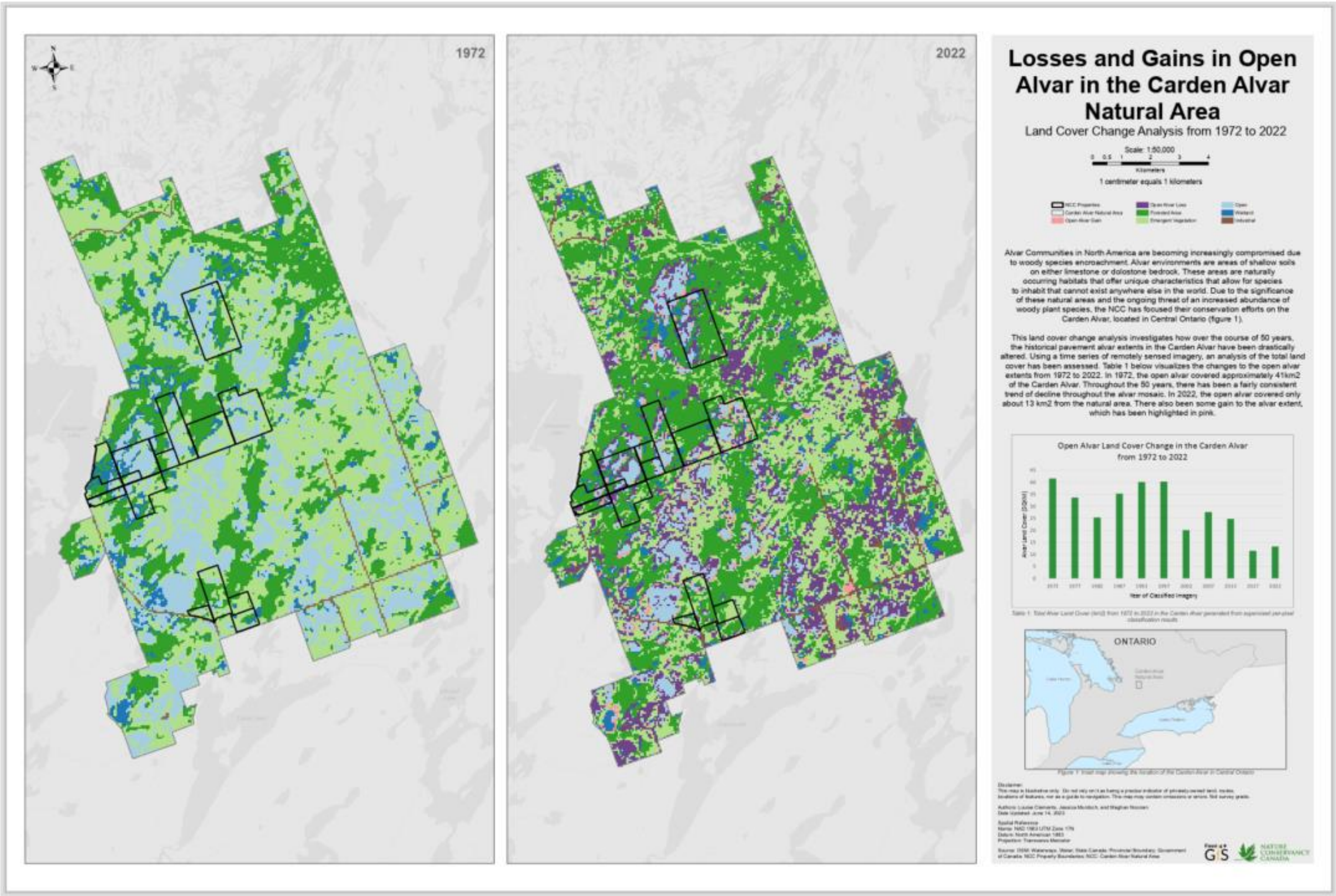

Figure 13: Final result for the static map comparing classifications between 1972 and 2022.

5. Conclusions and Recommendations

5.1 Project Summary

The Carden Alvar is one of the most important alvar communities in the World because of the diversity of species that inhabit the natural area (Nature Conservancy of Canada, 2023). There are species that live in the Carden Alvar that cannot live anywhere else, and the scale at which woody species encroachment has been occurring is significant and poses a threat to the species that inhabit the area. NCC has prioritized conservation efforts in the Carden Alvar, especially NCC owned and managed properties, in order to protect the species at-risk and restore the community to its natural state.

This report provides an in-depth explanation of how the project requirements set by Fleming College were fulfilled along with all of the client's needs in a timely and efficient manner. It outlines the multitude of steps that were taken to provide the final deliverables. These deliverables included a geodatabase containing all data used and/or generated, AGOL web map, AGOL dashboard, and a static map showcasing the results. The data acquisition and pre-processing steps provided all of data and information that was needed to complete the project. The supervised classification of Landsat imagery provided a detailed examination of the study area to provide visualization of the changes over a time period of 50 years. A user-friendly interactive ArcGIS dashboard has been created to allow for the non-GIS staff within the organization to easily access the information that has been generated from the data processing and classification results. The geodatabase has been added to the ArcGIS Pro file package that contains the maps and final layout to facilitate submission of data to the client.

5.2 Benefits of the Project

Providing the client with an ArcGIS Dashboard of the land cover changes to the open alvar in the Carden Alvar will help them to mitigate or contain where woody species succession as occurred. The dashboard also provides information about where certain species have been observed, using open-sourced data. This information will prove to be useful for when the client is deciding where the more important areas of the Carden Alvar are for prioritizing their conservation and restoration efforts. The client has also received the geodatabase and extra folders that contain all data used and classifications generated. This will prove to be of use for future analysis that is to be done in the Carden Alvar.

5.3 Limitations

The primary limitation that was faced during this project was the open-sourced data because of the inaccuracy and misrepresentation of species data. The data from iNaturalist and eBird typically do not represent the presence of a species correctly because the data tends to follow trails and roadways. This makes it difficult to accurately assess and discover trends in the data for where a particular species tends to inhabit.

5.4 Recommendations

Due to the time constraints of project, there are a couple of recommendations that are made by the group for the client. This project was an initiative for the client to gain a better understanding of where woody species succession has occurred and how the historic open alvar extent has changed over time. The scope of this project was generalized using Landsat imagery so that the client could visualize 50 years' worth of land cover change. For future projects and analysis of the Carden Alvar, it would prove useful to explore the scope of aerial photography. Aerial photography dates back much farther than the Landsat imagery so it would be useful for the client if they choose to explore earlier stages of the open alvar communities. Another option for the client to explore is the South Central Ontario Orthophotography (SCOOP). SCOOP imagery is taken every 5 years (starting in 2013) and provides 16cm resolution across central Ontario (MNRF, 2019). This would be extremely useful imagery to work with to gain a better understanding of the more current alvar extents within the past decade.

Overall, the final result of this collaborative project provides the client with the data and classifications to upscale the project to much larger extent to gain a more thorough understanding of the landscape changes that have impacted the open alvars in the Carden Alvar.

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7. Appendices

There a significant amount of pre-processing that has been completed during the process of this project. The following sections contain the information and data that was completed, but not included in the main portion of the report.

Appendix 1 – GEE Data Collection

When importing Landsat 8-9 OLI imagery into CATALYST the MTL.XML file can be dragged into the console and one file with all bands will be created in the file console. This format supports all analyses within CATALYST. For the older imagery, importing the MTL.XML produces an error indicating the file type is not recognized or supported by CATALYST. The CATALYST online documentation (PCI Geomatics, 2023) indicated the MTL.TXT file should be used instead. However, this file format was also unrecognizable to the CATALYST software. Efforts to reach out to CATALYST support were unsuccessful. Notably, the bands could be imported individually and merged, however, this would result in resampling of the data which was deemed unsuitable if an alternative approach existed. Additionally, the layer wizard can be used to make an RGB composite, however, the produced composite could not be exported as a PCDISK file and therefore analysis could not be conducted on the output. As such, contacts at the MNRF suggested using Google Earth Engine to download the Landsat imagery as a TIFF which would include all selected bands and the appropriate metadata for successful import into CATALYST.

Google Earth Engine works by using JavaScript to select Landsat imagery between a specified date range and download specific files to one drive. To acquire the imagery two scripts were used. The first script was used to list all Landsat imagery within a specified date range, list the image with the least cloud cover and to display the imagery as a false colour deposit for quality checking. The second script used the file path for the desired Landsat image and downloaded the imagery as a TIFF at the native resolution to OneDrive.

Appendix 2. NCC Reference Maps.

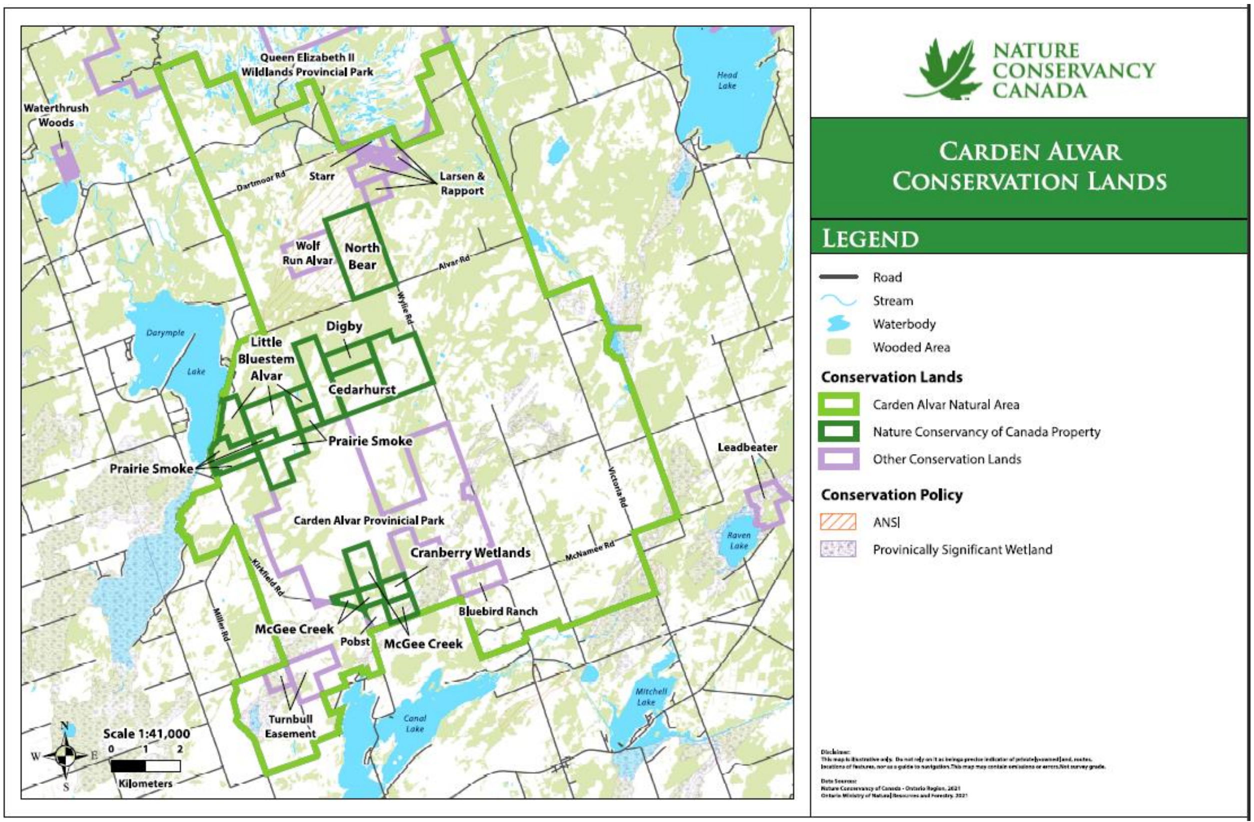

Figure 14: Conservation Lands in the Carden Alvar Area Reference Map Provided by the NCC

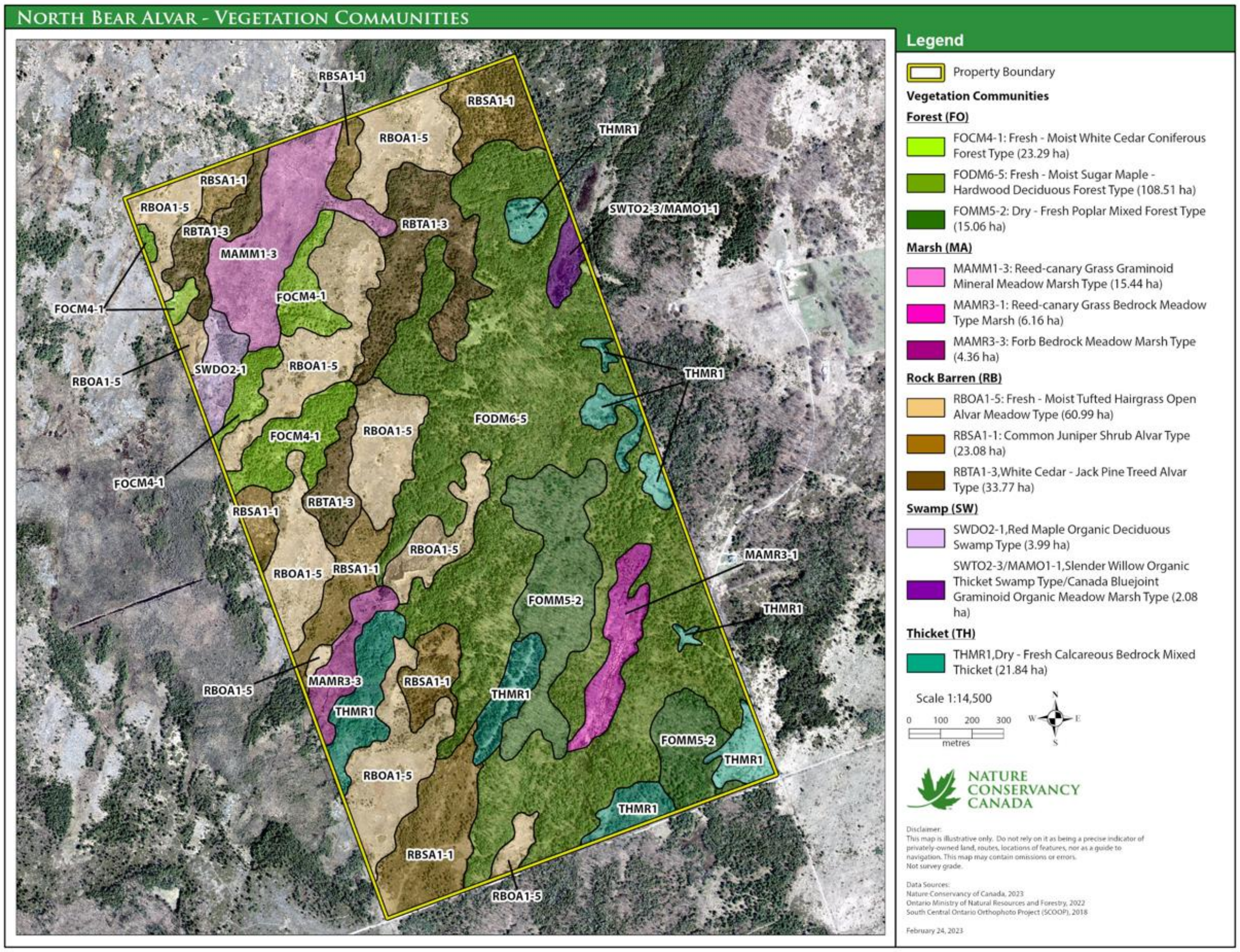

Figure 15: North Bear ELC 2023 reference map to facilitate classifications efforts

Appendix 3 – Description of Training Classes

Deciduous – Forest patches dominated by deciduous trees. Pixels are bright red and hot pink in the false colour composite.

Coniferous – Forest patches dominated by coniferous trees. The coniferous tree class also includes forested wetlands and is the most common class for open wetlands to be misclassified as. Pixels are dark red and dark purples in the false colour composite.

Emergent – Shrubs, sparsely vegetated areas and agricultural areas. Agricultural areas can be identified further due to their linear shapes, however, very little of the study area has active agriculture. The remaining areas would range from dense fields to shrubby grasslands. This class would encompass shrubby alvars. The pixels are light pink and light purple in the false colour composite.

Open – Bare ground or sparsely vegetated fields. This would be the class indicating open pavement alvars which have a thin soil layer and support minimal, sparse vegetation. The pixels are bright blue, light grey and light teal/green in the false colour composite.

Wetland – Open wetlands with less tree or vegetation cover. This class if the most common class to be misclassified as is easier to delineate when using spring imagery. If time permitted, performing post classification processing where known wetlands are overlaid and pixels are reclassified would be recommended. The pixels dark purple, dark teal, green and burgundy.

Water – Standing bodies of water, such as lakes or man-made ponds. Pixels are dark blue and black in the false colour composite.

Industrial – Quarries, cities, developments, and roads. Pixels are white or neon bright blue in the false colour composite. Can often misclassify as alvars due to similarities in pixel colours, however, patterns are easily discernible (straight roads, bright dense patches in false colour composite) making reclassification easy and accurate.

Table 2: Simple breakdown of the imagery used for each interval years landcover classification.

Landsat Type	Years	Resolution
Landsat 1-5 MSS	1972, 1977, 1982, 2012	60m
Landsat 4-5 TM	1987, 1992, 2002	30m
Landsat 8-9 OLI	2017, 2022	30m

Table 3: Detailed breakdown of the imagery used for each interval years landcover classification. Number in the brackets indicates the mission the Landsat imagery is from (i.e., June 30, 1982, uses Landsat 3 MSS – redundant information until we determine exactly what was desired)

Date	Landsat Type	Resolution	Bands	Notes
August 21, 1972	Landsat 1-5 MSS (1)	60m	7,5,4	N/A
June 11, 1977	Landsat 1-5 MSS (2)	60m	7,5,4	N/A
June 30, 1982	Landsat 1-5 MSS (3)	60m	7,5,4	N/A
June 15, 1987	Landsat 4-5 TM (5)	30m	4,3,2	Some clouds
August 6, 1992	Landsat 4-5 TM (5)	30m	4,3,2	If necessary, can use June as backup

August 4, 1997	Landsat 4-5 TM (5)	30m	4,3,2	
July 1, 2002	Landsat 4-5 TM (5)	30m	4,3,2	
June 29, 2007	Landsat 4-5 TM (5)	30m	4,3,2	If necessary, can use July as backup
July 15, 2013	Landsat 8-9 OLI (8)	30m	5,4,3	NCC chose 2013 instead of 2012 to avoid dip in resolution
June 8, 2017	Landsat 8-9 OLI (8)	30m	5,4,3	
June 14, 2022	Landsat 8-9 OLI (9)	30m	5,4,3	Some clouds but cloud shadow vector file included

Appendix 4. Species Data Pre-Processing Cleaning Methods

To clean both iNaturalist and eBird data it was necessary to perform data consistency checks which involved using SQL queries to check for duplicates with the DISTINCT query. No duplicates were found however, many records shared the same coordinates in the eBird data. This is also visible in ArcGIS PRO when clicking a point on some eBird data point, multiple records appear. Unnecessary fields were also removed which in this case included anything that did not relate in both tables. However, it was desired to keep the taxon type, which was only provided in the iNaturalist data, so a new field was created in the eBird data to include taxon and a query was made to set them all to 'Aves' as eBird only has bird species. For the iNaturalist data there was a "species guess" field, so that was used to see if the records in the common name and scientific names matched, no major issues were found. The last data consistency check was to see if all the iNaturalist data were of research grade as it was selected for exporting the table, only 1 record was found as 'Needs ID' so that record was deleted. All of the fields in the table required creating new fields to not alter the raw data in case mistakes were made.

Table 4: Fields that required formatting across both tables. Special characters refer to multiple fields specified in the description.

Formating Field	Description
Common Name	Searched for any lowercase as the first letter in common name, fixed with StrConv function.
Data and Time (iNaturalist Only)	• Multiple time and date columns, used the one that converted to UTC as it was all consistent. Some of them had no time listed and were left blank. • Needed to separate the time and date from the same field using the MID function to just grab the time portion and a where clause to specify which times to grab (to ignore where there was no time stated). • Used the left sql function to only insert the date portion of the field.
Time (eBird Only)	Converted to AM /PM to match with the iNaturalist data.
Time-zone	• For iNaturalist this was all set to UTC. • For eBird no data was found on what time zone it is referring to so it was set to unknown.
Special Characters	• Found special characters in the location and description for iNaturalist and in locality for eBird. This was found manually ordering the fields in ascending and scrolling through the records. • In ArcGIS PRO, performed a search by attribute for the record ID that displayed the errors to see if it decoded properly in ArcGIS PRO, it did display the record without special characters. • Used the replace SQL query to replace the special characters with reference to what it should be as shown in ArcGIS PRO.
Latitude/ Longitude	• In iNaturalist Data, the latitude and longitude precision varied from 2-9 decimal points. • In eBird data the latitude and longitude precision varied from 6-7 decimal points. • Chose to have it at 6 decimal points to have precision to 12 centimeters. • Used query to limit and round the decimal to 6 where needed with the Left sql function.

Once all the formatting was complete, merging both tables could be performed in Microsoft Access. A new table was created manually with desired data types for each field. First used the INSERT INTO function with the iNaturalist data and checked to make sure it appended correctly, then the same INSERT INTO was performed for the eBird data. To make sure all records were added, it was calculated how many records were in both tables separately and then checked to see that number matched the number of records in the new table. The exporting process as a text document resulted in a reduction of accuracy in the latitude and longitude to only 2 decimals. Exporting it as an Excel file but the time field reverted to a date field. To correct this, the field was changed to 'Time' in Excel which fixed the error and was double checked with the table in access to make sure it was converting properly.

Appendix 5. Metadata

Table 5: Feature Class Metadata in Geodatabase

Source File Name	Feature Dataset	New Name	Description	Columns	Rows	Currency	Date Acquired / Created	Geometry Type	Source Coordinate System	Source Projection	Source Datum	Source Unit of Measure	Data Source	Data Custodian	Source
StudyArea_CardenAlvar	ReferenceData	Study_Area_Carden_Alvar	Study area exten for the Carden alvar	4	1	2023	May 8th, 2023	Polygon	NAD 1983	NAD 1983 UTM Zone 17N	D North American 1983	Meters	NA	JML Cartolytics	Created by JML Cartolytics
Protected_Conserved_Area		NCC_Properties	NCC Properties clipped to study area	21	6	2022	May 8th, 2023	Polygon	Canada Albers Equal Area Conic	Albers	D North American 1983	Meters	NCC	NCC	Provided by NCC
CardenAlvar_NaturalArea.shp		Carden_Natural_Area_Boundary	Carden Alvar Boundary	14	1	2023	May 9th, 2023	Polygon	WGS 1984 Web Mercator (auxiliary sphere)	Mercator Auxiliary Sphere	D WGS 1984	Meters	NCC	NCC	Provided by NCC
Carden_ELC.shp		Carden_ELC	ELC for NCC properties	26	236	2023	May 9th, 2023	Polygon	NAD 1983	NA	D North American	Degrees	NCC	NCC	Provided by NCC
Carden_ELC.shp		Carden_ELC_Corrected	Corrected ELC for NCC properties	26	184	2023	June 8th, 2023	Polygon	NAD 1983	NA	D North American	Degrees	NCC	NCC	Provided by NCC, corrected by JML cartolytics
*gis_osm_landuse_a_free_1.shp		OSM_Quarry_Industrial	Used as reference for classification	8	8	2023	June 8th, 2023	Polygon	WGS 1984	NA	D WGS 1984	Degrees	OSM, Geofabrik	OSM, Geofabrik	http://download.geofabrik.de/north-america/canada.html
*road_segment_1		Geogratis_Roads	Used as reference for classification	80	313	2023	June 8th, 2023	Line	NAD 1983 (CSRS)	NA	D North American 1983 CSRS	Degrees	Geogratis	Geogratis	https://ftp.maps.canada.ca/pub/nrcan_rncan/vector/index/html/geospatial_product_index_en.html#link
ebird_StudyArea	SpeciesData	Species	Merged with iNaturalist Data	15	259,276	2023	May 28th, 2023	Point	GCS_WGS_1984	NA	D North American 1983	Meters	iNaturalist	iNaturalist	https://www.inaturalist.org/observations/export?flow_task_id=313641
iNaturalist_Species		Species	Merged with eBird Data	15	259,276	2023	May 28th, 2023	Point	GCS_WGS_1984	NA	D North American	Meters	eBird	eBird	https://ebird.org/data/download/ebd
Species		Species_Joined_ELC_NCC_Properties	Merged species joined to ELC and NCC	26	5,240	2023	June 5th, 2023	Point	GCS_WGS_1984	NA	D North American 1984	Meters	eBird, iNaturalist	JML Cartolytics	Modified by JML Cartolytics

* Not Kept in GDB

** All files were reprojected to NAD 1983 UTM Zone 17N with the Transverse Mercator Projection and have a Datum of D North American 1983 and all have a unit of measure of Meters.

Table 6: Raster Metadata Generated Layers

Data Source	Description	Layer Name	Included Database	Scale	Date Created	Format
Landsat_2022_06_14	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_2022	No	30m	12-Jun-23	TIFF
Landsat_2017_08_08	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_2017	No	30m	12-Jun-23	TIFF
Landsat_2013_07_15	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_2013	No	30m	12-Jun-23	TIFF
Landsat_2007_06_29	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_2007	No	30m	12-Jun-23	TIFF
Landsat_2002_07_01	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_2002	No	30m	12-Jun-23	TIFF
Landsat_1997_08_04	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_1997	No	30m	12-Jun-23	TIFF
Landsat_1992_08_06	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_1992	No	30m	12-Jun-23	TIFF
Landsat_1987_06_15	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_1987	No	30m	12-Jun-23	TIFF
Landsat_1982_06_30	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_1982	No	60m	12-Jun-23	TIFF
Landsat_1977_06_11	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_1977	No	60m	12-Jun-23	TIFF
Landsat_1972_08_21	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_1972	Yes	60m	12-Jun-23	TIFF
Landsat_1997_08_04	Raster layer generated through Landsat imagery classification in CATALYST at down sampled 60m resolution and clipped to the Carden Alvar Natural Area Boundary	Carden60_2022	Yes	60m	12-Jun-23	TIFF
Landsat_2022_06_14	Raster layer generated through Landsat imagery classification in CATALYST at down sampled 60m resolution and clipped to the Carden Alvar Natural Area Boundary	Carden60_1997	No	60m	12-Jun-23	TIFF
* All Files have a datum of WGS84, a projected coordinate system of WGS 1984 UTM Zone 17N and a projection of Transverse Mercator Zone with clipping extent set to the 'Study_Area_Carden_Alvar'						
** Files that are included in geodatabase have a projected coordinate system of NAD 1983 UTM Zone 17N with the Transverse Mercator Projection and have a Datum of D North American 1983.						

Table 7: Raster Metadata Raw

Year	Original File Name	File Path GEE	Description	New Layer Name	Source	Scale	Date Created	Original Format	New Format	Date Aquired	Mission
2022	LC09_L1TP_018029_20220614_20230412_02_T1	NA	prior to classifcation clipped to study area extent	Landsat_2022_06_14	USGS	30m	14-Jun-22	GeoTIFF	PIX	15-May-23	Landsat 9 OLI
2017	LC08_L1TP_018029_20170608_20200903_02_T1	NA	prior to classifcation clipped to study area extent	Landsat_2017_08_08	USGS	30m	08-Jun-17	GeoTIFF	PIX	15-May-23	Landsat 8 OLI
2013	LC08_L1TP_018029_20130715_20200912_02_T1	NA	prior to classifcation clipped to study area extent	Landsat_2013_07_15	USGS	30m	15-Jul-13	GeoTIFF	PIX	07-Jun-23	Landsat 8 OLI
2007	GEE_2007	LANDSAT/LT05/C02/T1/LT05_018029_20070629	prior to classifcation clipped to study area extent	Landsat_2007_06_29	GEE	30m	29-Jun-07	ClassicTIFF	PIX	07-Jun-23	Landsat 5 TM
2002	GEE_2002	LANDSAT/LT05/C02/T1/LT05_018029_20020701	prior to classifcation clipped to study area extent	Landsat_2002_07_01	GEE	30m	01-Jul-02	ClassicTIFF	PIX	07-Jun-23	Landsat 5 TM
1997	GEE_1997	**LANDSAT/LT05/C02/T1/LT05_018029_19970804**	prior to classifcation clipped to study area extent	Landsat_1997_08_04	GEE	30m	04-Aug-97	ClassicTIFF	PIX	06-Jun-23	Landsat 5 TM
1992	GEE_1992	LANDSAT/LT05/C02/T1/LT05_018029_19920806	prior to classifcation clipped to study area extent	Landsat_1992_08_06	GEE	30m	06-Aug-92	ClassicTIFF	PIX	06-Jun-23	Landsat 5 TM
1987	GEE_1987	LANDSAT/LT05/C02/T1/LT05_017029_19870615	prior to classifcation clipped to study area extent	Landsat_1987_06_15	GEE	30m	15-Jun-87	ClassicTIFF	PIX	05-Jun-23	Landsat 5 TM
1982	GEE_1982	LANDSAT/LM03/C02/T2/LM03_019029_19820630	prior to classifcation clipped to study area extent	Landsat_1982_06_30	GEE	60m	30-Jun-82	ClassicTIFF	PIX	31-May-23	Landsat 3 MSS
1977	GEE_1977	LANDSAT/LM02/C02/T2/LM02_019029_19770611	prior to classifcation clipped to study area extent	Landsat_1977_06_11	GEE	60m	11-Jun-77	ClassicTIFF	PIX	31-May-23	Landsat 2 MSS
1972	GEE_1972	LANDSAT/LM01/C02/T2/LM01_019029_19720821	prior to classifcation clipped to study area extent	Landsat_1972_08_21	GEE	60m	21-Aug-72	ClassicTIFF	PIX	30-May-23	Landsat 1 MSS

*All Files have a coordinate system of GCS WGS 1984, a projected coordinate system of WGS 1984 UTM Zone 17N, a projection of Transverse Mercator Zone and a WGS84 datum.

Table 8: Processing steps for classifications

Data Source		
GEE	Google Earth Engine	Google earth engine was used as to download imagery prior to 2013. Earlier imagery downloaded in a format that was currently not compatible with CATALYST. CATALYST help was contacted to alert them to the issue
USGS	United States Geological Survey	
Software	**Processing**	**Purpose**
CATALYST	First Clip	Clip to rectangular study area centered around the Carden Alvar Natural Area
CATALYST	Classifications	Classify imagery using supervised per pixel classification
CATALYST	Resample	Resample 1997 and 2022 imagery to make it comparable to 1972 imagery (60m resolution)
ArcGIS Pro	Second Clip	Clip classified imagery to the Carden Alvar Natural Area boundary to match species and property vector data extents
ArcGIS Pro	Compute Change Raster	Calculate change between sets of classified imagery to determine landcover change
ArcGIS Pro	Pixel Editor	Clean up classified imagery to reclassify misclassified pixels
ArcGIS Pro	Select by Attribute	Select cells transitioning to and from alvar to highlight total lost and gained alvar between each set of classification years
ArcGIS Pro	Raster to Polygon	Convert rasters to polygons for the compute change results and select classified images to upload to AGOL
ArcGIS Pro	Resample	Resample the 1997 and 2022 classifications to align pixels with the 1972 imagery. Shifts the pixels and aligns major features. Used Nearest Neighbor so no data was chnaged (compared attribute tables to confirm)
File Format		
PIX/PCIDSK	Supported by both ArcGIS Pro and CATALYST. File type required to set up supervised classification in CATALYST	
DateCreated		
Date created for the classifications is based on the day the classified imagery was clipped to carden alvar natural area extent and not on the classifcation date		

Table 9: Metadata for all the generated layers (classifications and compute changes). Visualized on pages 35 to 38

Data Source	Description	Layer Name	Included Database	Scale	Date Created	Format	Datum	Coordinate System	Projection	Clipping Extent Reference
Landsat_2022_06_14	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_2022	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Landsat_2017_08_08	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_2017	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Landsat_2013_07_15	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_2013	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Landsat_2007_06_29	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_2007	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Landsat_2002_07_01	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_2002	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Landsat_1997_08_04	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_1997	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Landsat_1992_08_06	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_1992	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Landsat_1987_06_15	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_1987	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Landsat_1982_06_30	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_1982	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Landsat_1977_06_11	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_1977	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Landsat_1972_08_21	Raster layer generated through Landsat imagery classification in CATALYST at native resolution and clipped to the Carden Alvar Natural Area Boundary	Carden_1972	Yes	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea

Landsat_1997_08_04	Raster layer generated through Landsat imagery classification in CATALYST at down sampled 60m resolution and clipped to the Carden Alvar Natural Area Boundary	Carden60_2022	Yes	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Landsat_2022_06_14	Raster layer generated through Landsat imagery classification in CATALYST at down sampled 60m resolution and clipped to the Carden Alvar Natural Area Boundary	Carden60_1997	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1972 and Carden_1977	Calculated change using compute change to determine per pixel changes between pair of classified imagery.	CC_72_77	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1977 and Carden_1982	Calculated change using compute change to determine per pixel changes between pair of classified imagery.	CC_77_82	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1987 and Carden_1992	Calculated change using compute change to determine per pixel changes between pair of classified imagery.	CC_87_92	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1992 and Carden_1997	Calculated change using compute change to determine per pixel changes between pair of classified imagery.	CC_92_97	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 18	CardenAlvarNaturalArea
Carden_1997 and Carden_2002	Calculated change using compute change to determine per pixel changes between pair of classified imagery.	CC_97_02	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_2002 and Carden_2007	Calculated change using compute change to determine per pixel changes between pair of classified imagery.	CC_02_07	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_2007 and Carden_2013	Calculated change using compute change to determine per pixel changes between pair of classified imagery.	CC_07_13	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_2013 and Carden_2017	Calculated change using compute change to determine per pixel changes between pair of classified imagery.	CC_13_17	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_2017 and Carden_2022	Calculated change using compute change to determine per pixel changes between pair of classified imagery.	CC_17_22	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1972 and Carden60_1997	Calculated change using compute change to determine per pixel changes between pair of classified imagery.	CC_72_97	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea

Carden_1972 and Carden60_2022	Calculated change using compute change to determine per pixel changes between pair of classified imagery.	CC_72_22	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1997 and Carden60_2022	Calculated change using compute change to determine per pixel changes between pair of classified imagery.	CC_97_22	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_72_77	Isolated raster loss and gain from the compute change results	LG_72_77	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_77_82	Isolated raster loss and gain from the compute change results	LG_77_82	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_87_92	Isolated raster loss and gain from the compute change results	LG_87_92	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_92_97	Isolated raster loss and gain from the compute change results	LG_92_97	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_97_02	Isolated raster loss and gain from the compute change results	LG_97_02	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 18	CardenAlvarNaturalArea
CC_02_07	Isolated raster loss and gain from the compute change results	LG_02_07	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_07_13	Isolated raster loss and gain from the compute change results	LG_07_13	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_13_17	Isolated raster loss and gain from the compute change results	LG_13_17	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_17_22	Isolated raster loss and gain from the compute change results	LG_17_22	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_72_97	Isolated raster loss and gain from the compute change results	LG_72_97	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea

CC_72_22	Isolated raster loss and gain from the compute change results	LG_72_22	Yes	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_97_22	Isolated raster loss and gain from the compute change results	LG_97_22	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1972	Isolated alvar cover from the classified imagery	Alvar_1972	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1977	Isolated alvar cover from the classified imagery	Alvar_1977	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1982	Isolated alvar cover from the classified imagery	Alvar_1982	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1987	Isolated alvar cover from the classified imagery	Alvar_1987	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1992	Isolated alvar cover from the classified imagery	Alvar_1992	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1997	Isolated alvar cover from the classified imagery	Alvar_1997	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_2002	Isolated alvar cover from the classified imagery	Alvar_2002	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_2007	Isolated alvar cover from the classified imagery	Alvar_2007	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_2013	Isolated alvar cover from the classified imagery	Alvar_2013	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_2017	Isolated alvar cover from the classified imagery	Alvar_2017	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_2022	Isolated alvar cover from the classified imagery	Alvar_2022	No	30m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden60_2022	Isolated alvar cover from the classified imagery	Alvar60_2022	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden60_1997	Isolated alvar cover from the classified imagery	Alvar60_1997	No	60m	12-Jun-23	TIFF	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea

Table 10: Metadata for layers in the AGOL Dashboard.

DataSource	Description	Layer Name	Included Database	Scale	Date Created	Format	Datum	Coordinate System	Projection	Clipping Extent Reference
Carden_1972	Vector layer generated generated from the raster classified imagery for 1972. Created specifically for the dashboard.	Carden_1972.shp	No - on AGOL	60m	14-Jun-23	SHP	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden60_2022	Vector layer generated generated from the raster classified imagery for 2022. Created specifically for the dashboard.	Carden60_2022.shp	No - on AGOL	60m	14-Jun-23	SHP	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden60_1997	Vector layer generated generated from the raster classified imagery for 1997. Created specifically for the dashboard.	Carden60_1997.shp	No - on AGOL	60m	14-Jun-23	SHP	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_72_22	Isolated alvar loss and alvar gain between 1972 and 2022. Generated from the compute change raster layer and isolated using extract by attribute. Created specifically for the dashboard.	LG_72_22	No - on AGOL	60m	14-Jun-23	SHP	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_72_97	Isolated alvar loss and alvar gain between 1972 and 1997. Generated from the compute change raster layer and isolated using extract by attribute. Created specifically for the dashboard.	LG_72_97	No - on AGOL	60m	14-Jun-23	SHP	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
CC_97_22	Isolated alvar loss and alvar gain between 1997 and 2022. Generated from the compute change raster layer and isolated using extract by attribute. Created specifically for the dashboard.	LG_97_22	No - on AGOL	60m	14-Jun-23	SHP	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden_1972	Isolated total alvar landcover for 1972. Generated using extract by attribute on the classified 1972 imagery. Created specifically for the dashboard.	Alvar_1972	No - on AGOL	60m	14-Jun-23	SHP	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden60_2022	Isolated total alvar landcover for 2022. Generated using extract by attribute on the classified 2022 imagery. Created specifically for the dashboard.	Alvar_2022	No - on AGOL	60m	19-Jun-23	SHP	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
Carden60_1997	Isolated total alvar landcover for 1997. Generated using extract by attribute on the classified 1997 imagery. Created specifically for the dashboard.	Alvar_1997	No - on AGOL	60m	19-Jun-23	SHP	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea
All classifications	Aggregated layer containing total alvar cover in SQKM for each classification year. Purpose is for the interactive dashboard figure which displays the data through filtering.	AllAlvar	No - on AGOL	60m	19-Jun-23	SHP	WGS84	WGS 84	Transverse Mercator Zone 17	CardenAlvarNaturalArea

Appendix 6: At-Risk Species table

Table 11: Species at risk found in the Carden Alvar and surrounding area. Species Status referenced from SARO and NCC.

Scientific Name	Common Name	Status
Birds		
Ammodramus savannarum	Grasshopper Sparrow	Special Concern
Antrostomus vociferus	Eastern Whip-poor-will	Threatened
Aquila chrysaetos	Golden Eagle	Endangered
Asio flammeus	Short-eared Owl	Special Concern
Cardellina canadensis	Canada Warbler	Special Concern
Chaetura pelagica	Chimney Swift	Threatened
Chlidonias niger	Black Tern	Special Concern
Chordeiles minor	Common Nighthawk	Special Concern
Coccothraustes vespertinus	Evening Grosbeak	Special Concern
Contopus cooperi	Olive-sided Flycatcher	Special Concern
Contopus virens	Eastern Wood-pewee	Special Concern
Coturnicops noveboracensis	Yellow Rail	Special Concern
Dolichonyx oryzivorus	Bobolink	Threatened
Euphagus carolinus	Rusty Blackbird	Special Concern
Falco peregrinus	Pereguine Falcon	Special Concern
Haliaeetus leucocephalus	Bald Eagle	Special Concern
Hirundo rustica	Barn Swallow	Special Concern
Hylocichla mustelina	Wood Thrush	Special Concern
Ixobrychus exilis	Least Bittern	Threatened
Lanius ludovicianus	Loggerhead Shrike	Endangered
Melanerpes erythrocephalus	Red-headed Woodpecker	Endangered
Podiceps auritus	Horned Grebe	Special Concern
Riparia riparia	Bank Swallow	Threatened
Setophaga cerulea	Cerulean Warbler	Threatened
Sturnella magna	Eastern Meadowlark	Threatened
Vermivora chrysoptera	Golden-winged Warbbler	Special Concern
Insects		
Bombus terricola	Yellow-banded Bumblebee	Special Concern
Danaus plexippus	Monarch Butterfly	Special Concern
Reptiles		
Chrysemys picta marginata	Midland Painted Turtle	Special Concern
Plants		
Fraxinus nigra	Black Ash	Threatened
Juglans cinerea	Butternut	Threatened

Appendix 7: Pixel count of classification results

Table 12: Total pixels for each class that was used in the classifications from 1972 to 2022.

Year	Deciduous	Conferous	Emergent	Open	Wetland	Water	Industrial	Cell Count	Resolution	AlvarSQM	AlvarSQKM
1972	3674	7566	21197	11561	3217	9	636	49832	60	41619600	41.6196
1977	4857	8271	22202	9351	2476	16	687	49837	60	33663600	33.6636
1982	3645	15556	18487	7053	2266	18	835	49842	60	25390800	25.3908
1987	13738	41326	87229	39233	7347	4	2561	193425	30	35309700	35.3097
1992	22632	41028	77014	44550	3764	100	2350	193430	30	40095000	40.095
1997	28703	33998	74003	44766	7361	122	2485	193435	30	40289400	40.2894
2002	15926	77180	68174	22372	4554	11	3221	193440	30	20134800	20.1348
2007	33446	39944	73813	30702	11067	167	2299	193445	30	27631800	27.6318
2013	14525	58803	75082	27543	13816	173	1496	193451	30	24788700	24.7887
2017	6496	75667	77240	12774	15392	106	3763	193455	30	11496600	11.4966
2022	11624	58372	81260	14823	22017	199	3143	193460	30	13340700	13.3407