ASSESSMENT USING TERRSET GEOVISUALISATION OF THE TEMPORAL AND SPATIAL EFFECTIVENESS OF THE PRESCRIBED BURN PROGRAM IN RE-ESTABLISHING THE OAK SAVANNAH HABITAT AT THE PINERY PROVINCIAL PARK

by

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(Source: Jennifer Johnson 2021)

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Major Advisor Second Reader

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ABSTRACT

Johnson J.M. 2022. Assessment using TerrSet geovisualisation of the temporal and spatial effectiveness of the prescribed burn program in re-establishing the oak savannah habitat at the Pinery Provincial Park

Oak savannah is a plant community of widely spaced deciduous trees with a canopy cover of between 25 to 35%, allowing grasses and other ground cover vegetation to thrive, providing habitats for numerous plant and animal species, including many endangered species. Historically, oak savannah covered large areas across North America but only 1% of these habitats still remain. Today, almost half of the oak savannah habitat in North America is found at the Pinery Provincial Park in Southern Ontario, but this has been threatened due to fire suppression, overgrazing and pine planting. Programs have been developed to re-establish the oak savannah at the Pinery, using a combination of deer population control, pine removal and prescribed burns. This thesis uses field observations together with TerrSet geovisualisation tools, satellite photographic records, and field mapping data to assess the temporal and spatial effectiveness of the programs to re-establish the oak savannah at the Pinery, and it makes future projections out to 2032. The results indicate that the oak savannah at the Pinery has been recovering since 2007, but forward projection indicates this may decline by 2032 unless a more intensive and frequent program of prescribed burns is adopted.

Keywords: mottled duskywing, New Jersey tea, oak savannah, Pinery Provincial Park, prescribed burns, TerrSet geovisualisation tools.

CONTENTS

TABLES

FIGURES

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INTRODUCTION

Oak savannah is an environmentally important ecosystem for both flora and fauna. It is commonly described as a plant community of widely spaced trees where the open canopy allows grasses and other vegetation to thrive (Buck 2018). Oak savannah is considered to have a canopy cover of between 25-35%, with oak being the principal tree (Buck 2018). Oak savannah conditions are generally found in a climatic zone intermediate between woodland and prairies, and the soils, which range from loam to sand, are always well drained. Oak savannah is ecologically important because it provides a habit for many endangered species (Aeon Web Studio 2020).

Historically large areas of North America were oak savannah, but today less than 1% of this habitat still remains and it is now one of the most endangered habitats. This loss of habitat has been influenced by several factors including urbanization, fire suppression and invasive species. Fire is critical to sustaining savannah conditions because it allows the tree canopy to remain open.

Ontario has five protected oak savannah areas, including Walpole Island; Ojibway Prairie Complex; St Williams Reserve; the Port Frank Wetlands Karner Blue Sanctuary, and the Pinery Provincial Park near Grand Bend in Southern Ontario (Rodger 1998).

The Pinery Provincial Park now has almost half of the remaining oak savannah in North America but this came under threat in the early 1960s when almost 3 million pine trees were planted at the park and forest fire suppression measures were introduced (FOP 2017). By the 1980s, there was a better understanding of the ecological importance of the oak savannah, and land management programs were put in place which included the use of prescribed burns and a pine cutting program (FOP October 2021). Today the

Pinery Provincial Park covers 2,532 hectares and it is home to over 757 plants, 319 bird species, 29 reptile species, 60 butterfly species and 32 species of mammals (FOP 2021). Current and historic photographs of the oak savannah at the Pinery are shown in Appendix 1. Key indicator species of oak savannah conditions include the eastern red cedar (*Juniperus virginiana* L.), black oak (*Quercus velutina* Lam.), prairie redroot (*Ceanothus herbaceus* L.) and the New Jersey tea (*Ceanothus americanus* L.) (FOP 2017, Linton 2015). Photographs of observed indicator species at the Pinery are shown in Appendix 1. The New Jersey tea is a critical plant for the eggs and larvae of the mottled duskywing (*Erynnis martialis* Scudder.), which is also shown in Appendix 1. The mottled duskwing is listed as an endangered species in Ontario (COSEWIC 2012). In the spring and summer 2021, the quality and extent of the habitat at the Pinery was deemed suitable for the release of mottled duskywing, eggs, larva, and butterfly back into the Pinery as part of the recovery strategy for the butterfly.

It is important to be able to measure how effective the remediation program has been in restoring the oak savannah at the Pinery, and to understand the changes in the flora that have occurred over time. This information can then be used to adapt the remediation programs based on the observed results. One approach to achieve this is to compare historic photographic records with current field observations. An alternative approach is to analyse historic and recent satellite images using advanced geovisualisation tools to determine how the vegetation at the Pinery has changed over time. This thesis reports the results of a study that used both the field observation approach and the comparison of satellite images taken over a period of approximately 30 years using geovisualisation tools to evaluate oak savannah recovery at the Pinery. The geovisualisation tools have also been used to make projections of the future condition of

the oak savannah out to the year 2032 based on the prescribed burn program at the Pinery.

OBJECTIVES

The objective of this thesis is to use geovisualisation tools, photographic records, and field mapping data to assess the temporal and spatial effectiveness of the prescribed burn and pine cutting programs in re-establishing oak savannah at the Pinery Provincial Park over the next decade, 2022-2032.

HYPOTHESIS

Advanced geovisualisation will have a positive effect on the planning and re-establishment of oak savannah at Pinery Provincial Park, through allowing visual analysis of landscape level ecological processes.

LITERATURE REVIEW

OAK SAVANNAH ECOSYSTEM

Oak savannah is considered to be the transition between western prairies and eastern deciduous forest habitats. The combining of the two habitats has given oak savannah its unique identity. Oak savannah was recorded in Ontario 4000-8000 years ago. The oak savannah at the Pinery is referred to as a "dry" savannah as it has formed on sandy soil (FOP 2017). In the early 1960s, over 3 million pine trees were planted in the park, and a policy of fire suppression was implemented forest fires were put out. These measures destroyed much of the oak savannah because the pines blocked out the light, and the fire suppression meant that the canopy was not being opened up. The restricted sunlight resulted in changes to the understory composition, which then impacted the fauna in the park, reducing biodiversity (FOP 2017). As forest community knowledge increased, the pine trees were thinned and fires were reintroduced using prescribed burns. Flowers and insects returned including the largest species of cicada found in Ontario. Oak savannah covers 60% of the park, which now represents almost a half of the area of oak savannah still remaining in North America (FOP 2017).

Even with the adoption of controlled burns and the removal of planted pine trees, a study of the changes in understory vegetation at the Pinery between 1985-1988 and 1994 found unexpected changes for a fire dependent community (Bakowsky 1994). It was determined that deer grazing in the park had led to some species being eliminated and others reduced in cover (Hopkins & Miyanishi 1993). Some species were not affected by deer grazing and remained stable, and the population of other species expanded because the deer grazing had reduced ground competition. This change in

plant structure also impacted insects and Arthropoda fauna linked to the ecosystem and so the need for a deer cull was suggested (Bakowsky 1994).

The Pinery flora and fauna are vulnerable in many ways. In order to monitor forest health at the Pinery it is important to have a number of effective indicators which can be easily monitored. In a recent study six indicators were selected to monitor the impact due to deer browsing, prescribed burns, visitor use, and trails on the understory plants growing beside the trails (Patel & Rapport 2000). The indicators were plant species richness, stem density, species cover, proportion of native species, median height of selected tree seedlings and proportion of foliar damage (insect and herbivory) on leaves of neighboring trees. It was concluded that high deer density caused significant declines in species richness, stem density, cover and median seedling height (Patel & Rapport 2000). Prescribed burns were beneficial to the forest, with stem density and cover increasing in burned areas. It was important to note that the number of exotic species also increased in areas that had been burned (Patel & Rapport 2000). High visitor use had a slightly positive impact on the forest with density and cover increasing. Native species were highest on trails with moderate visitor use. The study concluded that stem density, cover, and the proportion of native species responded strongly to deer browsing, fire, visitor use and trail impacts (Patel & Rapport 2000).

OAK SAVANNAH RECOVERY STRATEGIES

Oak savannah habitats are extremely rare in Ontario and are globally imperiled. Suppression of fires and over-grazing have affected plant communities. Effort is being made to re-establish oak savannahs in many areas (Tagliavia et al. 2002; Hayford & Chhin 2020). In their paper, Tagliavia et al. (2002) found that deer exclusion had a

significant impact on the restoration of the oak savannah at the Pinery. The Ontario Ministry of Natural Resources has recommended a carrying capacity for park deer herds of 7 deer/km^2, but in 1993 the deer population density at the Pinery was 73.2 deer/km^2 (Hynes et al. 2001). Culls reduced the deer population density to the extent that both grazed and ungrazed sample plots showed similar recovery trajectories. The paper concluded that removal of pine trees, intensive deer culling and the use of prescribed burns allowed the oak savannah plant communities at the Pinery to move away from the species composition of the early to mid 1990s (Tagliavia et al. 2002).

Prescribed burns are used to promote the re-establishment of the oak savannah at the Pinery Provincial Park (Mackenzie 2020). The success of the prescribed burns was examined by Etwell & Bazely (2004). Measurements of both the short-term and long-term effects of prescribed burns on vegetation and the monitoring of how the plant community responds need to be done over an extended time period. Plans were established for the long-term monitoring of plants following the long-term prescribed burn plan. The burn plan for the Pinery was based on a 10-year period. For specific areas with the Pinery, a comparison was made of the species richness and abundance at different time intervals after the last of the prescribed burns (Etwell & Bazely 2004). It was thought that the most frequent fire hypothesis would have the highest diversity and abundance, and that these would rapidly drop off with increasing time since the last burn. The actual data showed that the highest abundance and diversity was seen three years after a prescribed burn. Reasons for the delay were thought to include the removal of many of the deer from the park which allowed plants to recover, and the removal of pine trees which opened up the canopy allowing species to grow. The recommendation

developed by Etwell & Bazely (2004) was that a burn frequency of less than 10 years should be adopted for the Pinery.

Vegetation management protocols have been put in place at the park to support the reestablishment of the oak savannah community and protection of the environment (Fauteax 2014). The vegetation management principles used include managing the large conifer plantations leading to their eventual complete removal. Where rare or threatened plants exist, efforts should be made to create favourable habitat conditions. Prescribed burns should be used to support help create these favourable habitat conditions, and undesirable communities associated with conifer plantations should be removed. Indigenous species native to the park should be planted in areas where natural regeneration methods would be too slow. Non-native species to the Pinery should be removed using the most environmentally sound method available (Fauteax 2014).

The oak savannah at the Pinery is home to more than 75 rare and at-risk plant and animal species (Nicol 2016). To determine the effectiveness of restoration efforts that have taken place at the Pinery, plots were established with varying burn history and both plant composition and bee communities were measured. It was noted that plots that had been burned more frequently had more closed canopy than plots that had been burned once, indicating that the more recent frequent burns were of too low intensity (Nicol 2016). The plots with more open canopy had the greatest abundance of savannah plants, rare plants, and had the most abundant and species-rich diverse bee communities. Bee communities were sensitive to fire timing. Stem nesters were more abundant in the period shortly after a fire but their population decreased with time. Wood nesters showed an opposite trend with their population increasing with time since the burn (Nicol 2016). Nicol (2016) reported that over 70% of the Pinery had a canopy cover

greater than 60%. However, the greatest diversity and abundance of savannah plants and bees were found in areas where the canopy cover was between 10-35%. Canopy opening is critical to allow the oak savannah to flourish. To achieve this, it was concluded that more intense or more frequent burns would be necessary (Nicol 2016).

A paper by Buck (2018) looked at other techniques that could be used to restore woodland habitats. Oak woodlands have many similarities to oak savannah habitats but they have greater canopy closure (typically 36 - 60% closure), frequent but low intensity fires, and a patchy shrub layer (Buck 2018). In Southern Ontario, oak woodland provides important habitat for 142 species of plants of which 84 species are not usually found in other habitats, and 62 animal species that rely to some degree on oak woodlands. Fire suppression has allowed fire-intolerant species to invade the open spaces in oak woodland changing the structure of the oak woodland ecosystems, including increased shade due to the dense canopy, increased moisture at ground level, and leaf and branch litter that become easily soaked and less flammable (Buck 2018). The new tree species grow taller than the oaks, and out-compete the oaks for sunlight. Inappropriate planting and the introduction of non-native plants have led to the loss of many of the native species. Six steps have been identified to restore oak woodlands including recognizing sites that were originally oak woodland; removing non-native plants; allowing natural regeneration or introducing native seeds; prescribed burns, tree thinning and shrub thinning (Buck 2018).

Once a restoration program has been put in place, the progress needs to be monitored to determine when a site has been successfully restored. The paper by Chan & Packer (2004) concluded that the way to determine when a site has been successfully

restored was to evaluate whether the site could support the reintroduction of species which had previously been extirpated from the site. Five restored sites in Ontario, including the oak savannah at the Pinery, were assessed to determine whether they were suitable for the reintroduction of Karner blue butterfly (*Lycaeides melissa samuelis* Nabokov.). A number of biotic and abiotic criteria at each site were assessed including vegetation, the larval host plant, wild lupin (*Lupinus perennis* L.), first and second brood adult nectar source plants, tending ant species, temperature, light and humidity. The results were compared with three sites where large numbers of the butterfly could be found in the USA (Chan & Packer 2004). All of the Ontario sites were of lower quality compared to the three sites studied in the USA and further restoration was recommended. The Indiana Dunes National Lakeshore in the USA was identified to be the most similar to four of the potential Ontario sites and therefore should be used as the priority source site for butterflies when reintroduced into Ontario (Chan & Packer 2004).

OAK SAVANNAH FLORA AND FAUNA

The Pinery Provincial Park is home to over 757 plants, 319 bird species, 60 butterfly species, and 32 species of mammals (FOP 2021). The most commonly seen mammals are red squirrels (*Tamiasciurus hudsonicus* Erxleben.), chipmunks (*Tamias striatus* L.), raccoons (*Procyon lotor* Storr.), beavers (*Castor* canadensis L.), coyotes (*Canis latrans* Say.), flying squirrels (*Glaucomys volans* L.) and the white-tailed deer (*Odocoileus virginianus* Zimmermann.). Twenty-nine different species of reptiles and amphibians have been recorded at the pinery, including seven species of turtles, the five-lined Skink (*Plestiodon fasciatus* L.), which is Ontario's only species of lizard, as well as eight different species of snakes (FOP 2021). The Pinery's rare habitats provide

nesting space for 124 bird species including tundra swans (*Cygnus columbianus* Ord.), red-throated loons (*Gavia stellate* Pontoppidan.), scarlet tanagers (*Piranga olivacea* Gmelin.), Cerulean warblers (*Dendroica cerulea*. Wilson.), and red-tailed hawks (*Buteo jamaicensis* Gmelin.) and tufted titmice (*Parus bicolor* L.). There are hundreds of plant species at the Pinery including seven different oak species, the red oak (*Quercus rubra* L.), white oak, (*Quercus alba* L.), black oak, Chinquapin oak (*Quercus muehlenbergii* Engelm.), dwarf Chinquapin oak (*Quercus prinoides* Willd.), bur oak (*Quercus macrocarpa* Michx.), and swamp white oak (*Quercus bicolor* Willd.). The red oak and black oak are both indicator species for an oak savannah. The Park also has three species from the Buckthorn family, the New Jersey tea, redroot and common buckthorn (*Rhamnus cathartica* L.). Redroot and the New Jersey tea are both common indicator species of an oak savannah (FOP 2021).

In Canada there are several, at risk, butterfly species that rely on oak savannah habitats including the Karner blue, frosted elfin (*Callophrys irus* Godart.), and eastern persius duskywing (*Erynnis persius persius* Scudder.)(ECCC 2019). Major threats to these species include habitat loss, habitat fragmentation and the establishment of exotic and non-native invasive species. For Canada the long-term recovery objective over a fifty-year time period is to establish self-sustaining metapopulations of these endangered species. In the medium-term the objective is to restore, increase and manage suitable habitats within the historical range of the species in Canada. Suitable habitats include oak woodland and oak savannah, including the habitat at the Pinery Provincial Park. The recovery strategy developed for the three butterfly species identifies critical habitats which must be protected under The Species at Risk Act (ECCC 2019).

The Committee on the Status of Endangered Wildlife in Canada has designated the mottled duskywing butterfly as an endangered species for both the Great Lakes Plains population and the Boreal population (COSEWIC 2012). The Great Lakes Plains mottled duskywing population has disappeared from Quebec, but the butterfly is still found in a few locations in Ontario, although the numbers are in decline. The species is threatened by habitat loss and fragmentation as a result of land development, fire suppression, natural succession and extensive deer browsing. The Pinery Provincial Park is described as one of five historic protected sites in Ontario for the mottled duskywing although none have been recorded at the Pinery since 1990. The Prairie redroot and New Jersey tea are host plants for the mottled duskywing, but these have been in decline in some areas on Ontario. The project to restore the oak savannah at the Pinery includes planting the New Jersey tea which should improve habitat quality and increase habitat area for the mottled duskywing (COSEWIC 2012).

The Species at Risk stewardship program has provided funding to set up a recovery team to support recovery of the mottled duskywing in Ontario (MacDonald 2021). The recovery team is comprised of several organizations and groups including the University of York, Toronto Zoo, Western University, Ontario Parks, University of Guelph and the Ministry of Natural Resources Ontario. The mottled duskywing has been reared in captivity at the Cambridge Butterfly Conservatory giving the opportunity to better understand the lifecycle of the butterfly. The Pinery Provincial Park was chosen as the first location for reintroduction of the butterfly. The site was selected, because the oak savannah restoration has included the New Jersey tea as one of the of the most abundant understory shrubs. 692 mottled duskywings were released in the Pinery in

2021, and initial monitoring over a 6-week period showed that the females were laying eggs (Government of Ontario 2021). Monitoring also showed that the butterfly remained in the area of release which indicated the habitat was acceptable (MacDonald 2021).

GEOGRAPHIC INFORMATION SYSTEMS

Geospatial modelling is being used more frequently to visualize how villages, forests and cities may expand out to some future date (Eastman 2016). The TerrSet Geospatial Monitoring and Modelling System Manual describes all the key features of the program covering each of the applications used for monitoring and modelling the earth system for sustainable development. There are eight integrated applications within the software suite. The land change modeler analyzes land cover change and can be used to project future changes. The habit and biodiversity modeler is used for habitat assessment, landscape pattern analysis and biodiversity modelling. The GeOSIRIS application is used at the national level to aid reducing emissions from deforestation and forest degradation planning. The ecosystem service modeler is used to assess the value of ecosystem services, The earth trends modeler is used for analysing trends in earth systems such as temperature and precipitation. The climate change adaptation modeler looks at future climate change and the impact on sea level and species distribution. The IDRISI GIS analysis tool is mainly used for GIS data analysis and the IDRISI image processing system is used for restoring, enhancing transforming and classifying remotely sensed images (Eastman 2016).

Paudel & Yuan (2012) used spatial analysis and geospatial modelling to look at changes in landscape ecology linked to the urbanization of the seven-country Twin

Cities Metropolitan Area (TMCA) in southern Minnesota. Landscape change patterns from 1975 to 2006 were mapped and analyzed using ArcGIS focusing on urban, agriculture, and forest areas. Urban land expanded by 82%, agricultural land decreased by 20% and forest land by 14%. Landscape indices were computed for the whole TCMA and using this data it was projected that major deforestation within the urban area will have occurred by 2030 (Paudel & Yuan 2012).

A second paper by Sabree et al. (2020) looked at the future growth of Al Najaf city in Iraq out to the year 2036. Satellite images of the city taken during the period 1986-2016 were used to predict the change. Using the historic photographs, the city was classified by the GIS program according to six types of land use, including residential areas, agricultural lands, water sources, religious areas, industrial areas and open lands. This information was then analysed using the IDRISI program, simulating spatial and temporal changes (Sabree et al. 2020). The analysis used the Markov chain model to calculate the probability of future change based on the past, and the Cellular Automata model to determine the spatial location of the changes. The result was used to forecast future land transformation and economic and environmental impacts (Sabree et al. 2020).

The current study uses a combination of historic and current field observations and advanced geovisualisation tools to help determine how effective the prescribed burn program has been in re-establishing the oak savannah habitat at the Pinery Provincial Park. The geovisualisation tools have also been used to make projections of the future condition of the oak savannah out to the year 2032 based on the prescribed burn program at the Pinery. The methods used for this assessment are set out in the following section.

METHODS AND MATERIALS

PINERY PROVINCIAL PARK DATA COLLECTION

The study area for this report was Pinery Provincial Park located on the shores of Lake Huron southwest of Grand Bend 43.246981° N; -81.833135° W. A map showing the layout of the park is shown in Figure 1.

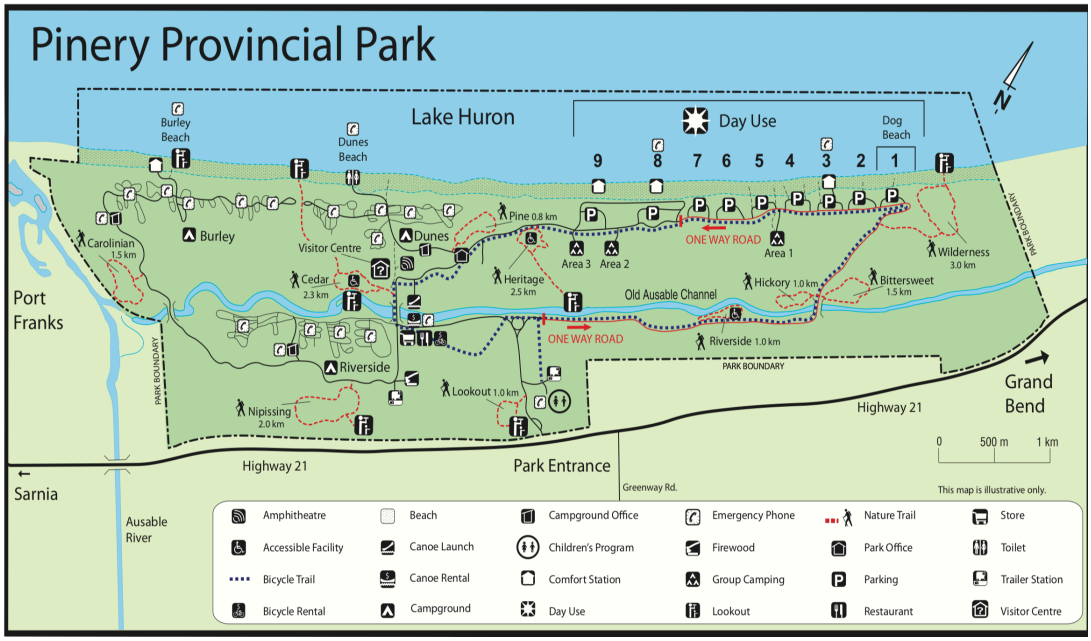


Figure 1. Map of Pinery Provincial Park, South West Ontario courtesy Ontario Parks

Three visits were made to the park on 25th June 2021, 30th July 2021, and 5th August 2021. The purpose of the visit on June 25th 2021 was an initial introduction to become familiar with the park layout and to see the New Jersey tea plants whilst still in bloom as a guide for identification for future visits.

The purpose of the visit on 30th July 2021 was to access the park archived resources working with members of the Pinery team and to record photographs of current park conditions for comparison. The initial search was for photographs showing

oak savannah areas during 1989, when prescribed burns were introduced. Archived pictures were obtained for locations on three of the park trails through the oak savannah, the Nipissing Look Out Trail, the Heritage Trail and the Bike Trail. Each trail was then walked and the locations of the archived photographs were identified and the GPS coordinates established using a compass application. A 2021 photograph was then taken at each location showing the current flora conditions. The invasive species, native species, wildlife observed and a visual estimate of percentage canopy cover was recorded for each location. The species growing at each location were identified using the "Picture This" App.

The Pinery visit on 5th August 2021 repeated the steps used during the previous visit to collect data for other areas of the oak savannah. Three photographs from 1991 were retrieved from the park archives covering the Ausable Channel, the Ski Trail and the Sassafrass Trail. Each trail was then walked and the locations of the archived photographs were identified, and the GPS coordinates were recorded. For the Sassafrass Trail, a member of the park staff who had worked at the site in 1991 came to help identify the location. Photographs were taken of the current flora growing at each location, and records were made of the invasive species, native species, wildlife observed and a visual estimate of percentage canopy cover at the photographed site.

Plans had been developed for reintroducing the mottled duskywing into the Pinery during summer 2021. Data had previously been gathered in 2020 on the locations within the Pinery where the New Jersey tea was growing. The New Jersey tea is both an indicator species for oak savannah and a critical plant for the mottled duskywing butterfly during its egg and larval stages as well as being a food source for the adult

butterfly (Government of Ontario 2021; MacDonald 2021). The biologist, Jessica Linton, who had developed a recovery strategy for the mottled duskywing in Ontario, was contacted and she provided a datafile with the locations of New Jersey tea that had been recorded at the Pinery. This data has been loaded into a QGIS digital map of the Pinery as described in the following section.

DIGITAL MAP OF THE PINERY PROVINCIAL PARK

The first stage in using geovisualisation tools was to build a digital map of the Pinery Provincial Park map in the geographic information system software package QGIS (QGIS Development Team 2019). This was completed in several stages using the software layering features.

Firstly, a shapefile giving the boundaries of the Pinery Provincial Park was downloaded from the Ontario GeoHub (Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry 2021), and uploaded into QGIS. A shapefile of the Ontario road network was then downloaded from GeoHub, and this was added as a layer and clipped in QGIS to just cover the Pinery and surrounding area. To add the Pinery water features, files of the Ontario Hydro Network waterbodies, watercourses and wetland features were downloaded and the water systems within and around the Pinery were selected and uploaded as three layers in the QGIS Pinery shapefile. The archived and current photographs taken at the locations listed in Table 1 and their geographic coordinates were uploaded into QGIS. Finally, the datafile of locations of the New Jersey tea at the Pinery were uploaded into QGIS and was mapped. The combined shapefile layers of the Pinery park, the roads and water features and the locations of the photographs are shown in Figure 2. The pink circles shown in Figure 2 identify the

locations of the archived and 2021 photographs. Other colours used in Figure 2 have been selected to help with image clipping in the next steps in the methodology.

LEGEND	
Location Number	Location Description
1	Nipissing Lookout
2	Bike Trail (side nearest to lake)
3	Ausable Channel
4	Sassafrass Trail
5	Heritage Trail
6	Ski Trail

Figure 2. QGIS digital map of the Pinery Provincial Park at a scale of 1: 100000 (Johnson 2021)

More detailed geophysical information associated with each of the photograph locations could then be accessed from QGIS. An example is shown in Figure 3 for the Ausable Channel, which is identified by the red circle on the figure.

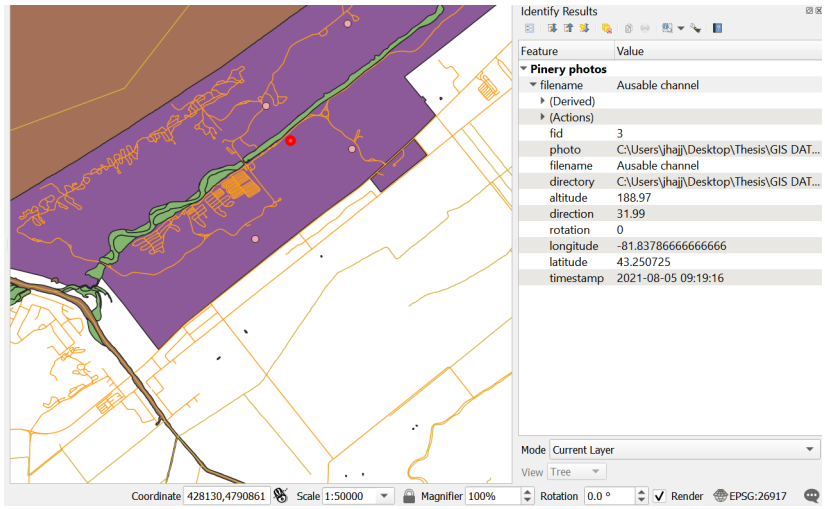


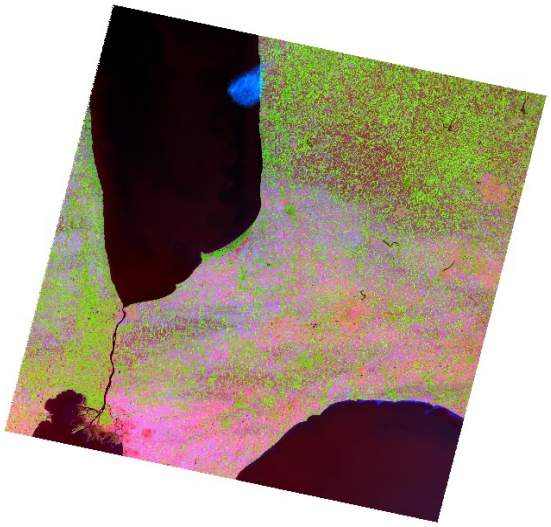
Figure 3. The Ausable Channel photograph location at Pinery Provincial Park showing feature details.

PINERY PROVINCIAL PARK SATELLITE IMAGE COMPARISON

To assess how the park has changed since the implementation of the main prescribed burns in 1989 a series of satellite images were used. Publicly available LandSat images were downloaded from the US Geological Survey (USGS 2021) database. The earliest image was selected for June 1988. Additional images were selected at approximately 10-year intervals. All the images had to fully cover the area of the Pinery and all the photographs had to be taken during the month of June. A further requirement was that the images were free of cloud cover. Based on these constraints, images were downloaded from USGS for June 1988, June 1998, June 2007 and the most recent image in June 2021 (USGS 2021). The downloaded satellite images for the four years are shown in Figure 4.

The four downloaded image files, including their geographic coordinates, were uploaded into QGIS and were clipped using the digital map described above so they just covered the area of the Pinery. The clipped images were then pansharpened to improve clarity. The resulting clipped and pansharpened images are shown in Figure 5.

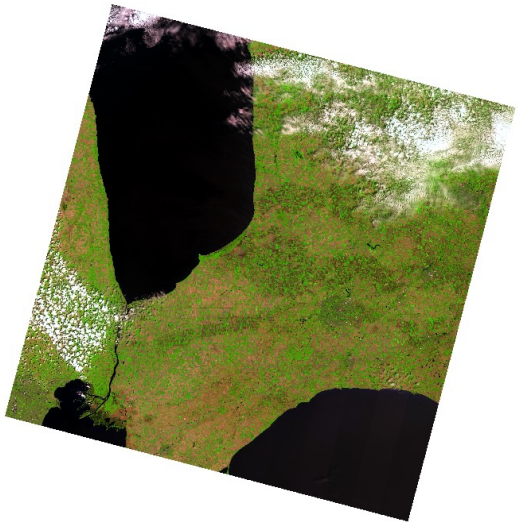
The cells within each of the four images were then colour classified into six categories according to whether they represented water, sand, bare earth, light deciduous vegetation or darker coniferous vegetation. The resulting images, which are shown in Figure 6, could then be compared with each other to identify and track changes.



Scale 1:2070560
A) Satellite Image 1988

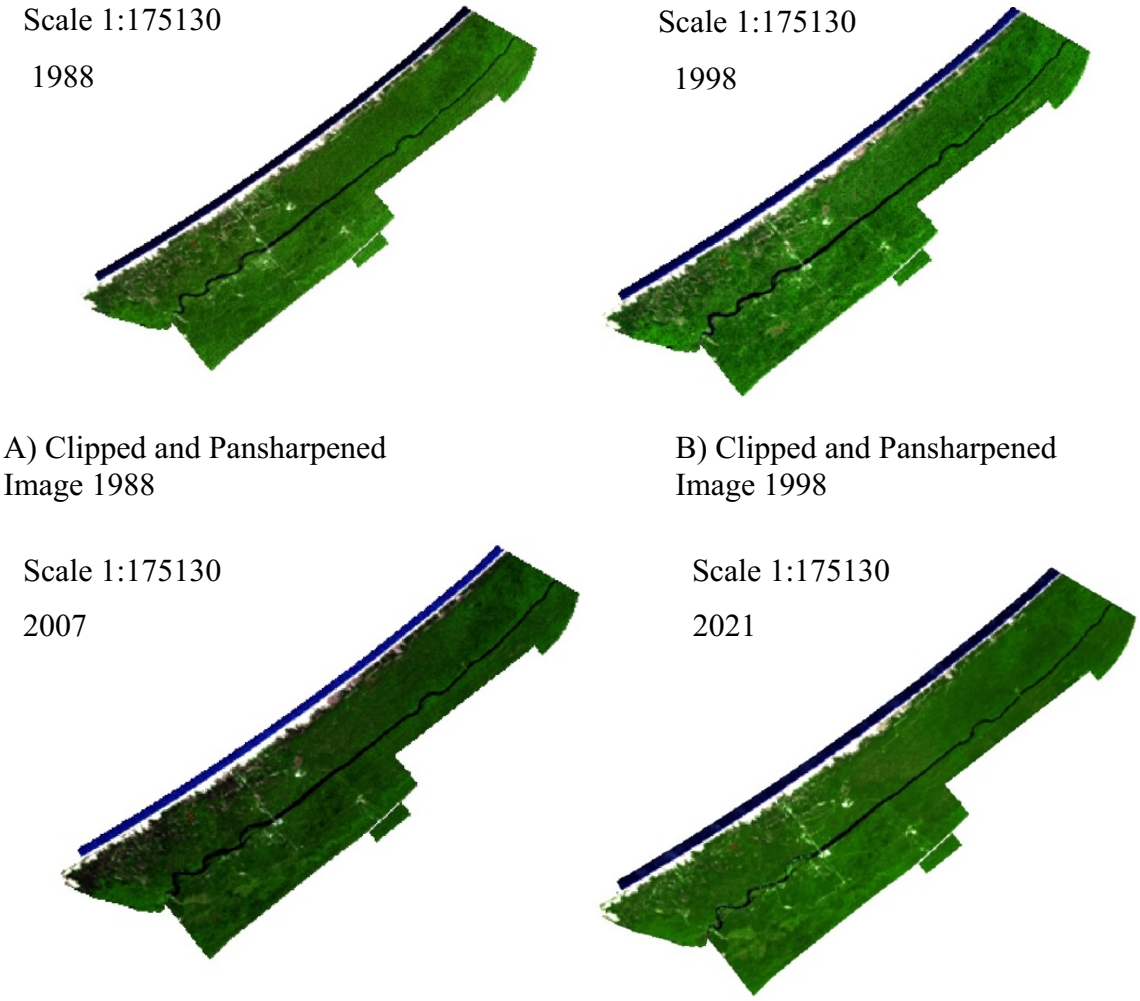
Scale 1:2070560
B) Satellite Image 1998

Scale 1:2070560
C) Satellite Image 2007



Scale 1:2070560
D) Satellite Image 2021

Figure 4. LandSat Images of South West Ontario (Source USGS 2021)



A) Clipped and Pansharpened Image 1988

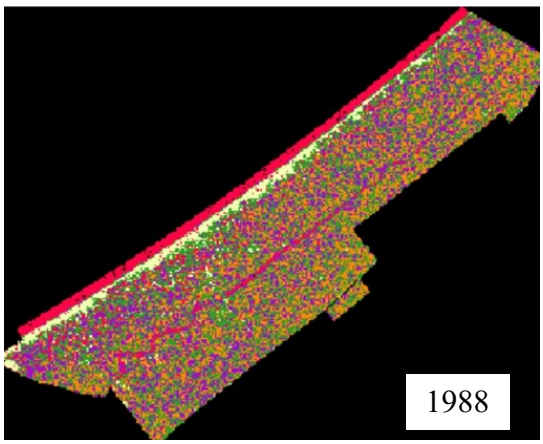
B) Clipped and Pansharpened Image 1998

C) Clipped and Pansharpened Image Image 2007

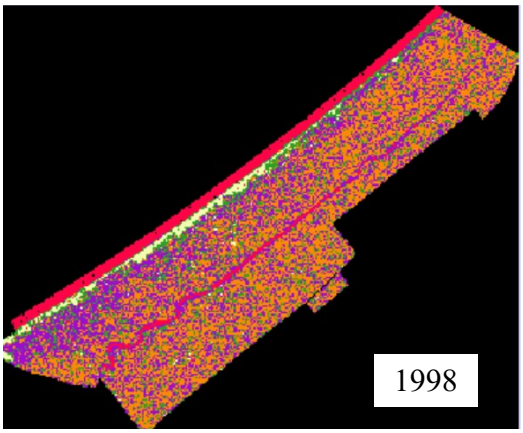
D) Clipped and Pansharpened Image 2021

Figure 5. Clipped and pansharpened images of the Pinery Provincial Park

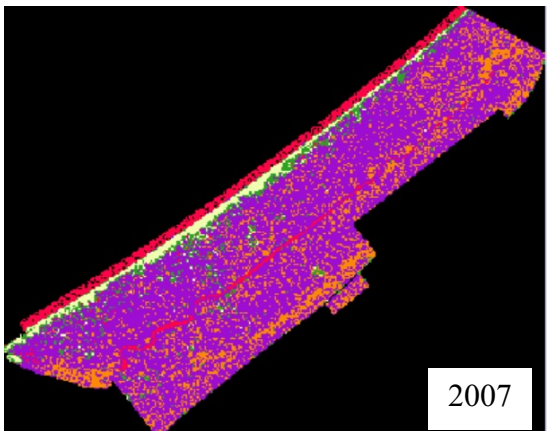
The change analysis was performed using the TerrSet 2020 Geospatial Monitoring and Modeling Software package, which includes the IDRISI GIS analysis and image processing tools and a Land Change Modeler. The classified images were uploaded into IDRISI and the Land Change Modeler was used to track the changes. The results of this analysis are presented later in the report.



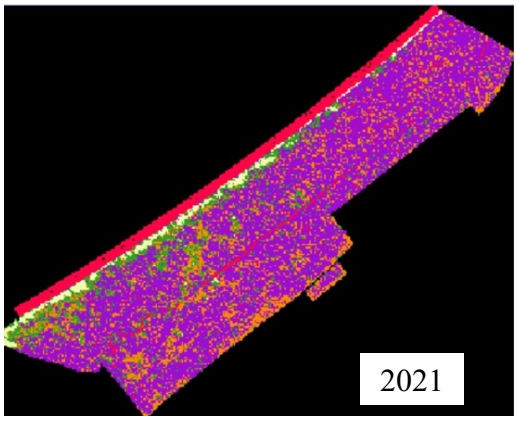
A) Classified Image 1988



B) Classified Image 1998



C) Classified Image 2007



D) Classified Image 2021

Colour Legend	Land Type
0	Not defined
1	Water
2	Sand
3	Soil
4	Deciduous
5	Conifer

Figure 6. Classified images of the Pinery Provincial Park

PROJECTIONS OF THE PINERY OAK SAVANNAH IN 2032

Forward projections of the changes in the oak savannah at the Pinery were performed using the IDRISI Land Change Modeler (Eastman 2016). The first step was to identify the variables that were likely to drive change in the park flora. Three factors

driving change were identified, including deer population reduction, pine tree removal, and prescribed burns. However, based on the availability of records, the driver for change specifically focused on prescribed burns. A report prepared in the year 2000 showing the locations of planned prescribed burns at the Pinery was used to develop a transitional variable in IDRISI that would drive future change (Tagliava et al. 2000).

A map showing the planned prescribed burns was georeferenced by uploading it into QGIS, and then cross-referencing a number of clearly identifiable locations on the map to the same locations within Google Maps. The resulting georeferenced map, including the areas of the prescribed burns identified in orange, is shown in Figure 7.

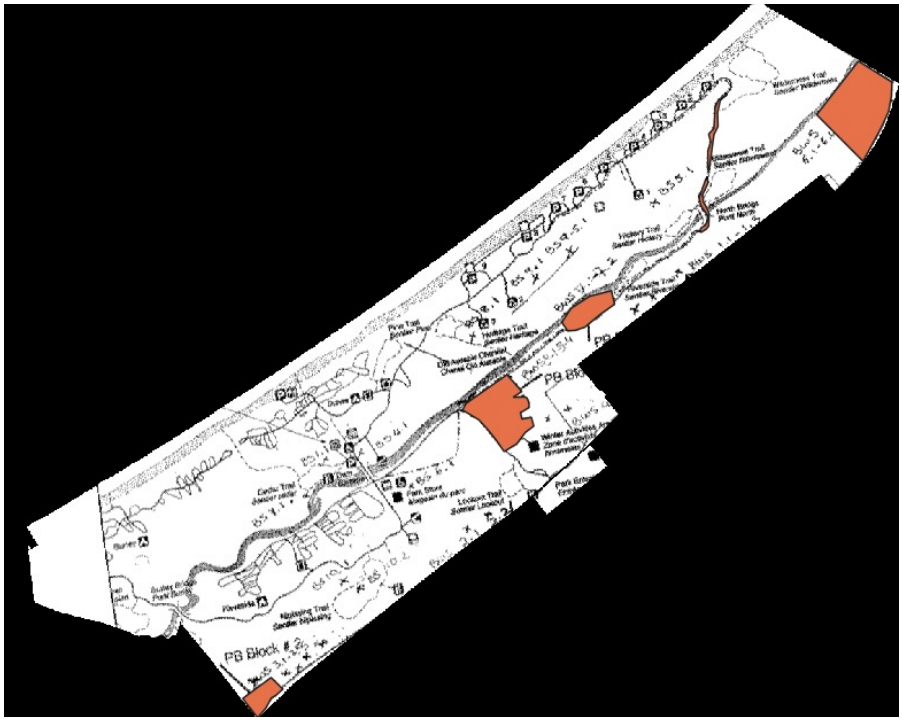


Figure 7. Georeferenced map of the Pinery Provincial Park showing the Burn Plan Implemented in 2000. Source data Tagliavia et al. 2000.

A transitional variable based on the prescribed burns was then developed using a series of concentric buffer rings around each prescribed burn area. The closer to the prescribed burn the greater the pressure for change. Different widths of buffer ring were

examined, including 1000m, 300m, and 100m. 1000m was too coarse and unrealistic, and 100m was too localised. Based on this a transitional variable of 300m buffer rings was developed and clipped so that it only covered changes within the area of the park and is shown as a "heat map" in Figure 8.

The prescribed burn transitional variable was then uploaded into the IDRISI Land Change Modeler and the program was run, projecting changes from the 2007 and 2021 classified images out to 2032.

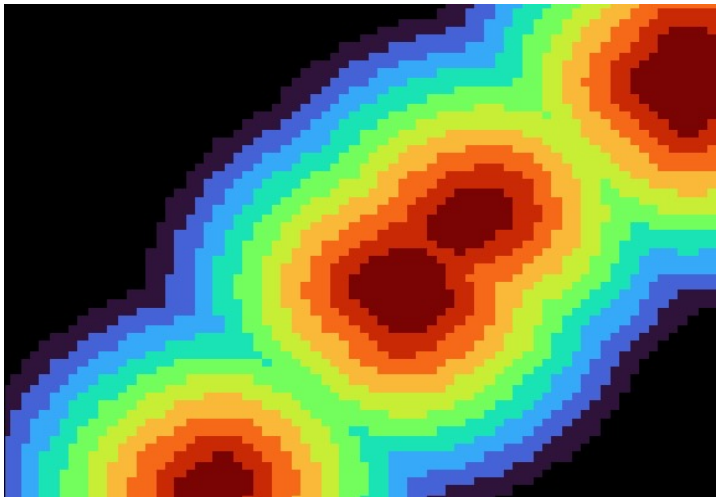


Figure 8. Digital 'heat map' of the transition variable based on the Pinery 2000 Burn Plan.

The results of the land category change analysis and forward projection analysis are presented in the following section.

RESULTS

FIELD OBSERVATIONS

The locations and GPS coordinates where the 2021 oak savannah photographs were taken at the Pinery Provincial Park are set out in Table 1, along with the observations of canopy cover, native and invasive species present and observed wildlife. Photographic records of the observations are set out in Appendix 1.

Table 1. Sampling locations and observations at the Pinery Provincial Park.

Date	Location and GPS Co-ordinates	Canopy Cover	Species Present	Invasive Species	Wildlife Present
30th July 2021	Nipissing Lookout Trail 43º 14' 18"N 81º 50' 31"W	40%	Black Oak, Fragrant Sumac, Bracken, Fern, Ashe's Juniper	Sweet Clover, Spotted Knapweed	Bees, Clear Wing Moths, Wasps, Garter Snake
30th July 2021	Heritage Trail 43°15' 48"N 81°49' 55"W	35%	Woodland Sunflower, Red Raspberry, Black-eyed Susan, Red Cedar	Sweet Clover, Spotted Knapweed	Bees, Clear Wing Moths, Wasps, Garter Snake
30th July 2021	Bike Trail 43°15' 18"N 81°50' 31"W	20%	Black Cherry, Fragrant Sumac, Canada Wood Betony	Sweet Clover, Spotted Knapweed	Bees, Clear Wing Moths Wasps, Garter Snake
5th August 2021	Ausable Channel 43º 15' 30"N 81º 50'16"W	45%	Common Evening Primrose, Fragrant Sumac	Sweet Clover, Spotted Knapweed	Black Squirrel

Table 1. (continued) Sampling locations and observations at the Pinery Provincial Park.

Date	Location and GPS Co-ordinates	Canopy Cover	Species Present	Invasive Species	Wildlife Present
5th August 2021	Ski Trail 43° 16' 58"N 81° 48' 6"W	40%	Black Oak Wild Carrot Flowering Spurge	Sweet Clover Spotted Knapweed	Bees, Clear Wing Moths, Wasps, Garter Snake
5th August 2021	Sassafrass Trail 43° 14' 58"N 81°49' 45"W	30%	Black Oak Common Chokecherry Red Raspberry	Spotted Knapweed	Bees, Monarch, Eastern Cicada, Killer Wasp

NEW JERSEY TEA MAPPING

The observations recorded in 2020 of the locations of New Jersey tea plants at the Pinery are indicated by the red circles on the digital map in Figure 9. They show widespread coverage of the New Jersey Tea along the sides of the major trails at the Pinery, including five areas where plant growth appears clustered.

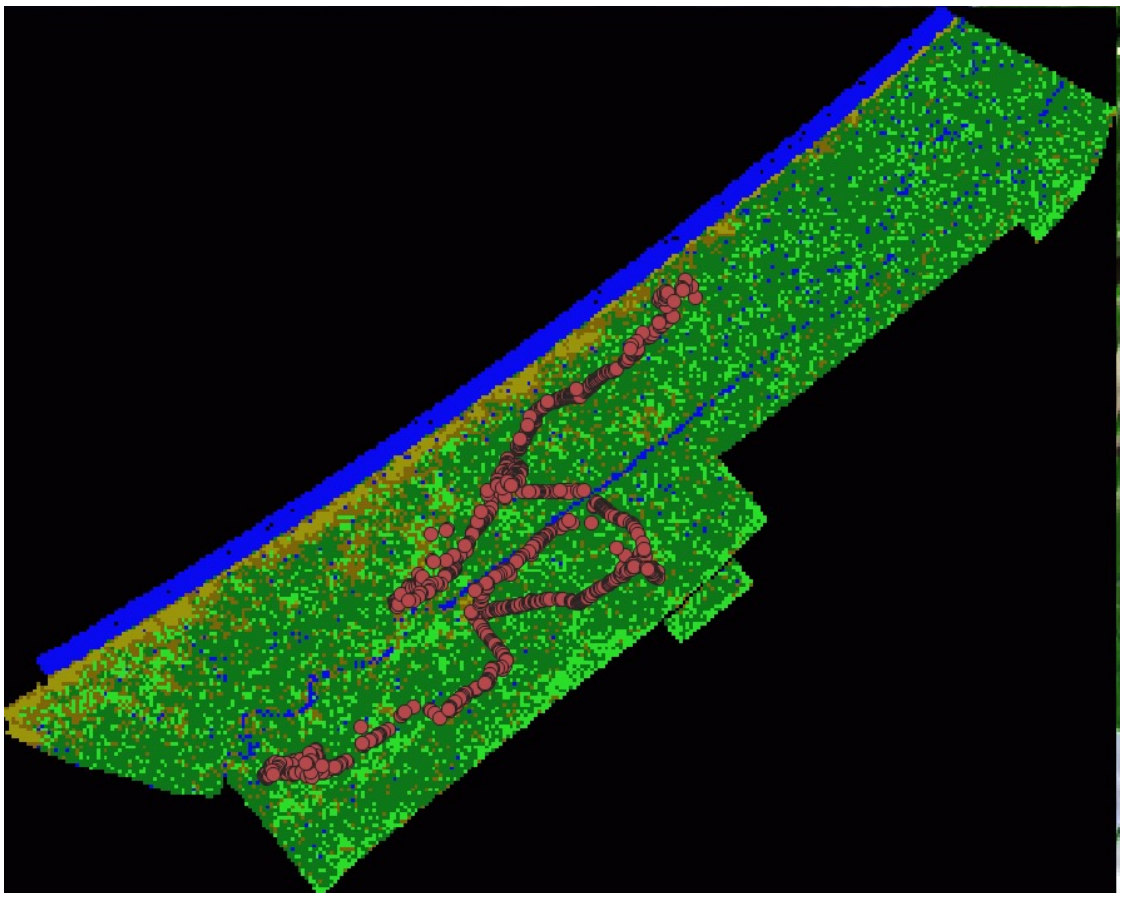


Figure 9. Map showing the locations of New Jersey tea observations at the Pinery Provincial Park in 2020.

PINERY PARK CLASSIFIED IMAGE COMPARISON

The classified image gains and losses for the areas of coniferous growth (dark vegetation), deciduous growth (light vegetation), bare earth, sand and water are shown in Figure 10. Figure 10 includes four separate bar charts showing the changes that occurred between the years 1989 - 1998, 1998 - 2007, 2007 - 2021 and 1988 - 2021.

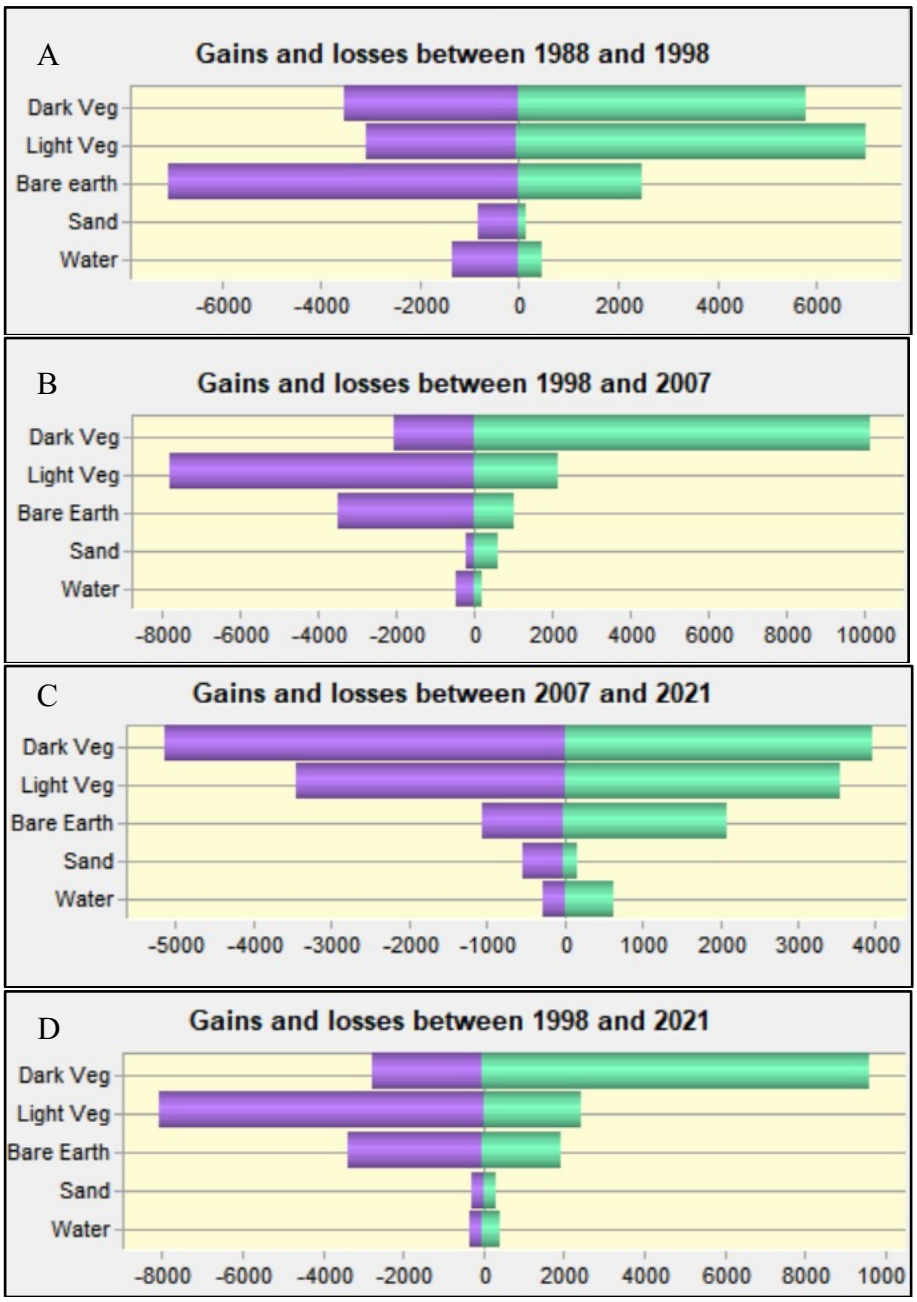


Figure 10. Land category gains and losses at the Pinery Provincial Park between (A) 1988- 1998, (B) 1998-2007, (C) 2007-2021 and (D) 1988 to 2021

The net changes in the areas for each of the five categories over the same time periods are shown in Figure 11. These results show that the area of conifer growth (dark vegetation) at the Pinery increased between 1988 and 2007, but since 2007 it has declined slightly. The area of deciduous growth increased between 1988 and 1998,

declined between 1998 and 2007, but since 2007 it has made a small recovery. Bare earth has also seen significant changes at the Pinery, decreasing sharply between 1988 and 2007, but it increased slightly since 2007. Figure 11 (D) shows that over the 33-year period between 1988 and 2021 the area of conifers at the Pinery has increased, while deciduous growth has decreased slightly and bare earth at the park has also decreased.

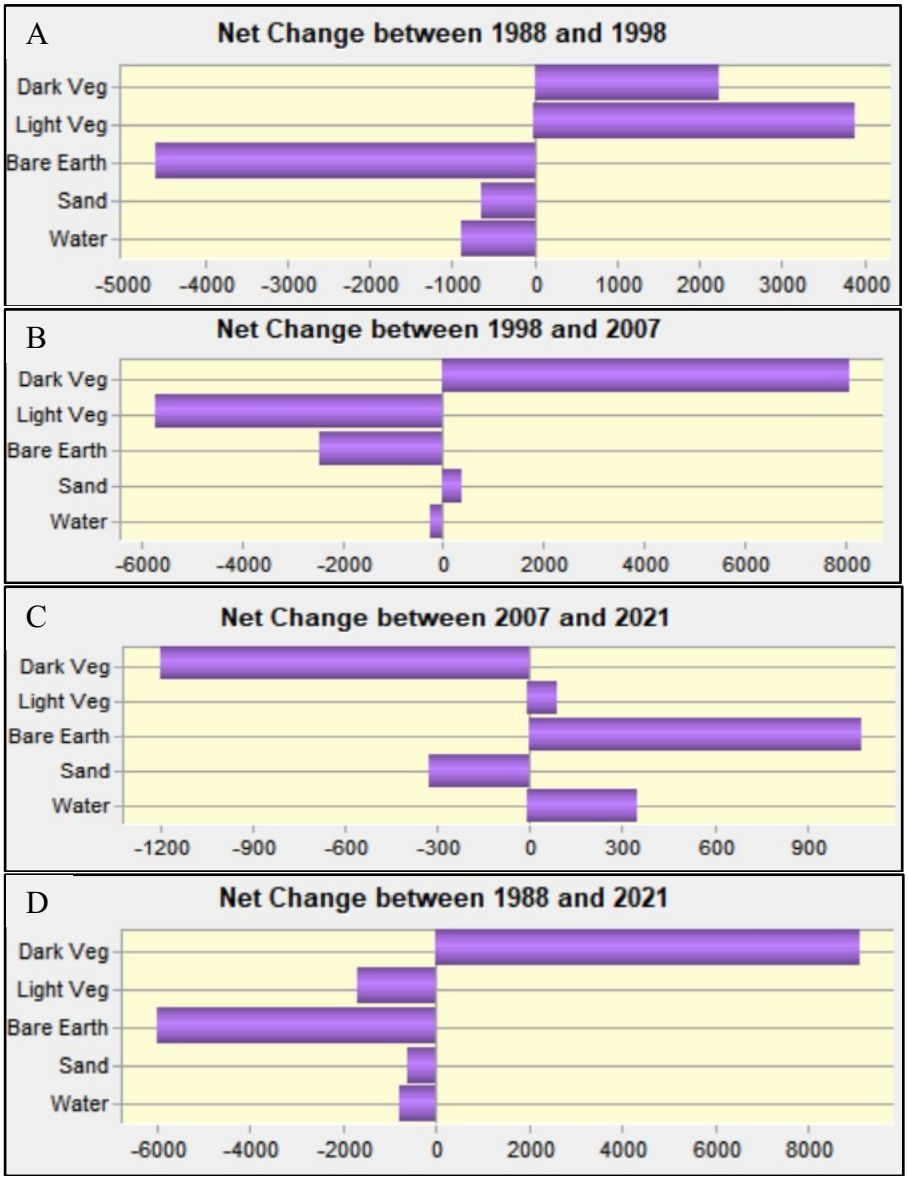


Figure 11. Net change of land categories at the Pinery Provincial Park between (A) 1988- 1998, (B) 1998-2007, (C) 2007-2021 and (D) 1988 to 2021.

The IDRISI module was then used to examine the locations where the changes were occurring. Most of the land area of the Pinery is either deciduous or coniferous flora and so the changes for these two categories was mapped over the time period between 2007 and 2021 as shown in Figure 12. The red pixels indicate locations where conifer growth has now changed to deciduous growth and the yellow pixels indicate where deciduous growth has changed to conifer growth. The red pixels are spread across the map, indicating that transitions from conifer to deciduous growth is occurring across the Pinery. The map shows clusters of yellow pixels at the southwest and northeast ends of the park as well as at the park entrance to the south. This indicates that although there are some changes from deciduous to conifer growth across the park the primary locations where this is occurring are in the southwest, northeast and at the entrance area of the park.

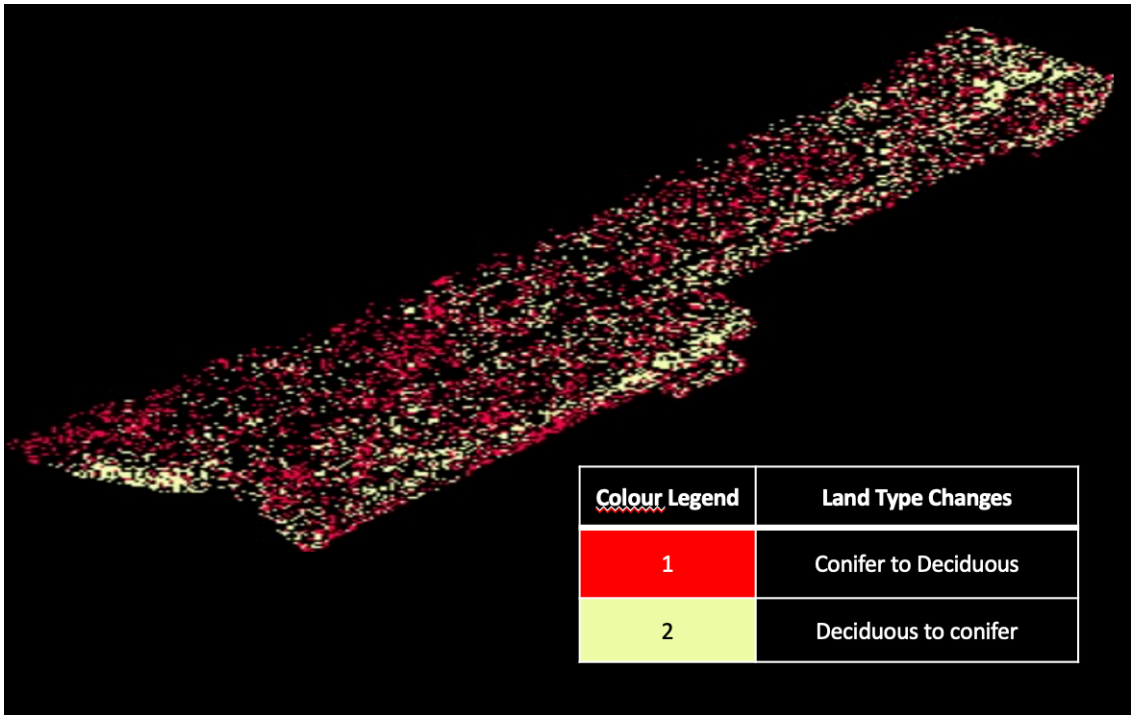


Figure 12. Map showing the Conifer Versus Deciduous Vegetation Changes at the Pinery Provincial Park between 2007 and 2021.

FORWARD PROJECTIONS OF THE PINERY LAND CATEGORIES TO 2032

Using the classified image data for 2007 and 2021, and the transitional variable developed for prescribed burns, projections were made of the gains and losses in area and net changes in the land type categories at the Pinery Provincial Park out to the year 2032 using the IDRISI Land Change modeler. Bar charts showing the predicted gains and losses and net changes for conifer (dark vegetation) and deciduous (light vegetation) growth are shown in Figures 13 and 14.

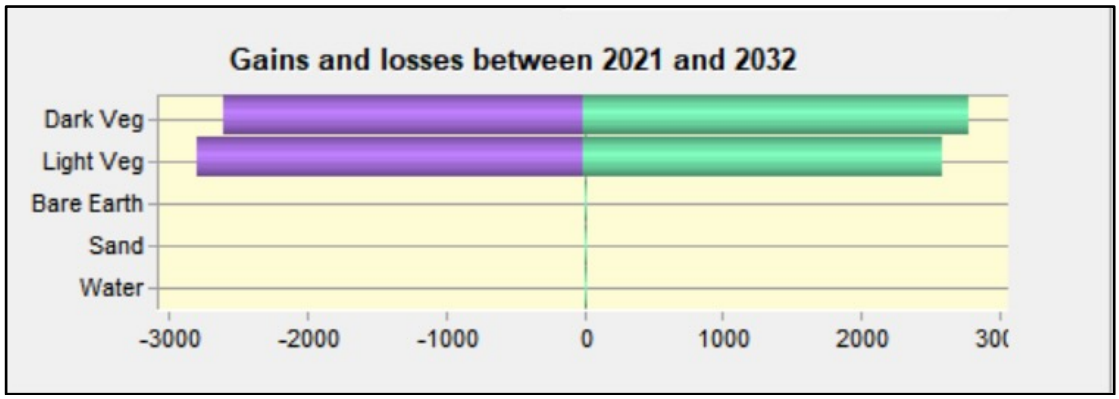


Figure 13. Prediction of the area gains and losses of deciduous (light vegetation) and coniferous (dark vegetation) growth between 2021 to 2032.

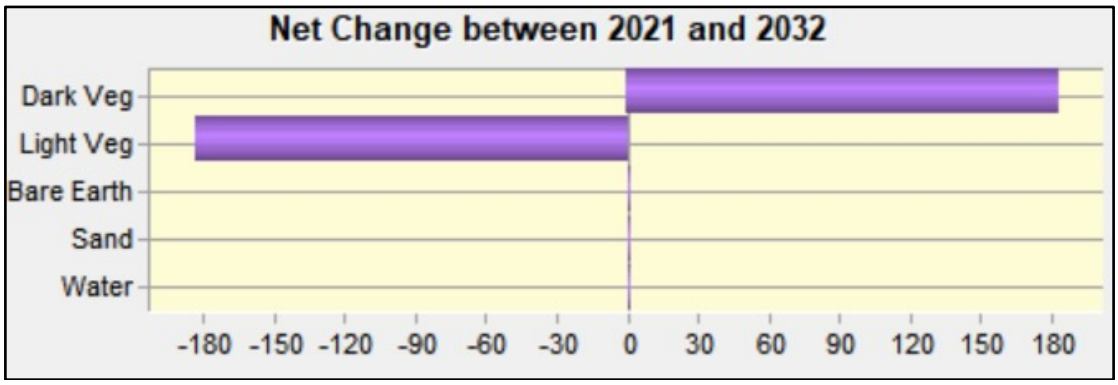


Figure 14. Prediction of the net area changes for deciduous (light vegetation) and coniferous (dark vegetation) growth between 2021 to 2032.

The results show significant gains and losses for both coniferous and deciduous growth but the net projected change is a small decrease in deciduous growth.

DISCUSSION

COMPARISON OF ARCHIVED AND CURRENT PINERY FIELD PHOTOGRAPHS

The 2021 Nipissing Lookout trail photograph appears to show more open canopy with less conifers present than in 1989. The black oak, fragrant sumac (*Rhus aromatica* L.), Ashe's juniper (*Juniperus ashei* J.*),* New Jersey tea and western bracken fern (*Pteridium aqilinum* (L.) Khun.) were identified in 2021 (FOP 2021). Black oak is an indicator species for oak savannah (FOP 2017).

The Heritage Trail photographic comparison between 1989 and 2021 shows some thinning of trees has taken place. The species observed in the understory in 2021 included woodland sunflower (*Helianthus divaricatus* L.), red raspberry (*Rubus idaeus* L.), black-eyed Susan (*Rudbeckia hirta* L.*)*, and red cedar. None of the these are indicator species for oak savannah.

The Bike Trail photographs of 1989 and 2021 indicate little difference in tree density and the canopy appears fairly open. The species observed in 2021 included black cherry (*Prunus serotina* Ehrh.), eastern white pine *(Pinus strobus* L.), fragrant sumac, Canada wood betony (*Pedicularis canadensis* L.). Canada wood betony is an indicator species for oak savannah (Aeon Web Studio 2020).

Comparing the Ausable channel photographs from 1991 and 2021 was challenging due to different seasons but it is clear that work had been done on tree removal in 1991. Common species observed in 2021 included evening primrose (*Oenothera biennis* L.*)*, fragrant sumac, wild carrot (*Daucus carota* L.), wild dwarf Chinquapin oak and flowering spurge (*Euphorbia corollate* L.). Chinquapin oak are often found associated with oak savannah (Aeon Web Studio 2020).

In the Ski Trail area, the tree density looked similar in both the photographs taken in 1991 and 2021. The species observed in 2021 included black oak wild carrot, flowering spurge, black cherry and Canada goldenrod (*Solidago canadensis* L.). Black oak is an indicator species for oak savannah (FOP 2017).

The Sassafrass Trail, formerly known as the Lookout Trail, showed similar open canopy in both the photographs taken in 1991 and 2021. The species observed in 2021 included black oak, common chokecherry (*Prunus virginiana* L.), and red raspberry. Black oak is an indicator species for oak savannah (FOP 2017).

Throughout the Park invasive species such as sweet clover (*Melilotus albus* Medik.), spotted knapweed (*Centaurea stoebus* L.) were found. The wildlife observed during the data collection visits to the Pinery included bees, monarch butterflies, eastern cicada, wasps, moths, garter snakes and black squirrels. The 2021 visually estimated canopy cover ranged from 20-40%.

OAK SAVANNAH RECOVERY

The classified image comparisons shown in Figure 11(C) indicate that the oak savannah at the Pinery has been recovering since 2007, with coniferous growth reducing and deciduous growth increasing slightly. Also, the map of the changes shown in Figure 12 suggests that the gains in deciduous growth are occurring across the park whereas coniferous gains are mainly occurring at the northeast and southwest ends of the park and around the area of the park entrance. The increase in deciduous growth suggests that the oak savannah at the Pinery is now starting to recover. This result is supported by the field observations reported in Table 1, as well as the distribution of New Jersey tea shown in Figure 9, which is an indicator species for oak savannah (FOP 2021).

Comparing the classified images between 1988 and 2007 actually shows a decline in deciduous growth, and even though there has been recovery of oak savannah since 2007, the projections out to 2032 shown in Figure 14 indicate that the oak savannah recovery seen in recent years will start to decline again.

Plans to achieve oak savannah recovery at the Pinery required reducing the deer population density in the park from 73.2 deer/km^2 to 7 deer/km^2, as well as a pine reduction program and a prescribed burn frequency of at least once every ten years (Etwell & Bazely 2004). The deer population has now been reduced to levels where ground cover growth in areas where deer grazing was restricted was the same as areas where deer were roaming free (Tagliavia et al. 2002). No plans or records were found for pine removal. Although plans exist for conducting prescribed burns, in practice competing pressures at the park have meant that some of the prescribed burns have not taken place.

A previous study conducted in 2016 (Nicol 2016) reported 67% deciduous canopy cover in some areas of the Pinery, which is well above the 25-35% level needed for oak savannah conditions (Buck 2018). This finding, together with the vegetation growth projections in this thesis, indicate that a more intensive and frequent fire burn program should be considered to support continued recovery of the oak savannah.

USE OF GEOVISUALISATION TOOLS IN PLANNING OAK SAVANNAH RECOVERY

The methodology followed in this thesis demonstrates that spatial and temporal geovisualisation tools can be used as an aid to planning the recovery of oak savannah at the Pinery Provincial Park. In particular the classification of georeferenced satellite images has allowed the area of the Pinery to be categorised according to land type and vegetation type and this can then be used to track changes and make forward projections. This can provide feedback on the effectiveness of the measures to recover the oak savannah and future plans can then be adjusted based on the measured progress.

The process relies on being able to categorise the land types accurately. This was straightforward for features that can easily be distinguished such as the sand and the large body of water, Lake Huron, which border the Pinery. However, there were challenges analysing the satellite images to distinguish bare earth, deciduous growth and coniferous growth as the image resolution was low. Future work should consider use of aerial images or drone images that provide better detail. This may help identify more clearly the ground and canopy cover, vegetation type. Drone photography could also focus on areas where prescribed burns have been carried out and can be more easily repeated at regular intervals to monitor recovery trends.

RECOMMENDATIONS

Based on the results presented in this thesis it is recommended that a more intensive and frequent program of prescribed burns should be considered to support continued recovery of the oak savannah at the Pinery Provincial Park.

It is also recommended that more work is carried out to check the repeatability of the classifications of land types at the Pinery when using satellite images. Ideally different satellite images taken at similar times should be used to confirm the process is repeatable. The geovisualisation could also be improved by using large format area array images taken during aerial surveys, or by the use of drone photography to establish more close-up images of areas before and at intervals after prescribed burns to monitor recovery trends.

CONCLUSION

The results support the hypothesis that advanced geovisualisation techniques can be used to have a positive effect on planning the re-establishment of the oak savannah at the Pinery Provincial Park through allowing visual analysis of the landscape level ecological processes. The results indicate that the oak savannah at the Pinery has been recovering since 2007, however the forward projection indicates this may decline by 2032 unless a more intensive and frequent program of prescribed burns is adopted.

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APPENDIX

APPENDIX I

PHOTOGRAPHIC OBSERVATIONS RECORDED AT SIX LOCATIONS IN THE OAK SAVANNAH AT PINERY PROVINCIAL PARK

This Appendix presents the historic photographs taken of the Pinery in 1989 and 1991 and the photographs taken at the same locations in 2021. In addition, species photographs taken at the various locations are also presented, as well as a photograph of the mottled duskywing. A list of the figures is set out in Table A1 to facilitate access to specific photographs.

Table A1. List of figure numbers of photographic observations recorded at six locations in the oak savannah at Pinery Provincial Park

Table A1. (continued) Table providing a list of figure numbers of photographic observations recorded at six locations in the oak savannah at Pinery Provincial Park

Figure A19.	Flowering spurge
Figure A20.	The Ski Trail in 1991
Figure A21.	The Ski trail at Pinery Provincial Park in 2021
Figure A22.	Black cherry
Figure A23.	Canada goldenrod
Figure A24.	The Sassafras trail in 1991.
Figure A25.	The Sassafras Trail at Pinery Provincial Park in 2021
Figure A26.	Common chokecherry
Figure A27.	Black oak
Figure A28.	Red raspberry
Figure A29.	Mottled duskywing

Photographs of the Nipissing Look Out Trail at Pinery Provincial Park in 1989 and 2021 are shown Figures A1 and A2.

Figure A1. Nipissing Look Out Trail in 1989 (Pinery Provincial Park Archives).

Figure A2. The Nipissing Lookout Trail at Pinery Provincial Park 2021 at co-ordinates 43º 14' 18"N 81º 50' 31"W (Johnson 2021).

Examples of understory species found growing beside the Nipissing Trail in 2021 are shown in Figures A3, A4, A5 and A6.

Figure A3. Black oak leaf (Photograph Johnson 2021).

Figure A4. Western bracken fern (Photograph Johnson 2021).

Figure A5. Fragrant sumac
(Photograph Johnson 2021)

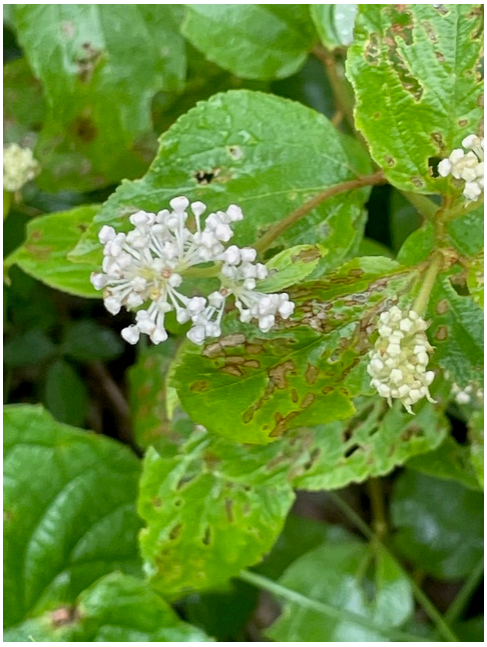

Figure A6. New Jersey tea
(Photograph Johnson 2021)

Photographs of the Heritage Trail at Pinery Provincial Park in 1989 and 2021 are shown in Figures A7 and A8.

Figure A7. The Heritage Trail 1989 (Pinery Provincial Park Archives).

Figure A8. The Heritage Trail at Pinery Provincial Park in 2021 at coordinates 43°15' 48"N 81°49' 55"W (Photograph Johnson 2021).

Examples of understory species found growing beside the Heritage Trail in 2021 are shown in Figures A9 and A10.

Figure A9. Red raspberry (Photograph Johnson 2021).

Figure A10. Woodland sunflower
(Photograph Johnson 2021).

Photographs of the Bike Trail at Pinery Provincial Park in 1989 and 2021 are shown in Figures A11 and A12.

Figure A11. The Bike trail near the maintenance office in 1989
(Pinery Provincial Park Archives).

Figure A12. The Bike trail at Pinery Provincial Park in 2021 near the maintenance office at coordinates 43°15' 18"N 81°50' 31"W (Photograph Johnson 2021).

Examples of understory species found growing beside the Bike Trail in 2021 are shown in Figures A13 and A14.

Figure A13. Canada wood betony (Photograph Johnson 2021).

Figure A14. Eastern white pine (Photograph Johnson 2021).

Photographs of the Ausable Channel at Pinery Provincial Park in 1991 and 2021 are shown in Figures A15 and A16.

Figure A15. The Ausable Channel in 1991 (Pinery Provincial Park Archives).

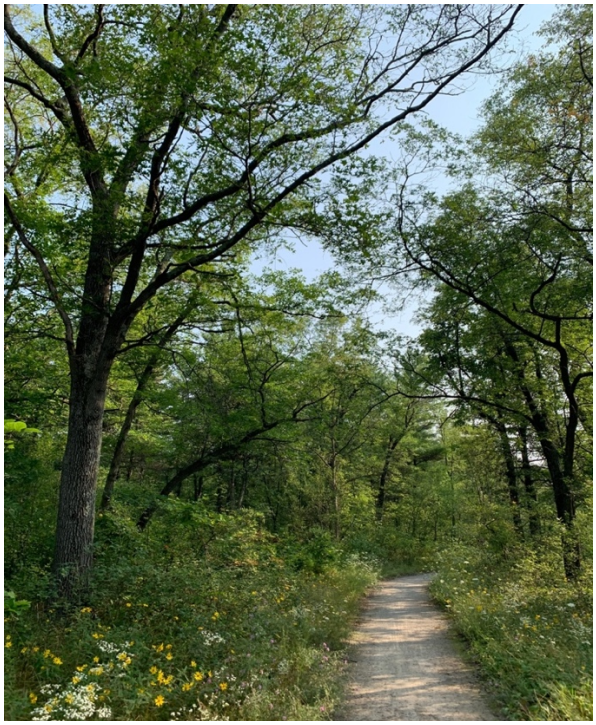

Figure A16. The Ausable Channel at Pinery Provincial Park in 2021 at co-ordinates 43° 15' 30"N 81° 50'16"W (Photograph Johnson 2021).

Examples of understory species found growing beside the Ausable Channel in 2021 are shown in Figures A17, A18 and A19.

Figure A17. Wild carrot (Photograph Johnson 2021).

Figure A18. Wild dwarf Chinquapin Oak (Photograph Johnson 2021).

Figure A19. Flowering spurge (Photograph Johnson 2021).

Photographs of the Ski Trail at Pinery Provincial Park in 1991 and 2021 are shown in Figures A20 and A21.

Figure A20. The Ski Trail in 1991 (Pinery Provincial Park Archives).

Figure A21. The Ski trail at Pinery Provincial Park in 2021 at coordinates 43º 16' 58"N 81º 48' 6"W (Photograph Johnson 2021).

Examples of understory species found growing beside the Ski Trail in 2021 are shown in Figures A22 and A23.

Figure A22. Black cherry (Photograph Johnson 2021).

Figure A23. Canada goldenrod
(Photograph Johnson 2021).

Photographs of the Sassafrass Trail at Pinery Provincial Park in 1991 and 2021 are shown in Figures A24 and A25.

Figure A24. The Sassafras trail in 1991 (Pinery Provincial Park Archives).

Figure A25. The Sassafras Trail at Pinery Provincial Park in 2021 at coordinates 43º 14' 58"N 81º49' 45"W (Photograph Johnson 2021).

Examples of understory species found growing beside the Ski Trail in 2021 are shown in Figures A26, A27 and A28.

Figure A26. Common chokecherry (Photograph Johnson 2021).

Figure A27. Black oak (Photograph Johnson 2021).

Figure A28. Red raspberry
(Photograph Johnson 2021).

An example of the mottled duskywing, which was reintroduced into the Pinery in 2021 is shown if Figure A29.

Figure A29. Mottled Duskywing
Source: Will Stuart, (CC BY-NC 4.0)
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