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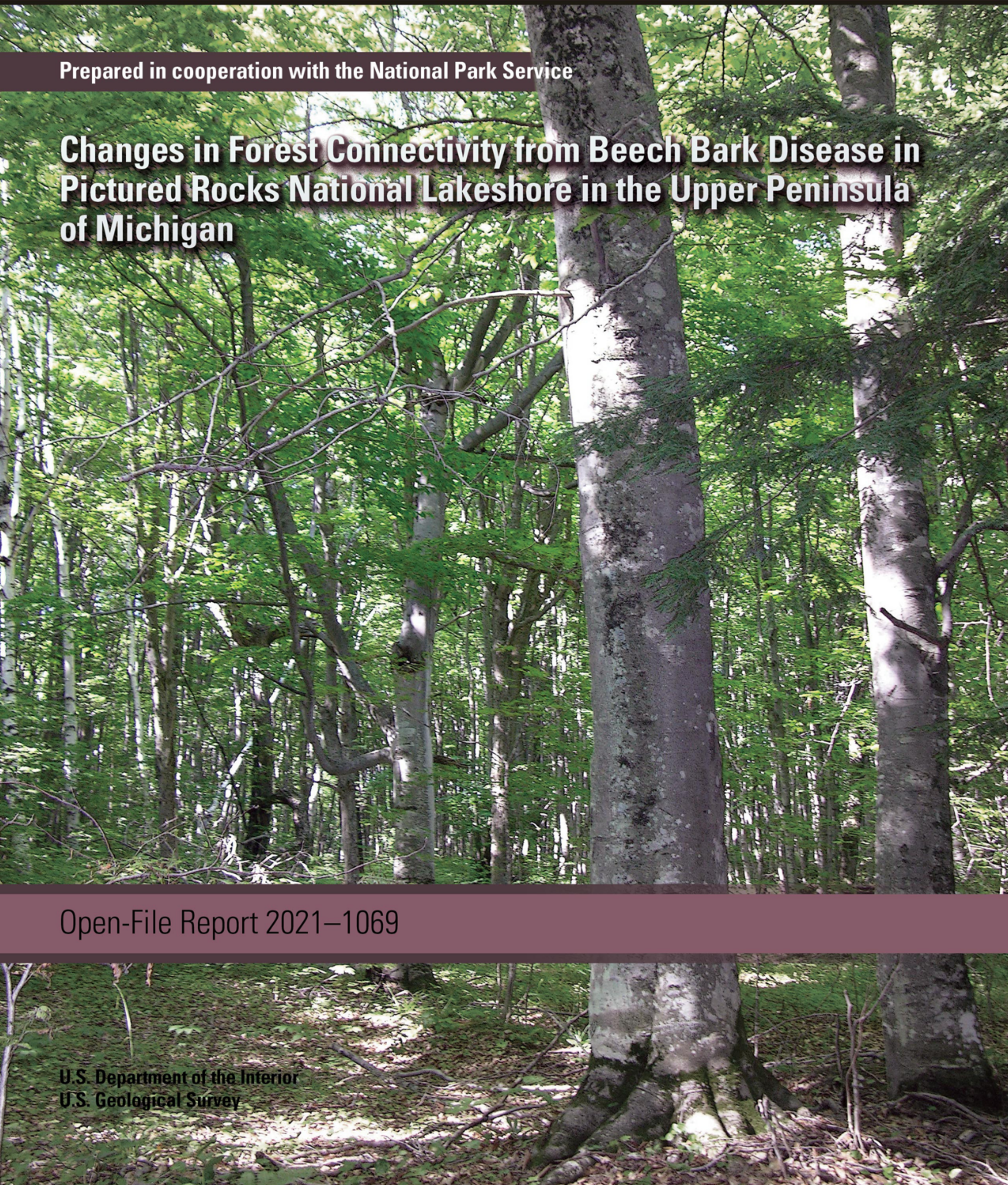
Changes in Forest Connectivity from Beech Bark Disease in Pictured Rocks National Lakeshore in the Upper Peninsula of Michigan



Open-File Report 2021–1069

U.S. Department of the Interior
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Front cover. Hardwood forest where forest canopy gaps are forming in Pictured Rocks National Lakeshore in the Upper Peninsula of Michigan. These canopy gaps are created by *Fagus grandifolia* Ehrh. (American beech) dying from beech bark disease. Photograph by the National Park Service.

Changes in Forest Connectivity from Beech Bark Disease in Pictured Rocks National Lakeshore in the Upper Peninsula of Michigan

By Stephanie R. Sattler

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U.S. Geological Survey, Reston, Virginia: 2021

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Area	
acre	0.4047	hectare (ha)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
	Area	
hectare (ha)	2.471	acre

Abbreviations

BBD beech bark disease

OBIA object-based image analysis

PIRO Pictured Rocks National Lakeshore

Changes in Forest Connectivity from Beech Bark Disease in Pictured Rocks National Lakeshore in the Upper Peninsula of Michigan

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Abstract

Within the forests of Pictured Rocks National Lakeshore, biologists are trying to understand the effects beech bark disease has on wildlife species, especially species that need forest connectivity to thrive. This project used aerial imagery collected in 2005, shortly after beech bark disease infestation, and satellite imagery from 2018. The 2018 imagery represents present day conditions and was used to locate forest canopy gaps through object-based image analysis. Forest canopy gaps were identified using the multiresolution segmentation algorithm within Trimble's eCognition software. A time change analysis was completed to understand how the forest canopy had changed from 2005 to 2018. The analysis showed areas that had maintained forest canopy, maintained a forest canopy gap, created a new canopy gap (closed forest canopy in 2005 but open canopy gap in 2018), or created new forest canopy (open canopy gap in 2005 but closed forest canopy in 2018). There were 9,127 acres of forest canopy lost, and 72.8 percent of that lost canopy occurred in a forest type where *Fagus grandifolia* Ehrh. (American beech) is a common tree species. The datasets developed through this project can enhance knowledge of where canopy gaps exist and help place focus on certain areas for wildlife studies. In addition, these datasets can be used in future studies to monitor the health of the forest and conduct additional change analyses.

Introduction

Beech bark disease (BBD) is caused by the combination of *Cryptococcus fagisuga* (beech scale insect) and two fungal species, *Neonectria faginata* and *Neonectria ditissima.* The beech scale insect pierces the tree's bark and sucks out the sap, then the fungal species enter and infect the tree through the hole left by the beech scale insect. BBD was first discovered in Pictured Rocks National Lakeshore (PIRO) in 2001. Scale insects are shield-like shaped and feed on the sap in trees or other plants. It is estimated that 80–90 percent of the mature beech trees in PIRO will not survive because of BBD (National Park Service, 2019). Once a tree is infected, it may take only a few years for that tree to die. Shortly after the infected tree dies, it will fall to the ground creating a canopy gap. The loss of the closed canopy forest and nest trees and a near complete loss of beechnuts (nuts of the only hard mast in PIRO) will have far-reaching effects on wildlife species that scientists are only beginning to understand (National Park Service, 2019). By analyzing forest connectivity at different periods during the BBD infestation, managers can have a better understanding of how forest cover and composition have changed, model how wildlife species are responding to the forest changes, better understand how to manage for certain species, and begin to plan for forest restoration.

PIRO is located in the Upper Peninsula of Michigan and is home to many wildlife species that depend on forest canopy connectivity to thrive. The National Park Service and others are interested to learn how recent forest canopy loss caused by BBD is affecting these wildlife species. In addition, wildlife species such as *Ursus americanus* Pallas (black bears), *Odocoileus virginianus* (white-tail deer), and a variety of birds can be studied to understand how their diets are changing because of the decrease in beechnut production. To begin observing and collecting data on these species, it is important to know where forest canopy gaps exist and to identify where the greatest canopy connectivity loss has occurred. This project uses R scripting and object-based image analysis (OBIA) to produce forest canopy gap geospatial layers and a time change analysis for PIRO to help understand the changes in forest connectivity.

Study Area

The study area coincides with the study area boundary from the vegetation mapping project completed by Hop and others (2010) (fig. 1). The study area is located in the Upper Peninsula of Michigan, specifically along the shores of Lake Superior northeast of Munising, Mich. According to Hop and others (2010), the study area contains 70,610 acres of forest and woodland, which accounts for 84.61 percent of the total area mapped. *Fagus grandifolia* Ehrh. (American beech) is one of the common tree species found in the Maple-Yellow Birch Northern Hardwoods Forest (map class FMB), which was identified to be 51.3 percent of the forested area in PIRO (Hop and others, 2010).

Methods

Originally, the project was going to use the National Aeronautics and Space Administration's stereo pipeline (Beyer and others, 2018) to create a digital surface model that would be subtracted from a digital terrain model to develop a canopy height model. It was determined that the 2005 aerial imagery (Hop and others, 2010) did not have adequate camera information for the stereo pipeline to produce an accurate digital surface model. Therefore, a new method using OBIA was identified and tested to ensure a high-quality, accurate, forest canopy gap dataset could be produced from the 2005 aerial imagery (Hop and others, 2010). After testing multiple imagery datasets, the 2018 National Agriculture Imagery Program imagery appeared to be accurate, consistent, and reliable at locating dark areas, which represent forest gaps, within the forest canopy using OBIA.

Locating Forest Canopy Gaps Using the eCognition Software

Because of the size of the study area, the aerial and satellite imagery was clipped down into manageable file sizes for processing: 6 areas for the 2005 imagery and 3 areas for the 2018 imagery. Because the goal of the study was to conduct a time change analysis, the imagery needed to have the same imagery resolution. The 2005 aerial imagery had a resolution of 0.18 meter, whereas the 2018 National Agriculture Imagery Program imagery had a 0.6-meter resolution; therefore, the 2005 aerial imagery was resampled using the Erdas software at 0.6 meter.

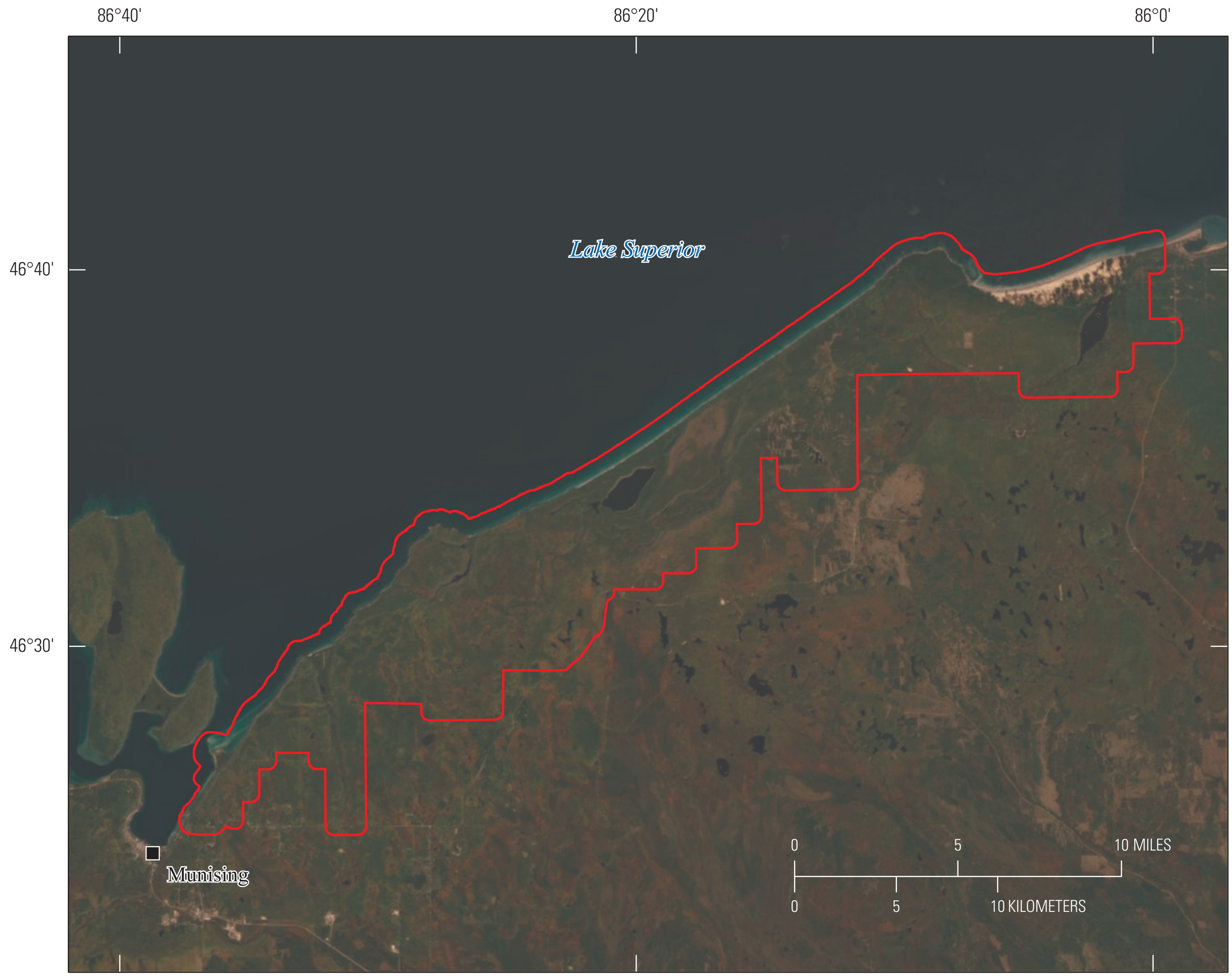
Forest canopy gaps were identified using the multiresolution segmentation algorithm in the eCognition software using methods described by Nyamgeroh and others (2018). "In object-based image analysis (OBIA), individual pixels in an image are combined on the basis of their spectral similarity or, in some cases, in relation to an external variable (for example, land ownership) not obtained from the image. In this process, color (the spectral values) and shape properties (smoothness and compactness) are used to describe the homogeneity criterion: the similarity between adjacent objects in the image. The pair of objects that show the least increase in homogeneity criterion is merged until this increase exceeds a user-defined threshold, known as the scale parameter. The higher the scale parameter, the more merging takes place, resulting in the formation of larger objects" (Nyamgeroh and others, 2018, p. 633). The OBIA settings put forth in the study by Nyamgeroh and others (2018) were used as a starting point for determining the settings for the multiresolution segmentation for this project. Several iterations were completed to determine which settings were most effective in separating dark (canopy gaps) and light areas (tree canopy). Each iteration produced a polygon layer that was visually compared to canopy gaps seen in the imagery. After a visual comparison, another iteration with a different setting (for example, lowering the scale parameter) would be processed to compare the two outputs. The iterations that appeared to reliably identify canopy gaps were layer weights given a value of one (except for the green band which was given a value of two), scale parameter given a value of 50, shape given a value of 0.1, and compactness given a value of 0.5 (figs. 2 and 3).

In order to classify objects as canopy gaps, several spectral (color) value thresholds were applied to separate dark areas (gaps) from bright areas (tree canopy) (table 1). In the 2005 aerial imagery, there were two smaller areas that differed in spectral values from the rest of the imagery dataset. The threshold values were fine-tuned by increasing or decreasing the upper threshold value to produce a polygon output from the multiresolution segmentation algorithm that was similar to the rest of the study area.

Developing Forest Canopy Gaps and Forest Connectivity Datasets

The objects classified as forest canopy gaps are all areas that appeared as dark areas in the imagery. To ensure quality control of eCognition classified forest canopy gaps, the 2005 vegetation map produced by Hop and others (2010) was used to remove areas of misclassified canopy gaps found outside forested areas. This was done by selecting all forest map classes in the vegetation map (table 2) and eliminating all misclassified canopy gaps that were not found adjacent to a forest type.

The R Project for Statistical Computing 4.0.3 (R Core Team, 2019) was used to merge all adjacent forest canopy gap polygons and calculate the area, in hectares, of the canopy gaps. Then, in Esri's ArcMap 10.6, all polygons that were less



Service layer credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS user community

Figure 1. Map showing the location of the study area in the Upper Peninsula of Michigan.

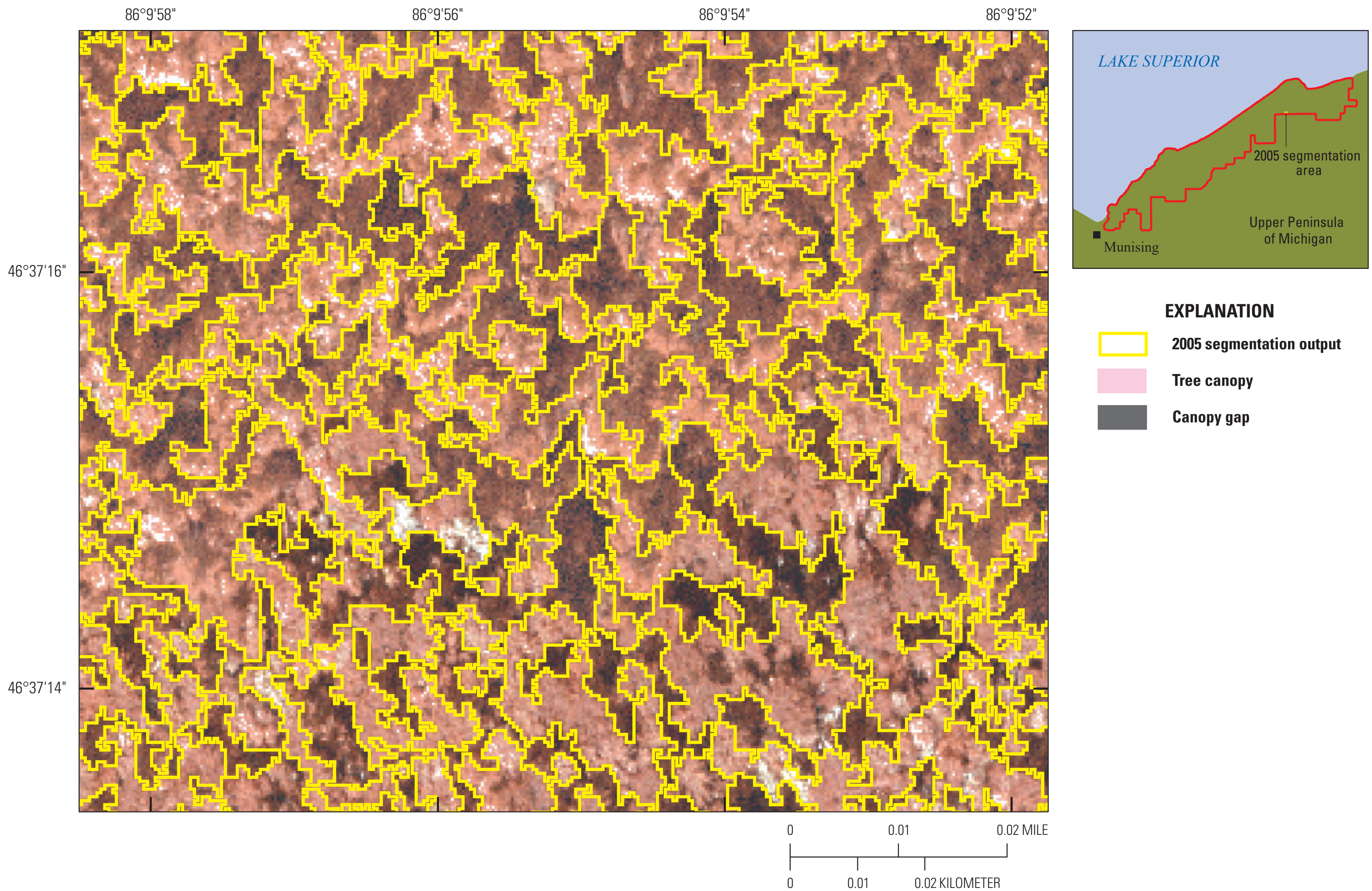


Figure 2. Map showing the 2005 segmentation output. Yellow lines illustrate how the multiresolution segmentation grouped together similar spectral values based off the aerial imagery in 2005. The darker areas of the image represent gaps; the lighter areas represent forest.

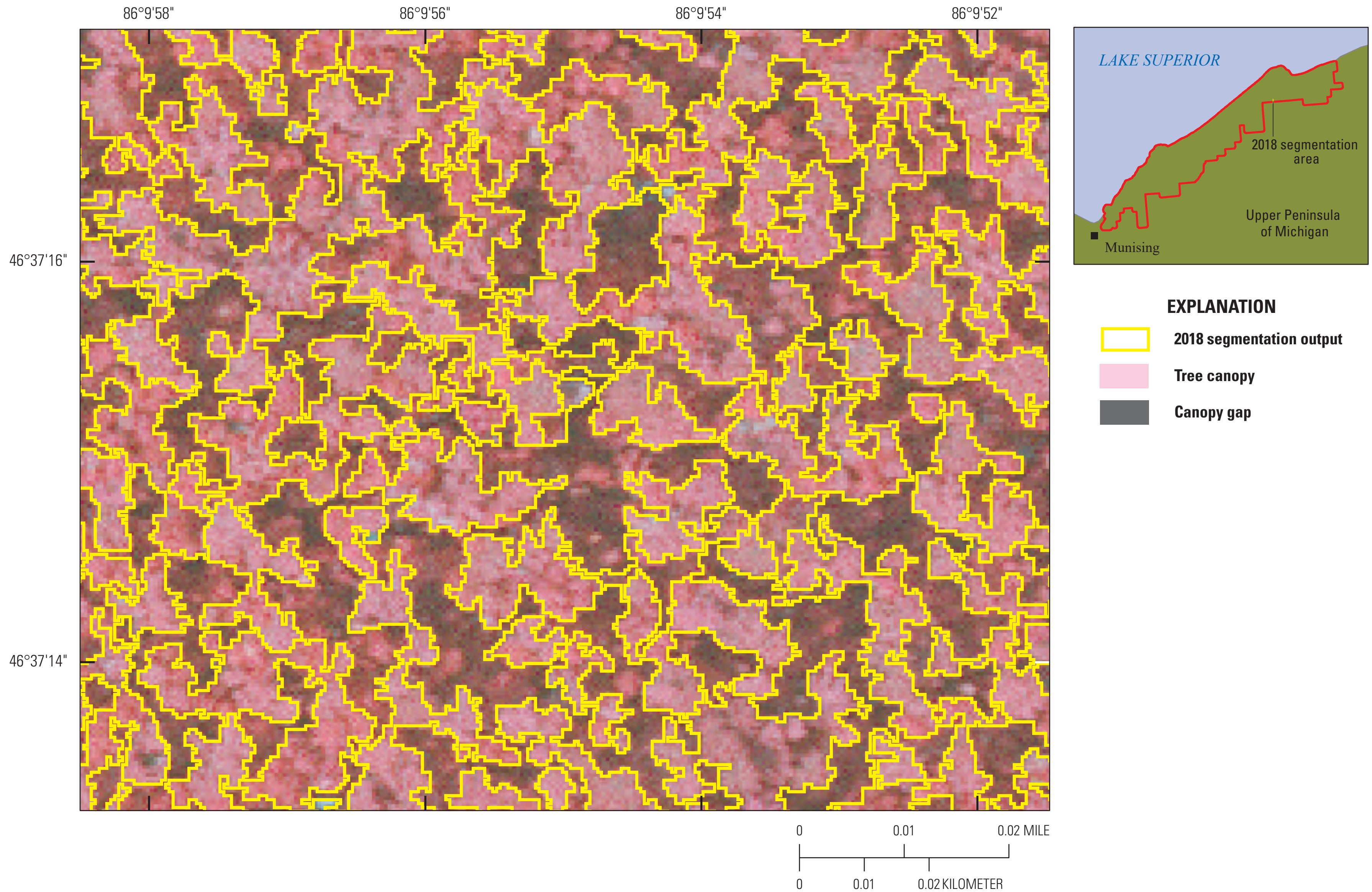


Figure 3. Map showing the 2018 segmentation output. Yellow lines illustrate how the multiresolution segmentation grouped together similar spectral values based off the aerial imagery in 2018. The darker areas of the image represent gaps; the lighter areas represent forest.

Table 1. Spectral value threshold ranges used to locate dark areas (canopy gaps).

[NAIP, National Agriculture Imagery Program; n.d., no data]

	2005 aerial imagery		2018 NAIP imagery	
Threshold value	**Lower threshold**	**Upper threshold**	**Lower threshold**	**Upper threshold**
Brightness	n.d.	85 (106)	45	85
Mean layer 1	n.d.	n.d.	35	65
Mean layer 2	n.d.	n.d.	35	80
Mean layer 3	n.d.	70 (80)	40	60
Mean layer 4	n.d.	n.d.	65	145
Maximum difference	n.d.	1.2 (1, 1.5)	0.3	1.3

Table 2. Map classes used to identify true forest canopy gaps and create the forest connectivity layer.

Map class code	Map class name
FBA	Black Ash-Mixed Hardwood Swamp
FBS	Black Spruce/Feathermoss Forest
FCA	White-cedar-Black Ash Swamp
FCC, FCM	White-cedar-Boreal Conifer Mesic Forest
FCP	Spruce-Fir-Aspen Forest
FCS	White-cedar-(Mixed Conifer)/Alder Swamp
FCX	Conifer Ruderal Forest
FDX	Hardwood Ruderal Forest
FFB	Balsam Fir-Paper Birch Forest
FGF	Paper Birch/Fir Forest
FHB	Great Lakes Hemlock-Beech-Hardwood Forest
FHC	Hemlock Mesic Forest
FHM	North-Central Hemlock-Hardwood Forest
FHS	Hemlock-Yellow Birch Swamp Wet-Mesic Forest
FJB	Jack Pine/Blueberry/Feathermoss Forest
FJF	Jack Pine/Balsam Fir Forest
FJM	Jack Pine-Aspen/Bush-honeysuckle Forest
FLD	Black Ash-Mixed Hardwood Forest
FMB, FMF, FMM, FMY	Maple-Yellow Birch Northern Hardwoods Forest
FMX	Conifer-Hardwood Ruderal Forest
FPB	White Pine-Mixed Deciduous/Bracken Barren Forest and Scrub
FPD	Great Lakes Dune Pine Forest
FPE	Conifer Plantation
FRA	Red Pine-Aspen-Birch Forest
FRP	Red Pine/Blueberry Dry Forest
FSF	Spruce-Fir/Mountain Maple Forest
FSS, FTS	Black Spruce-Tamarack/Labrador-tea Poor Swamp
FWA	White Pine-Aspen - Birch Forest
FWH	Great Lakes White Pine-Hemlock Forest
FWM, FWW	White Pine-Red Maple Swamp
FWO	White Pine-Red Oak Forest
FWP	White Pine/Blueberry Dry-Mesic Forest
HPB, HPW	Great Lakes Coast Pine Barrens
SSS	White Pine-Mixed Deciduous/Bracken Barren Forest and Scrub

than the minimum mapping unit, 0.026 hectares, were deleted from the dataset. This is the minimum mapping unit used to create the forest canopy gaps along the Mississippi and Illinois River bottomland forests (Sattler and Hoy, 2020).

Several attributes pertaining to the canopy gap and surrounding area of the canopy gap were applied to each canopy gap (table 3) to help inform biologists and managers in making decisions based on the forest canopy gaps. Using the forest canopy gap dataset produced by Sattler and Hoy (2020), attributes that were deemed useful were applied to each canopy gap using the Forest Canopy Gap Locator R Script (Sattler, 2020a). Datasets supporting this project are available in Sattler (2020b).

To create the forest connectivity layers, the forest polygons (table 2) were merged to create a forest connectivity layer. By using Esri's Erase tool, the forest canopy gaps were used to create a hole (representing the canopy gap) within the forest canopy. The forest connectivity layer would then resemble how the forest canopy would appear from a bird's-eye view.

Time Change Analysis

To better understand how forest connectivity has changed over time because of BBD, a time change analysis was completed. By using the Union tool in ArcMap, a polygon shapefile was created showing both forest connectivity and canopy gaps for each period. A raster was created from each shapefile at a resolution of 1 meter where canopy gaps were given a cell value of one and forest connectivity was given cell values of zero. The Reclassify tool was executed on each raster to allow for four values to represent each of the different scenarios that could have occurred to the forest over time: maintained forest canopy (forest canopy in 2005 and 2018), maintained forest canopy gap (forest canopy gap in 2005 and 2018), closed forest canopy gap (forest canopy gap in 2005 but forest canopy in 2018), and formed forest canopy gap (forest canopy in 2005 but a forest canopy gap in 2018) (table 4). Then, the Raster Calculator was used to complete the time change analysis by adding the 2018 raster to the 2005 raster.

Table 3. Attribute names and descriptions added to the forest canopy gap shapefile.

[lidar, light detection and ranging]

Attribute name	Description
G_Area	Area of the canopy gap in acres
G_Perim	Perimeter of the canopy gap in meters
G_APR	Canopy gap area/perimeter ratio
G_Dom	Dominant vegetation map class within the canopy gap taken from the vegetation map classes in the 2005 vegetation map[1]
Dom_Name	Map class name of the map class code in G_Dom from the 2005 vegetation map[1]
G_AvgHt	Average height of the 2015 lidar[2] returns from within the canopy gap
G_MinHt	Minimum height of the 2015 lidar[2] returns from within the canopy gap
G_MaxHt	Maximum height of the 2015 lidar[2] returns from within the canopy gap
G_NFP	Percentage of the canopy gap perimeter that is nonforest
S_MjFCT	Vegetation map class majority forest type (as defined in table 2) within a 150-meter buffer of the canopy gap
MjFCT_Name	Map class name of the map class code in S_MjFCT from the 2005 vegetation map[1]
S_PFA	Percentage of the 150-meter buffer area surrounding the canopy gap that is classified as forest in the 2005 vegetation map[1]
S_PWA	Percentage of the 150-meter buffer area surrounding the canopy gap that is classified as water in the 2005 vegetation map[1]
S_PNwNf	Percentage of the 150-meter buffer area surrounding the canopy gap that is classified as neither forest nor water in the 2005 vegetation map[1]

[1]The vegetation map used was produced by Hop and others, 2010.

[2]The lidar dataset used was produced by USGS, 2017.

Table 4. Raster cell value definitions and explanations on the time change analysis.

Raster cell value	Definition	Explanation
6	Forest canopy gap closed	Identified as a canopy gap in 2005 but no longer exists in 2018
8	Forest canopy gap maintained	Identified as a canopy gap in 2005 and in 2018
9	Forest canopy maintained	Identified as a forest canopy in 2005 and 2018
11	Forest canopy gap formed	Identified as a forest in 2005 but was identified as a canopy gap in 2018

Discussion and Conclusions

The objective of this project was to produce multiple geospatial layers of PIRO forest connectivity to reveal the effects of BBD. By analyzing the produced forest connectivity layers at different periods during the BBD infestation, managers can have a better understanding of how forest cover and composition have changed. PIRO managers can also model how wildlife species are responding to the forest changes, better understand how to manage for certain species, and begin to plan for forest restoration. The final geospatial layers, or datasets (Sattler, 2020b), illustrate a change in forest canopy from 2005 to 2018.

The settings used in eCognition, specifically for the multiresolution segmentation algorithm, detected small canopy gaps but not many large canopy gaps. In addition, the threshold spectral value ranges of dark areas (canopy gaps) varied within the same imagery set making it more difficult to determine a value range for forest canopy gaps to be correctly identified. There are also some tree canopies that had darker values than others, which led to a falsely identified forest canopy gap. Upon visual inspection, it appears that the algorithm and spectral threshold values located forest canopy gaps reliably, but it was also apparent that there were many canopy gaps unclassified.

Interpretation of Time Change Analysis

The time change analysis demonstrates the changes the forest has undergone from 2005 to 2018 (fig. 4). Over the 13-year period, 72.11 percent of the forest remained as an intact closed canopy, where 54.11 percent of the canopy remained within the FMB map class (Maple-Yellow Birch Northern Hardwoods Forest). From 2005 to 2018, 12.96 percent (9,127 acres) of the forest in PIRO converted from a forest canopy to a canopy gap (table 5). The map class that saw the most forest canopy change to a canopy gap was the FMB map class (Maple-Yellow Birch Northern Hardwoods Forest) at 55.41 percent. When analyzing map classes where American beech commonly grows (FHB, FHM, FMB, FMF, FMM, FMY, and FWO), 72.80 percent of the new canopy gaps occurred in one of those forest types (table 6). The average size of these gaps was 0.05 acre, which could indicate that the majority of new canopy gaps could be because of a single mature canopy tree dying, possibly an American beech dying from BBD. Interestingly, the same map class that had the most forest canopy convert to a canopy gap was the same map class that had the most canopy gaps close to create a forest canopy at 35.23 percent. This could indicate the gap was created in the early stages of the BBD infestation (2001), or it was there prior to the BBD infestation. There were 2.97 percent of forest canopy gaps in 2005 that remained in 2018. These gaps would be of interest for further investigation if they are true gaps and if they are, determining what factors are inhibiting new trees from growing to fill the canopy gap could be investigated.

Canopy gaps, canopy gaps that formed after the 2005 imagery, and maintained canopy gaps from 2005 totaled 11,210 acres, 15.93 percent of the forested area analyzed. The average canopy gap size when combining these two scenarios was 0.03 acre, which does not meet the minimum mapping unit of this project. This would indicate that the canopy gaps identified through the time change analysis may not be true canopy gaps.

Dataset Inaccuracies

Unfortunately, this project did not collect field data to corroborate the accuracy of the identified forest canopy gaps. Initially, a different method utilizing the National Aeronautics and Space Administration's stereo pipeline (Beyer and others, 2018) and Forest Canopy Gap Locator R Script (Sattler, 2020a) had field data validating the accuracy of identified canopy gaps. That method was determined to be incompatible with the 2005 aerial imagery because of insufficient camera information for the imagery. Therefore, when OBIA was identified as the new method to identify canopy gaps, field data collection was beyond the scope of the project to test how accurate the eCognition and OBIA process was at locating canopy gaps.

Further investigation could be made with regard to the eCognition settings, specifically the multiresolution segmentation algorithm and threshold values. This may reduce the number of identified canopy gaps classified as either shadows or dark tree canopy upon visual inspection. Some of the settings that could be tested include lowering the scale parameter, changing value threshold ranges, and conducting multiple multiresolution segmentations.

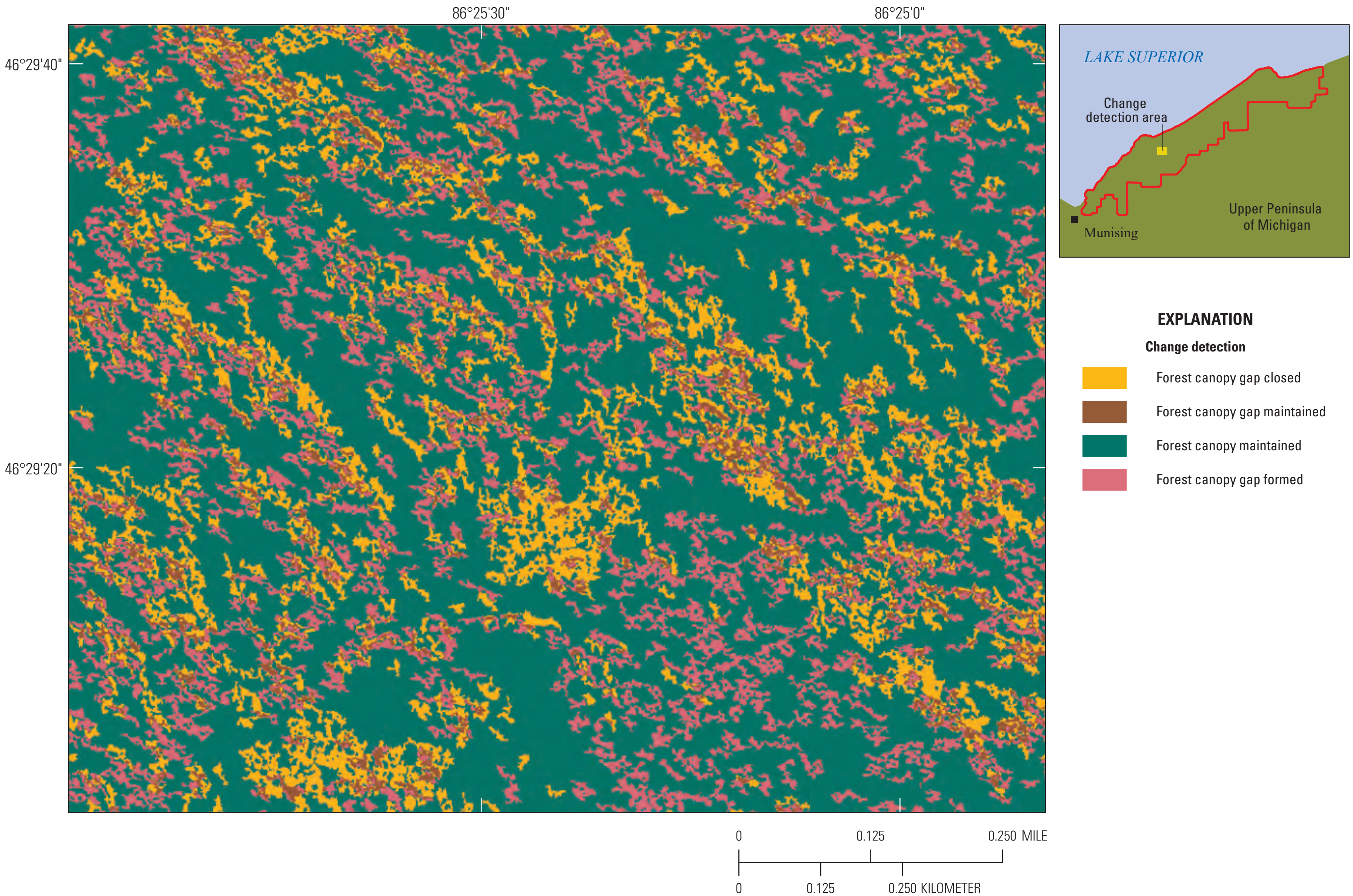


Figure 4. Map showing time change analysis in Pictured Rocks National Lakeshore.

Table 5. Acres and hectares for each change scenario in the time change analysis.

Change scenario	Acres	Hectares	Percentage of forest
Forest canopy gap closed	8,426	3,410	11.96
Forest canopy gap maintained	2,090	845.7	2.97
Forest canopy maintained	50,800	20,560	72.12
Forest canopy gap formed	9,127	3,694	12.96
Total	70,440	28,510	100

Table 6. Summary of map classes that contain *Fagus grandifolia* Ehrh. (American beech) in formed forest canopy gaps.

Map class code-name	Acres	Hectares	Percentage of formed canopy gaps
FHB: Great Lakes Hemlock-Beech-Hardwood Forest	425.1	172.0	4.66
FHM: North-Central Hemlock-Hardwood Forest	274.6	111.1	3.01
FMB: Maple-Yellow Birch Northern Hardwoods Forest	5057	2047	55.41
FMF: Maple-Yellow Birch Northern Hardwoods Forest	119.6	48.40	1.31
FMM: Maple-Yellow Birch Northern Hardwoods Forest	621.3	251.4	6.81
FMY: Maple-Yellow Birch Northern Hardwoods Forest	141.2	57.14	1.55
FWO: White Pine-Red Oak Forest	7.32	2.96	0.08
Total	6,646	2690	72.83

Suggestions for Future Studies

This study is the first step in providing biologists and managers at PIRO with useful information on forest canopy gap locations to complete wildlife studies and inform managerial decisions. These datasets (Sattler, 2020b) provide input on the change the forest canopy has endured during the BBD infestation. Further analysis may enhance the effectiveness of the datasets created and potentially help answer questions about forest connectivity and how wildlife species are adapting to their changing environment.

To better understand the quality and accuracy of the OBIA method for locating forest canopy gaps, field data collection would be beneficial. As stated in the previous section, there are inaccuracies in these datasets, and conducting an accuracy assessment on the 2018 imagery identified forest canopy gaps could allow the OBIA process to be updated and provide a forest canopy gap dataset with lower uncertainty. Further investigation into different multiresolution segmentation settings in eCognition could also be tested to identify the best settings (for example, scale parameter at 30 instead of 50) for locating forest canopy gaps with the provided imagery in PIRO. In addition, putting in place a proximity rule would combine smaller canopy gaps that were identified as separate gaps into one larger gap (fig. 5).

A comparison between two methods of identifying forest canopy gaps would provide insight on which method is more accurate in locating canopy gaps within the PIRO boundary. The 2015 lidar dataset (U.S. Geological Survey, 2017) could be used in the Forest Canopy Gap Locator R Script (Sattler, 2020a), and that output could be compared with the 2018 dataset produced in this study.

Beech bark disease is still prevalent in PIRO, and likely will not be the only pest that alters tree composition in the forest. It would be beneficial to conduct future time change analyses to monitor forest connectivity and provide additional information on the condition of the forest canopy.

Because American beech is a common tree species in several U.S. National Vegetation Classification (United States National Vegetation Classification [USNVC], 2019) forest classification types found throughout PIRO, a future study could focus on visiting forest canopy gaps to identify the present USNVC classification. Because the USNVC classification was used to create the map classes in the 2005 PIRO vegetation map (for example, *Tsuga canadensis* - *Fagus grandifolia* - (*Acer saccharum*) Great Lakes Forest Association (CEGL005042) was placed in the FHB map class), a comparison can be completed to gain a better understanding of how the forest types are changing because of American beech loss.

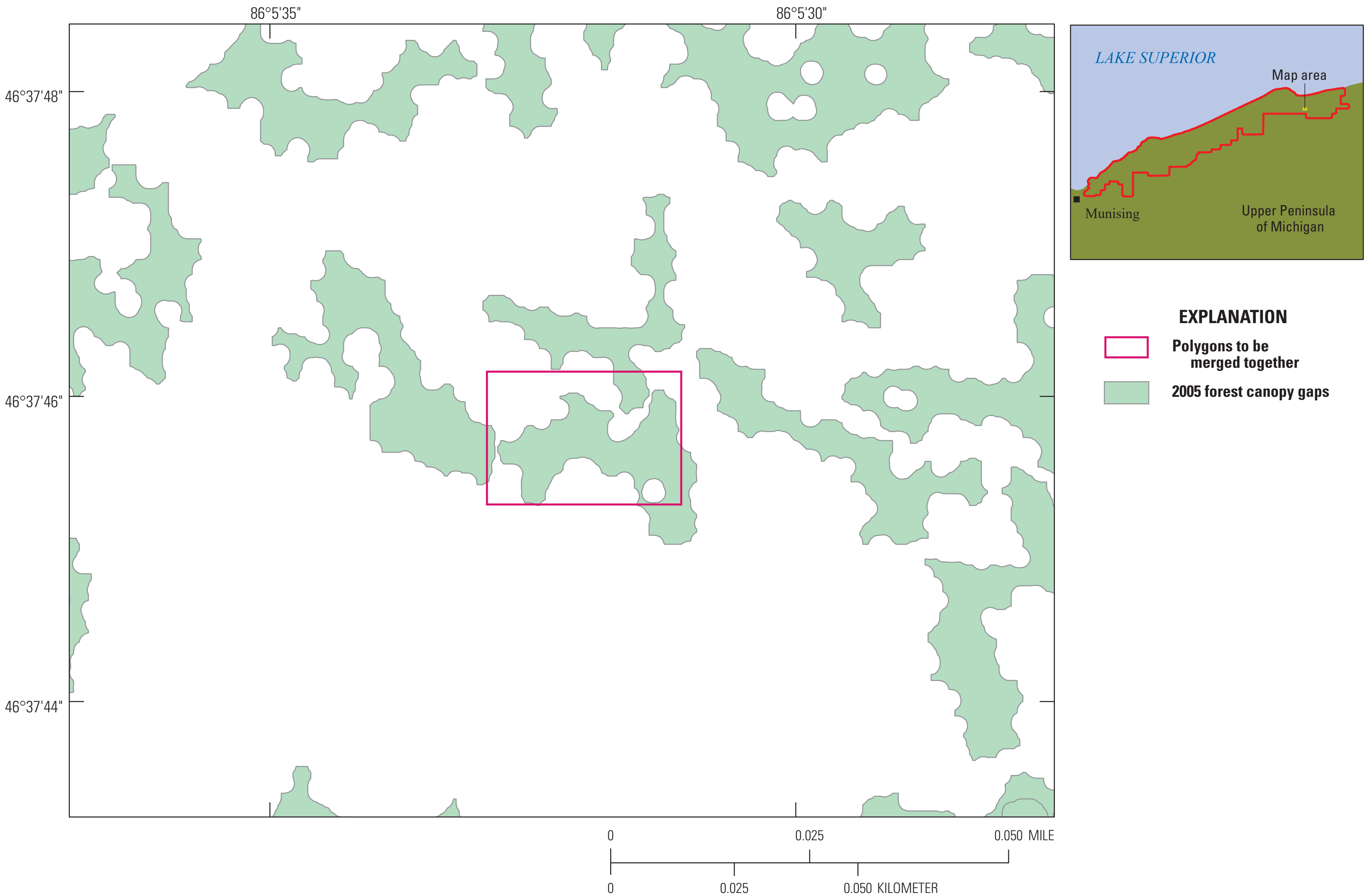


Figure 5. Map showing three canopy gaps that could potentially be merged together by using an adjacency rule in a future project.

Summary

Since the introduction of beech bark disease in Pictured Rocks National Lakeshore in 2001, the forest canopy and composition have been changing and affecting the wildlife inhabitants. It is estimated that most of the mature beech trees will not survive the beech bark disease, so conducting time change analyses shows how the forest canopy is changing. This study showed that since 2005, 9,127 acres have been converted from a closed canopy to a canopy gap. Of those acres, 72 percent occur in a forest type where *Fagus grandifolia* Ehrh. (American beech) is a common tree species.

The datasets developed from this project can aide biologists and managers in quantitively understanding the ecological effect the beech bark disease has had on the forests within Pictured Rocks National Lakeshore by giving them the first quantitative measure of canopy gaps in Pictured Rocks National Lakeshore.

References Cited

Beyer, R.A., Alexandrov, O., and McMichael, S., 2018, Ames Stereo Pipeline: Documentation-Release 2.7.0., accessed November 31, 2019, at https://ti.arc.nasa.gov/tech/asr/groups/intelligent-robotics/ngt/stereo/.

Hop, K., Menard, S., Drake, J., Lubinski, S., and Dieck, J., 2010, National Park Service Vegetation Inventory Program—Pictured Rocks National Lakeshore: Fort Collins, Colo., National Park Service, Natural Resource Report NPS/GLKN/NRR—2010/201, accessed November 3, 2020, at https://irma.nps.gov/DataStore/Reference/Profile/2124843.

National Park Service, 2019, Beech bark disease: National Park Service web page, accessed January 14, 2021, at https://www.nps.gov/piro/learn/nature/beechbarkdisease.htm#:~:text=Beech%20bark%20disease%20is%20the%20result%20of%20a,sharp%20mouth%20parts%20and%20sucking%20out%20the%20sap.

Nyamgeroh, B.B., Groen, T.A., Weir, J.C.M., Dimov, P., and Zlatanov, T., 2018, Detection of forest canopy gaps from very high resolution aerial images: Ecological Indicators, v. 95, part 1, p. 629–636, accessed March 3, 2020, at https://doi.org/10.1016/j.ecolind.2018.08.011.

R Core Team, 2019, The R Project for statistical computing: Vienna, Austria, R Foundation for Statistical Computing. [Also available at https://www.R-project.org/.]

Sattler, S.R, 2020a, Forest Canopy Gap Locator R Script: U.S. Geological Survey code release, https://doi.org/10.5066/P9YONHY2.

Sattler, S.R., 2020b, Effects of beech bark disease on forest connectivity in Pictured Rocks National Lakeshore from 2005 to 2018: U.S. Geological Survey data release, https://doi.org/10.5066/P9EZEAYD.

Sattler, S.R., and Hoy, E.E., 2020, Forest canopy gaps identified by lidar for portions of the Mississippi and Illinois River: U.S. Geological Survey data release, https://doi.org/10.5066/P9BLTSTZ.

U.S. Geological Survey, 2017, USGS Lidar Point Cloud MI AlgerCo 2015 LAS 2017: U.S. Geological Survey National Land Cover Database, accessed January 15, 2020, at https://viewer.nationalmap.gov/basic/.

United States National Vegetation Classification [USNVC], 2019, United States National Vegetation Classification Database, V2.03: Washington D.C., Federal Geographic Data Committee, Vegetation Subcommittee, accessed January 14, 2021, at https://gcc02.safelinks.protection.outlook.com/?url=http%3A%2F%2Fwww.usnvc.org%2F&data=04%7C01%7Cssattler%40usgs.gov%7C7dc620aa4ab84ec4351c08d8fea369fe%7C0693b5ba4b184d7b9341f32f400a5494%7C0%7C0%7C637539325093145612%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C1000&sdata=pwTFGnCSdYLQzGhat07LNkqRz9%2FOGU3f229f5AGKzE8%3D&reserved=0.

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