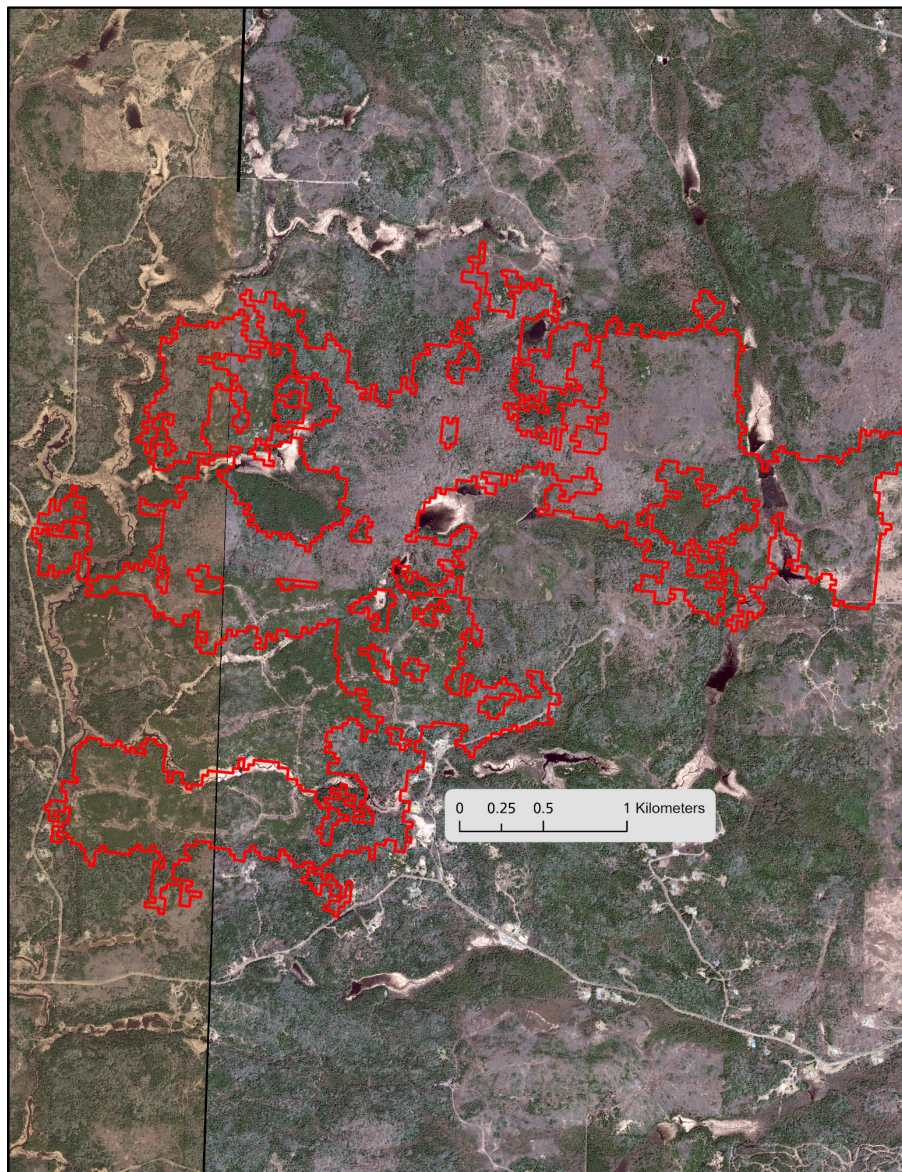




Landsat-based Monitoring of Landscape Dynamics at Isle Royale National Park *1995–2017*

Natural Resource Data Series NPS/GLKN/NRDS—2021/1324



ON THE COVER

The single largest forest harvest within the analysis area occurred on the adjoining mainland in Ontario in 2001. It was 650 hectares (1,600 acres) in size. Image from WorldView satellite, with polygon added.

Landsat-based Monitoring of Landscape Dynamics at Isle Royale National Park

1995–2017

Natural Resource Data Series NPS/GLKN/NRDS—2021/1324

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U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Abstract

Landscape disturbances such as forest harvest, blowdowns, fire, and development activities create patches on the landscape that modify the structure and function of ecosystems and watersheds. Understanding the timing, location, size and intensity of these disturbances can assist resource managers while making decisions regarding management options. To provide information regarding these metrics, the Great Lakes Inventory and Monitoring Network implemented a long-term monitoring project to quantify landscape dynamics inside and surrounding Isle Royale National Park using an automated satellite-based change detection program called LandTrendr (Landsat-based detection of trends in disturbance and recovery). This is the second report for Isle Royale NP and varies slightly from the original report published in 2012 in terms of analysis area and the time period analyzed. We have doubled the analysis area outside the park and have increased the number of years analyzed from 2003–2008 (6 years) to 1995–2017 (23 years). Inside the park, disturbances due to beaver affected the largest amount of land (20.16 ha, average 0.87 ha per year), followed closely by fire (15.80 ha, average 0.69 ha per year), with blowdown being the only remaining disturbance that was detected inside the park (1.44 ha). Lands adjacent the park in Ontario, Canada, experienced far greater levels of disturbance, with forest pathogens accounting for about half of the land disturbed outside the park (15.03%, average 0.65% per year). The second most prevalent disturbance agent outside the park was forest harvest, with 14.52% (average 0.63% per year) of the land disturbed outside the park during the 23-year analysis period. Long-term monitoring of this analysis area will contribute to our understanding of how these disturbances may affect the dispersal of wildlife to the island.

Introduction

We report on disturbances for Isle Royale National Park (ISRO) and the surrounding area using change detection methodology described in the Great Lakes Inventory and Monitoring Network (GLKN) Landscape Dynamics monitoring protocol (Kennedy et al. 2010a). Here we summarize disturbances that occurred between 1995 and 2017 (23 years).

Methods

Study Area

The analysis was conducted inside and adjacent to Isle Royale National Park (ISRO). The analysis area extended into Ontario, Canada (Figure 1). In total 412,251 ha of land was monitored, of which 53,210 ha was land inside ISRO. Included in the analysis area is one U.S. watershed as defined by level 10 delineations of the National Hydrography Dataset's Hydrologic Unit Code (HUC) (nhd.usgs.gov) and 14 additional watersheds in Canada as defined by the quaternary level of the Ontario watershed delineation (ontario.ca/page/land-information-ontario) (Figure 2). Landcover within the analysis area was dominated by forest, as classified in the U.S. by the 2006 National Land Cover Database (NLCD) (Fry et al. 2011) and in Canada by the Canada-wide Earth Observation for Sustainable Development of Forests (EOSD) (Wulder et al. 2003) (Figures 3 and 4).

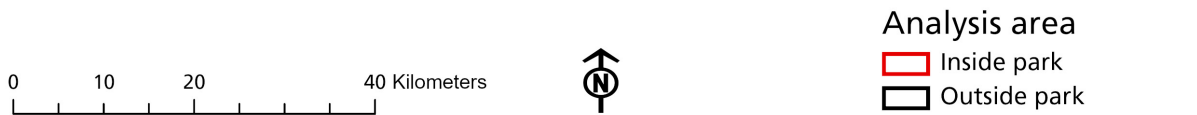
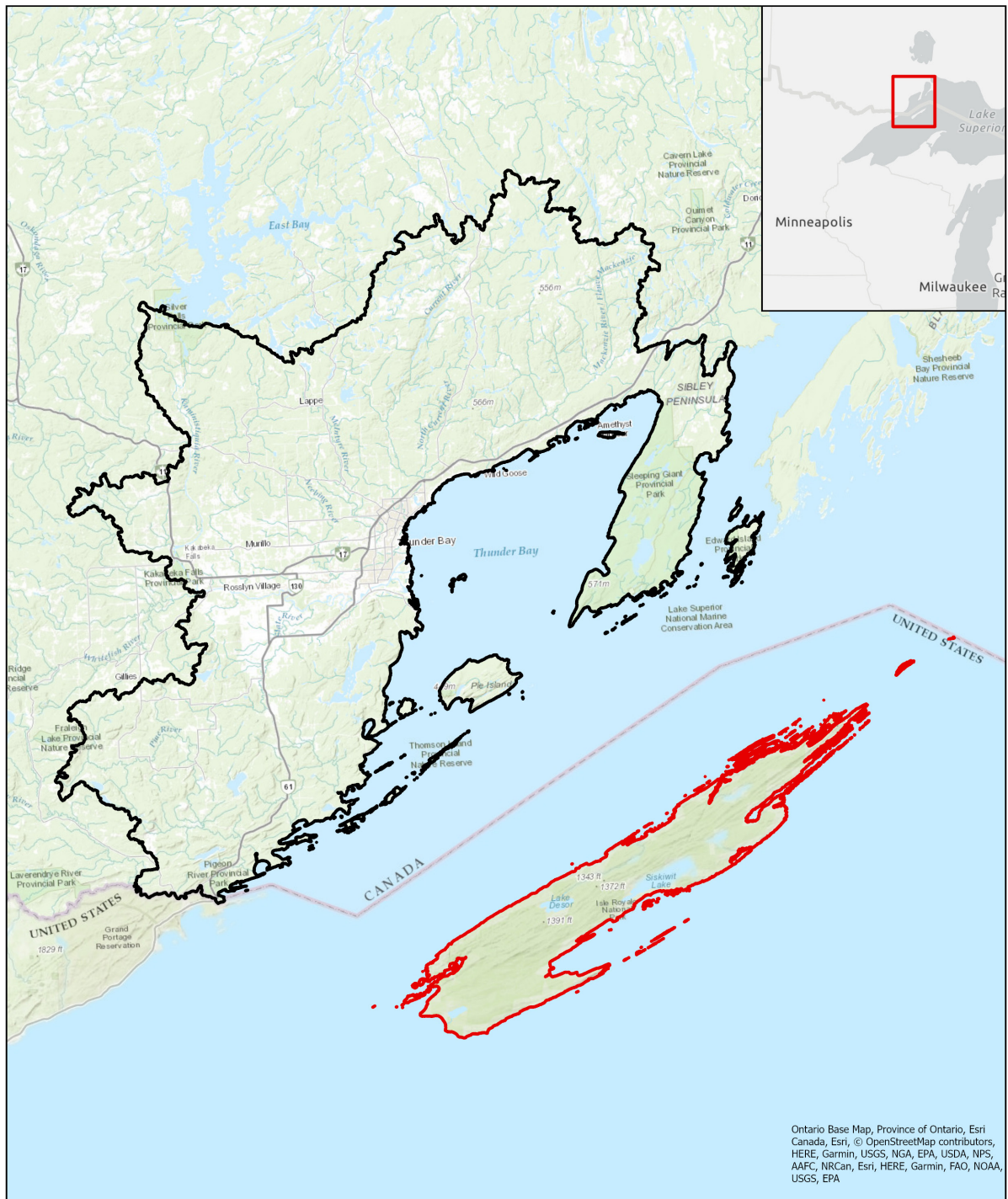


Figure 1. Analysis area for monitoring landscape dynamics in the greater Isle Royale National Park ecosystem. Red outline indicates park extent and black outline indicates area monitored outside the park in the Thunder Bay, Ontario area.

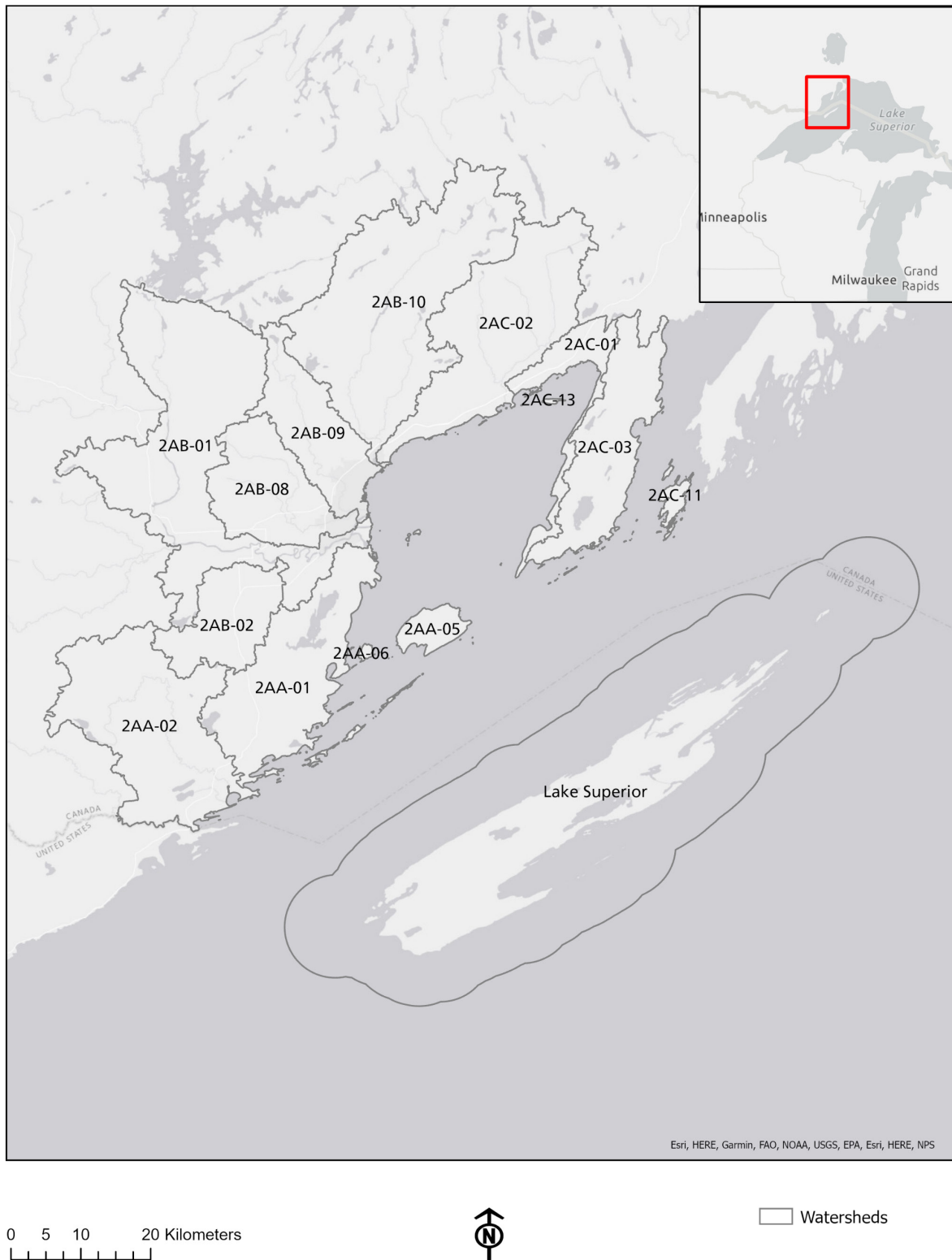


Figure 2. Labeled watersheds (*gray outlines*) included in this analysis, as defined by level 10 Hydrologic Unit Codes (HUCs) in the U.S. and level 4 watersheds in Ontario.

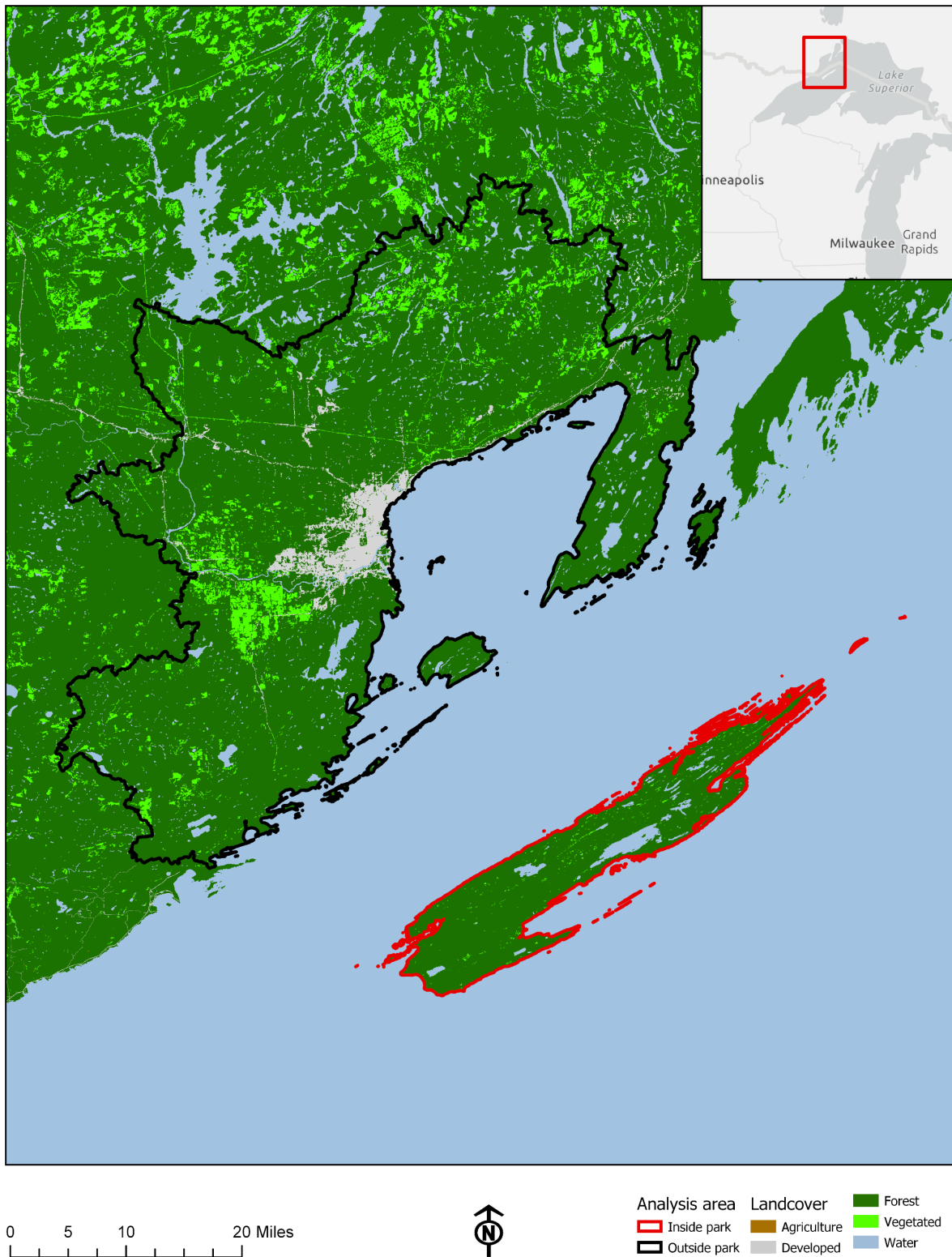


Figure 3. Aggregated vegetation classes in the analysis area, as mapped by the National Land Cover Database (U.S.) and Earth Observation for Sustainable Development of Forests (Ontario).

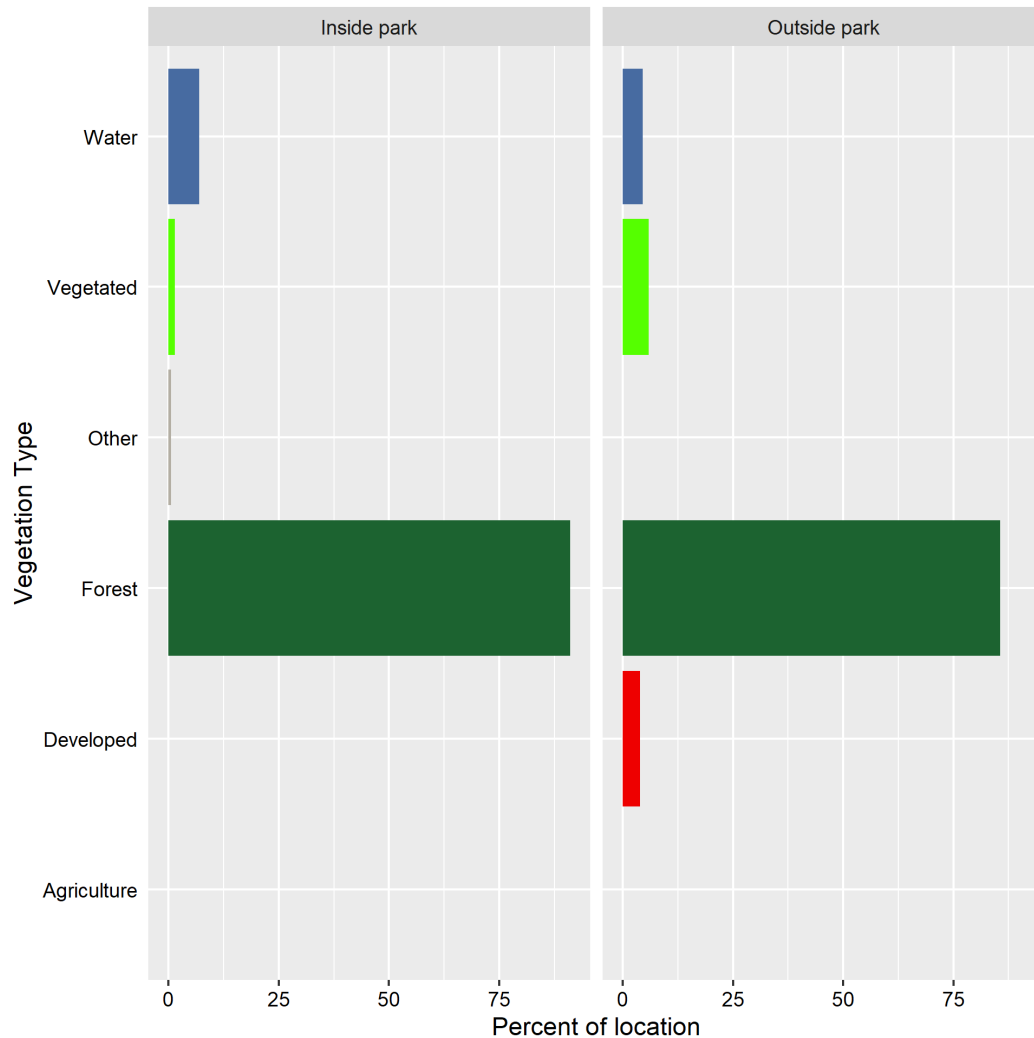


Figure 4. Percent of each aggregated vegetation class in the analysis area, as mapped by the National Land Cover Database (U.S.) and Earth Observation for Sustainable Development of Forests (Ontario).

Ownership

Two sources of land ownership exist for the analysis area. In the U.S. portion we used the U.S. Geological Survey (USGS) GAP analysis program’s Protected Areas Database (PADUS) version 2.1 (U.S. Geological Survey Gap Analysis Project 2020). Because this database was developed for the U.S., it lacks information regarding lands in Canada. In Ontario, we used ownership data obtained from Ontario Land Information Office (LIO; www.ontario.ca/page/land-information-ontario). Within the analysis area, the largest percent of lands were patent (49%) followed by crown and federally-owned lands (37% and 13%, respectively) (Table 1). Patent lands in Ontario are typically those lands transferred from the crown (federal) to provincial or other local governments. Crown land is still typically federally owned, although most of the land is commonly leased to private industrial companies for timber management and wood extraction.

Table 1. Ownership within the analysis area. Ownership data from the Protected Areas Database, version 1.4 (U.S.) and the Ontario Land Information Office (Canada).

Ownership	Area (ha)	Percent land
Crown	162,402	38
Federal	57,965	13
Native American	6,345	2
Patent	211,371	49
Unknown	3,096	1

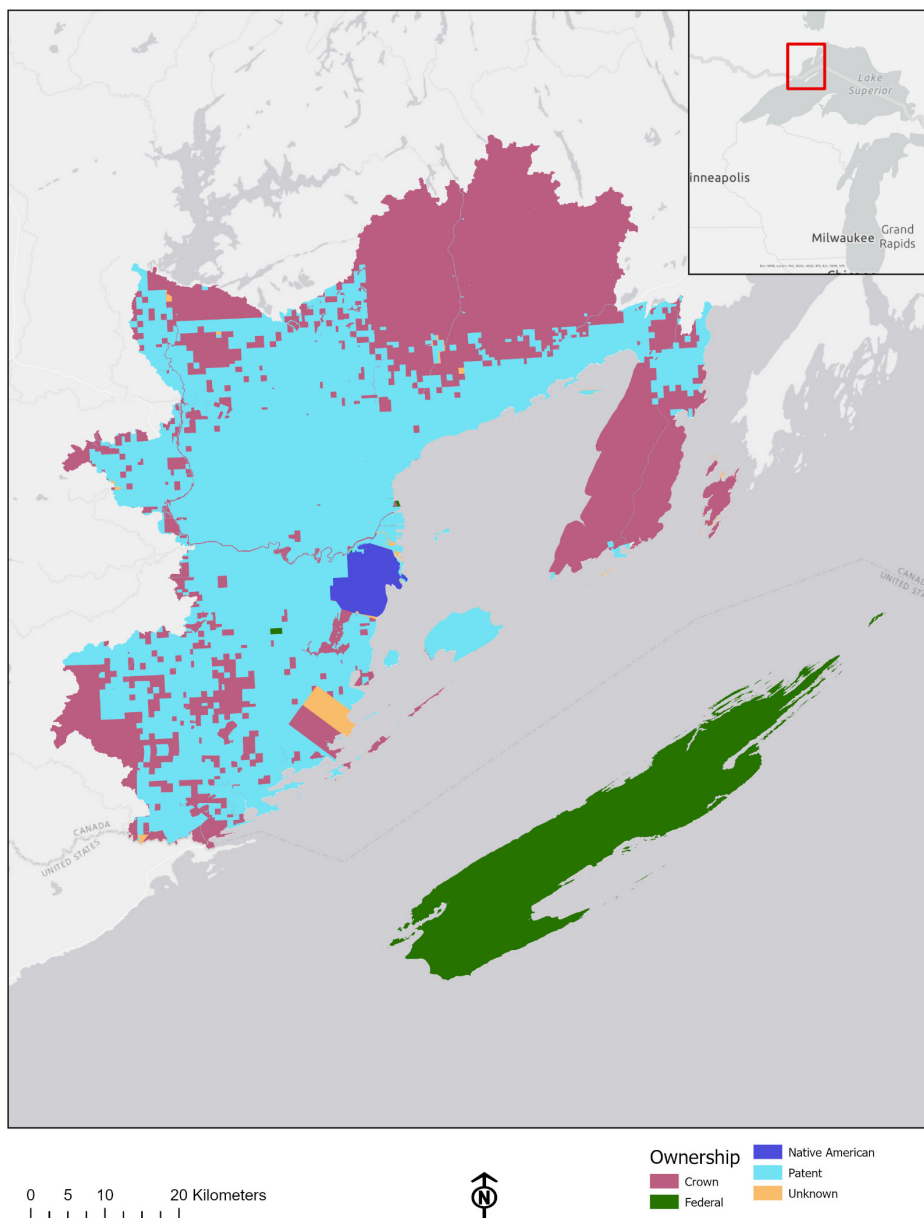


Figure 5. Ownership within the analysis area. Ownership data for U.S. from the Protected Areas Database (version 1.4) and in Canada from the Ontario Land Information Office.

Disturbance Detection Methodology

We used a set of processing and analysis steps collectively known as LandTrendr (Kennedy et al. 2010a, 2010b, 2012). Using statistical fitting algorithms, LandTrendr works on a per pixel (30-m resolution) basis to describe a time series of spectral reflectance values, capturing the shape of the time series curve, while smoothing undesired random noise, such as phenological condition or sun angle at the time of image acquisition. LandTrendr identifies periods of spectral stability (no change) and instability (change). For this analysis we only report on changes, where and when they occur.

To minimize effects of phenological variation we selected Landsat images between July and September of each year (1984–2017). Atmospheric correction, cloud and cloud shadow masking, and segmentation (disturbance detection) was performed using LandTrendr algorithms implemented through Google Earth Engine (Kennedy et al. 2018). Although Landsat has multiple reflectance bands, LandTrendr can only be run on one band or index for disturbance detection. We chose to use an ensemble composite index (ENC) which incorporates the average of the six highest ranked disturbance indices in Cohen et al. (2018). This index balances the omission and commission error rates and allows the detection of short abrupt changes as well as more subtle disturbances.

Patch Definition

To delineate patches, adjacent pixels experiencing disturbances in the same year were assumed to have experienced the same event and were grouped together using an 8-neighbor adjacency rule. Patches with 10 or fewer pixels (ca. 1 ha, 2.5 ac) were removed from the dataset to avoid small, often unverifiable disturbance events. This size was small enough to capture most forest harvests in addition to other disturbance agents such as beavers, some development activities, and blowdowns.

Interpreter-based Validation and Attribution of Change Agents

We chose to validate every (census) disturbance polygon that was generated by LandTrendr to remove commission errors (false positives) and at the same time determine the change agent. If a polygon spanned boundaries (watershed, ownership), we attributed the polygon with the majority of the polygon represented. Validation of possible disturbances followed details given in Kirschbaum and Gafvert (2010) and are briefly summarized here.

After disturbance polygons were created by LandTrendr, the next step was to validate whether a change occurred in the polygon and document the agent of change (Table 2). Although we can confidently distinguish up to ten change agents during the validation process, for this report we have grouped these ten into six for ease of reporting (Table 3). If we are confident a disturbance did occur, but are unable to attribute a change agent, we use a disturbance agent of “unknown.”

To determine whether changes had occurred we used high resolution (≤ 1 m) imagery (air photo and satellite). Much of the imagery used for the U.S. portion was from the National Agriculture Imagery Program (NAIP), with a pixel resolution of 1 m. When validating disturbances in Canada where NAIP imagery was not available, we relied on satellite imagery from various satellites such as WorldView-1, WorldView-2, Quickbird, and GeoEye-1, with pixel resolutions ranging from 0.3 m to 1 m. Contextual information such as forest type, ownership, and drainage patterns were important for determining the disturbance agent and land cover classes. Lastly, we also viewed the entire Landsat image stack (1985–2017) for each prospective disturbance and a graph of the reflectance values through time (1985–2017) of said disturbance.

Table 2. Disturbance agents identified during manual validation in a GIS environment and how interpreters identify each.

Disturbance agent	Description and means of identification
Agriculture	Conversion of a non-agricultural land use/land cover type (e.g., forest, wetland) to an agricultural land use (row crops, pasture, hay).
Beaver	Landscape changes caused by beaver dams. Identified by flooding (i.e., presence of water) of wooded wetlands and the subsequent killing of trees.
Blowdown	The uprooting and tipping over of trees by wind. Blown down trees are evident in high resolution airphotos and are usually oriented in the direction of the wind event.
Development	Permanent conversion of vegetated surface to non-vegetated surface such as mines, paved roads, parking lots, buildings, and houses.
Fire	Detection is limited to instances where there is mortality in the overstory. Thus, areas in which fires only burn the understory are not delineated.
Forest harvest (light)	Most easily identified by the proximal presence of pervious roads and very linear features outlining the extent of the disturbance. This category of forest harvest has 60%–90% of the overstory remaining.
Forest harvest (moderate)	Same contextual information as forest harvest (light) however, this harvest category has 30%–59% of the overstory remaining.
Forest harvest (heavy)	Same contextual information as forest harvest (light) however, this harvest category has 0%–29% of the overstory remaining.
Insect/disease (defoliation)	Disturbances in the overstory due to insects or diseases that result in tree defoliation.
Insect/disease (mortality)	Disturbances in the overstory due to insects or diseases that result in tree mortality.
Other	This category is used when the interpreter is unable to determine the causal agent.

Table 3. Simplified disturbance agent groupings used in this report and the agents present in each group.

Disturbance agent grouping	Disturbance agents present in group
Development	Agriculture, development
Beaver	Beaver
Blowdown	Blowdown
Fire	Fire
Forest harvest	Forest harvest categories light, moderate, and heavy
Forest pathogen	Insect/disease defoliation and mortality
Other	Other

In a GIS environment, utilizing high resolution imagery, ancillary datasets, and the Landsat imagery itself, we validated a total of 30,516 LandTrendr-delineated disturbance polygons, removing all false positive (commission) polygons from the summary analysis. Since the analysis area contains a significant amount of water, disturbance area was computed as percentage of land area, excluding bodies of water as classified by the 2006 National Land Cover Database (Fry et al. 2011) and Earth Observation for Sustainable Development of Forests (EOSD) (Wulder et al. 2003).

Our validation workflow corroborates what has been shown in past studies (Cohen et al. 2010, Antonova et al. 2011), that on-screen validation of polygons with the aid of high spatial resolution imagery, high temporal resolution (yearly) Landsat imagery, and Landsat reflectance values is as good as any ancillary or ground-based validation method. The most obvious disturbances, such as forest clearcuts (forest harvest) and development, are the two main disturbances that can be field validated. However, they are also the disturbances most easily validated with high resolution imagery and/or Landsat imagery. More subtle or older disturbances are largely not possible to validate in the field due to logistical constraints (too remote to access) or because the evidence (e.g., insect/disease, low level forest harvests) has been masked by time (Cohen et al. 2010, Antonova et al. 2011).

Results

Disturbance Agent Summaries

Maps of disturbances

Here we present maps that show the location of disturbances in the analysis area by disturbance agent (Figures 6 and 7) and by year (Figure 8). Because the patches of some disturbance agents are small, we have exaggerated the polygons for beaver, blowdown, fire, and development. Due to the extremely large defoliation event that occurred in 2001, we have provided two maps of disturbances by agent, one including the defoliation (Figure 7) and one leaving the defoliation out (Figure 6). The defoliation event was caused by forest tent caterpillar and was well documented by the Forest Health Monitoring Division of the Ontario Ministry of Natural Resources. This outbreak was a defoliation event and to our knowledge did not cause any tree mortality. If we exclude the defoliation event, the most widespread and ubiquitous change agent was forest harvest, found nearly everywhere outside the park (Figure 7). In the northeast part of the analysis area in Ontario, there were many disturbances occurring in 2010 to 2015 (Figure 8). Inside the park, there was a very low level of disturbance overall (Figure 6). Of those that were detected, disturbances due to beaver were the most common (Figure 6). Disturbances due to fire and blowdown were the only remaining disturbances detected during the analysis period.

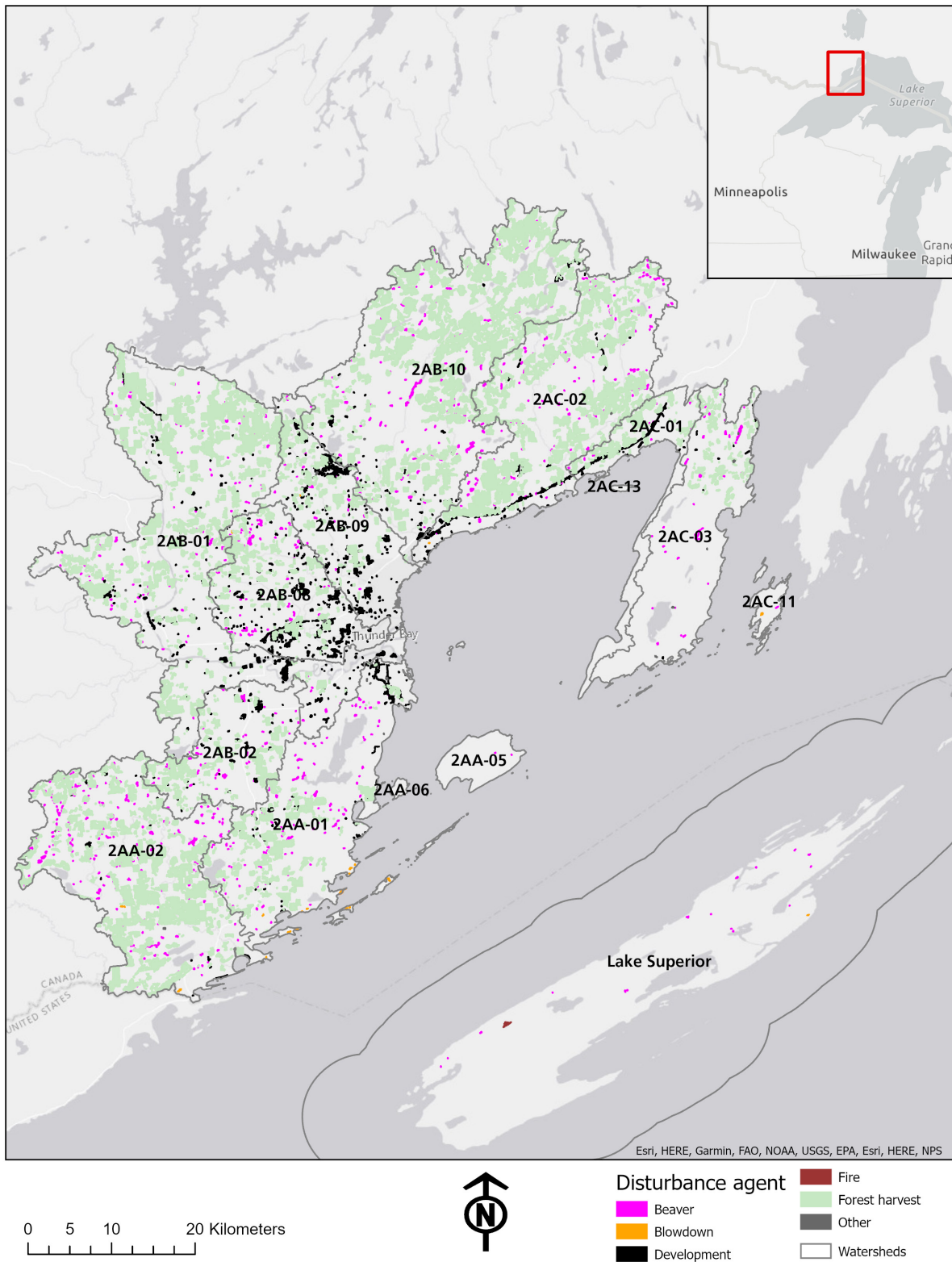


Figure 6. Spatial extent of disturbances on Isle Royale and a portion of the adjacent Canadian mainland, by disturbance agent, with watershed boundaries overlaid. This map does not include the forest pathogen agent because its extent in one year (2001) overwhelms the other categories. See Figure 7.

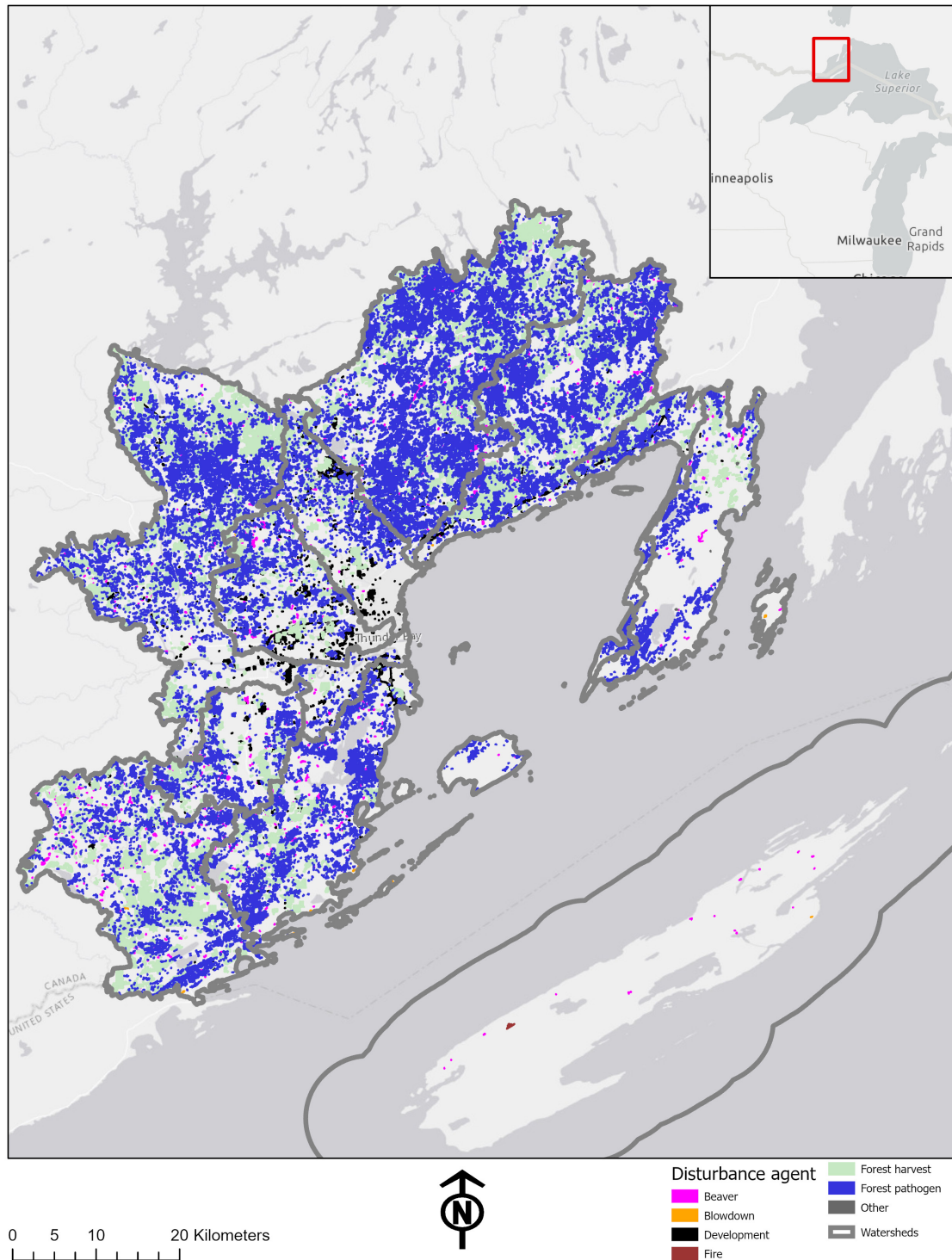


Figure 7. Spatial extent of disturbances on Isle Royale and a portion of the adjacent Canadian mainland, by disturbance agent, with watershed boundaries overlaid. This map includes the forest pathogen agent, which is primarily accounted for by one extremely large defoliation event in 2001.

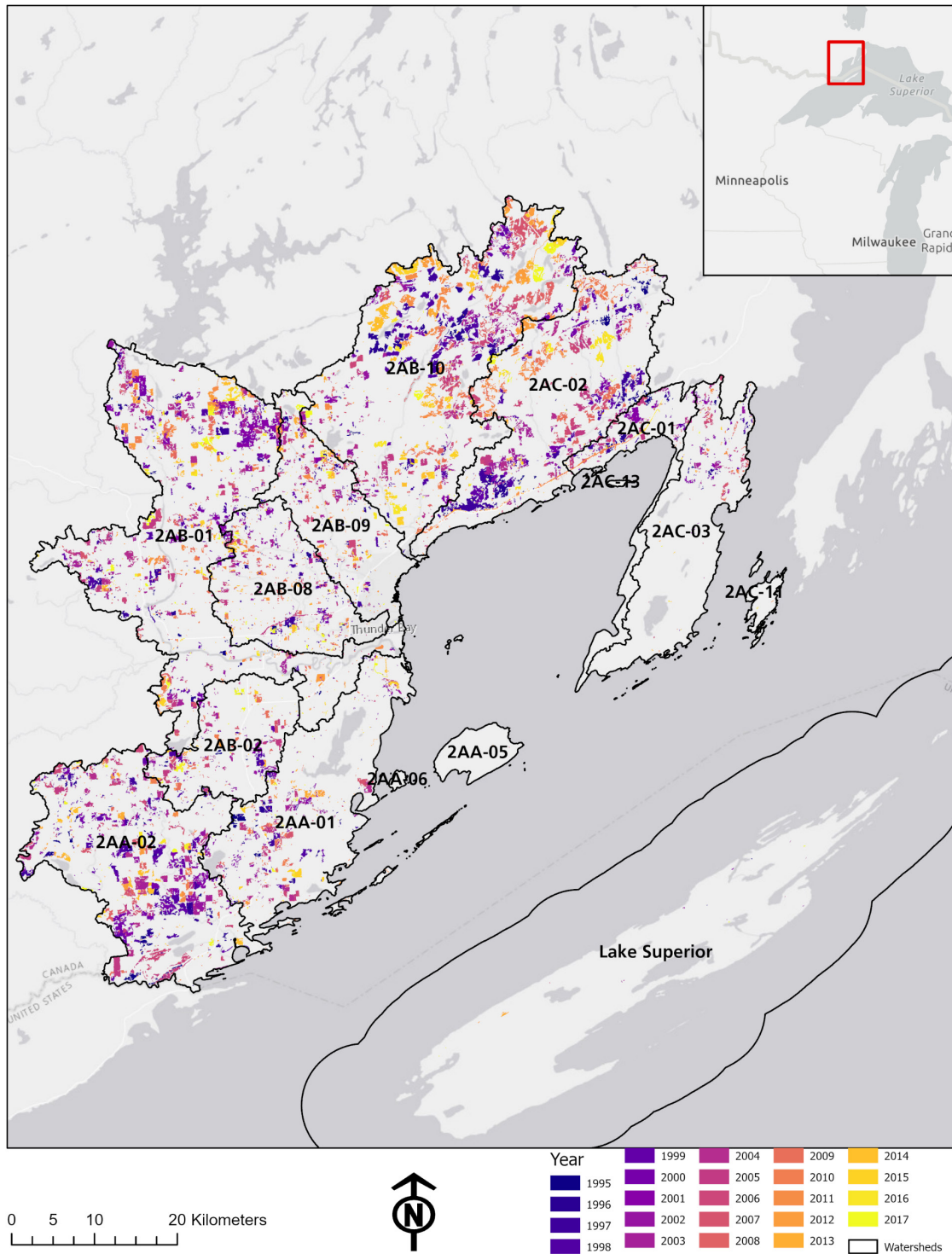


Figure 8. Disturbance patch locations on Isle Royale and a portion of the adjacent Canadian mainland, identified by year of onset, with watershed boundaries overlaid. This map does not include the forest pathogen event (defoliation) of 2001.

Inside vs. outside the park

Inside the park boundary, disturbances due to beaver disturbed the largest amount of land (0.04%, 20 ha) over the time period, followed closely by fire (0.03%, 15.80 ha) (Figure 9 and Table 4). Beaver was also the most consistent agent of change, occurring in just under half of the years in the analysis period. Disturbance due to fire was detected in only one year (2013), and a small amount of blowdown was detected in one year (2002) (Figure 9 and Table 4).

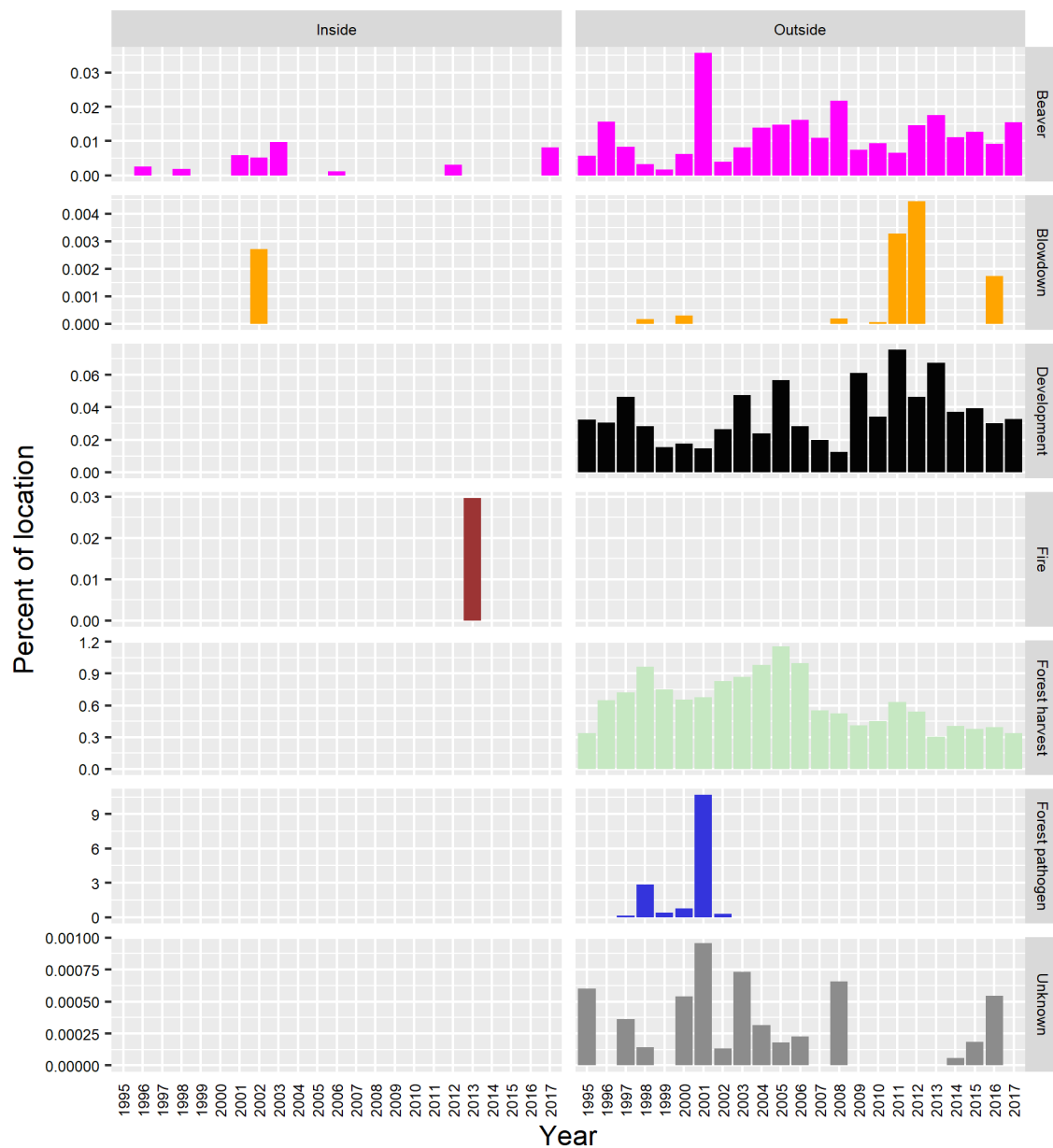


Figure 9. Percent of land disturbed inside and outside the park, by disturbance agent and year. Note: Y axis scale varies by disturbance agent.

Table 4. Total area (hectares) and percent of land disturbed *inside the park*, by disturbance agent, 1995–2017.

Disturbance agent	Area (ha)	Percent land disturbed
Beaver	20.02	0.04
Blowdown	1.44	<0.00
Fire	15.80	0.03
Forest harvest	0.00	0.00
Forest pathogen	0.00	0.00
Other	0.00	0.00

Outside the park, disturbance due to forest pathogen (defoliation) in 2001 disturbed the largest amount of land, with a total of just over 15% of land affected (Figure 9 and Table 5), although much of this type of disturbance occurred in one year. The disturbance agent that was the most prevalent through time was forest harvest. Land disturbed as a result of forest harvest totaled just over 52,000 ha, or 14.52% (average 0.63% per year) of the land area outside the park (Table 5). Prior to 2007, forest harvest averaged close to 0.8%/yr, while from 2007 to present it has averaged closer to 0.5%/yr (Figure 9). The next most prevalent agent of change was development, which disturbed a total of nearly 3,000 ha (average 136 ha/yr) during the analysis time period (Table 5) and was relatively consistent throughout the analysis time period (Figure 9). Lastly, disturbances due to beaver activity were present each year of the analysis period, although the overall percent of land disturbed was low (0.27% total land disturbed, 972 ha) (Figure 9 and Table 5).

Table 5. Total area (hectares) and percent of land disturbed *outside the park*, by disturbance agent, 1995–2017.

Disturbance agent	Area (ha)	Percent land disturbed
Beaver	971.89	0.27
Blowdown	36.54	0.01
Development	2,964.80	0.83
Fire	0.00	0.00
Forest harvest	52,129.53	14.52
Forest pathogen	53,970.90	15.03
Other	20.26	0.01

Watershed

There were 15 watersheds located within the study area, 14 of which were in Ontario and the remaining in Isle Royale NP (see Figure 2). Of the Ontario watersheds, 2AB-10 had the highest disturbance rates (24.38% of the land disturbed) during the analysis period (Figure 10 and Table 6). Forest harvest was the major disturbance agent present, and the amount disturbed was largely consistent through time. There were two years (1995 and 1997) where the percent of the watershed harvested was over 1.5% (Figure 10). The watershed with the second highest disturbance rate is 2AC-02 (which borders 2AB-10). Forest harvest was again the major disturbance agent in this watershed, and the forest harvest rates were more variable through time.

Other watersheds of note are 2AB-08 and 2AB-09 which experienced consistent disturbance due to development activities. These watersheds are northwest of Thunder Bay, and many of the development disturbances were the result of clearing land for new housing, both single dwelling and multi-unit housing. Another large development activity of note is the active expansion of a stone crushing pit operated by RA Milne, located in the northern part of watershed 2AB-09.

The watershed experiencing the lowest disturbance rate (excluding forest pathogen) was 2AC-13, a very small island to the northwest of the Sibley Peninsula (Figure 10).

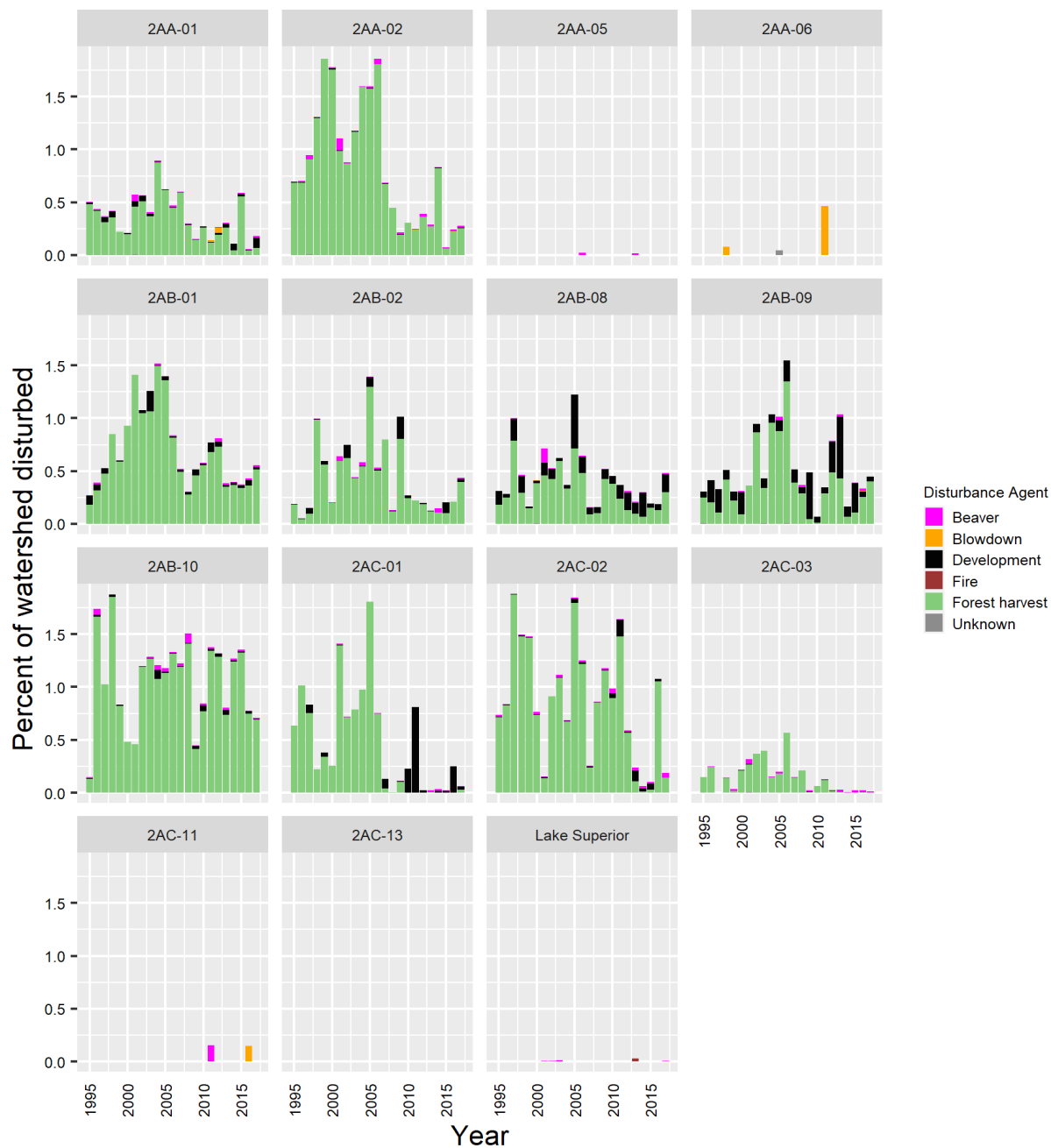


Figure 10. Percent of land disturbed within each watershed, by disturbance agent and year, 1995–2017. Note: forest pathogen is not included in this figure.

Table 6. Total percent and area of watershed disturbed, 1995–2017.

Watershed	Area (ha)	Percent land disturbed	Area (ha) (including forest pathogen)	Percent land disturbed (including forest pathogen)
2AA-01	2,963.66	8.65	8,329.19	24.31
2AA-02	8,917.29	19.49	13,591.47	29.71
2AA-05	1.64	0.04	180.38	4.30
2AA-06	4.65	0.59	7.62	0.97
2AB-01	11,502.10	16.71	21,316.04	30.97
2AB-02	1,867.12	10.28	3,768.25	20.74
2AB-08	2,352.09	10.08	4,722.67	20.24
2AB-09	2,655.23	12.46	4,481.50	21.03
2AB-10	15,042.71	24.38	29,654.71	48.05
2AC-01	1,167.33	11.50	3,068.93	30.24
2AC-02	8,750.20	20.34	17,836.49	41.47
2AC-03	893.87	3.48	3,128.56	12.19
2AC-11	5.13	0.30	6.48	0.38
2AC-13	0.00	0.00	1.62	1.16
Lake Superior	37.26	0.07	37.26	0.07

Ownership

The ownership category experiencing the greatest percent of land disturbed was Crown Land Unpatented, with 17% of the land being disturbed during the analysis period, followed closely by Patent Land External (15.49%) (Figure 11 and Table 7). Among the ownerships, disturbances due to beaver activity was the most consistent, present in most years and in all but the “Unknown” ownership type (Figure 11). The ownership experiencing the largest percent of land disturbed due to forest harvest (16.59%) was Crown Land Unpatented. Patent Land External followed closely behind, with 13.95% of land being disturbed by forest harvest (Figure 11). Lastly, disturbances due to development were mainly found on Native American and Patent Land External lands (Figure 11).

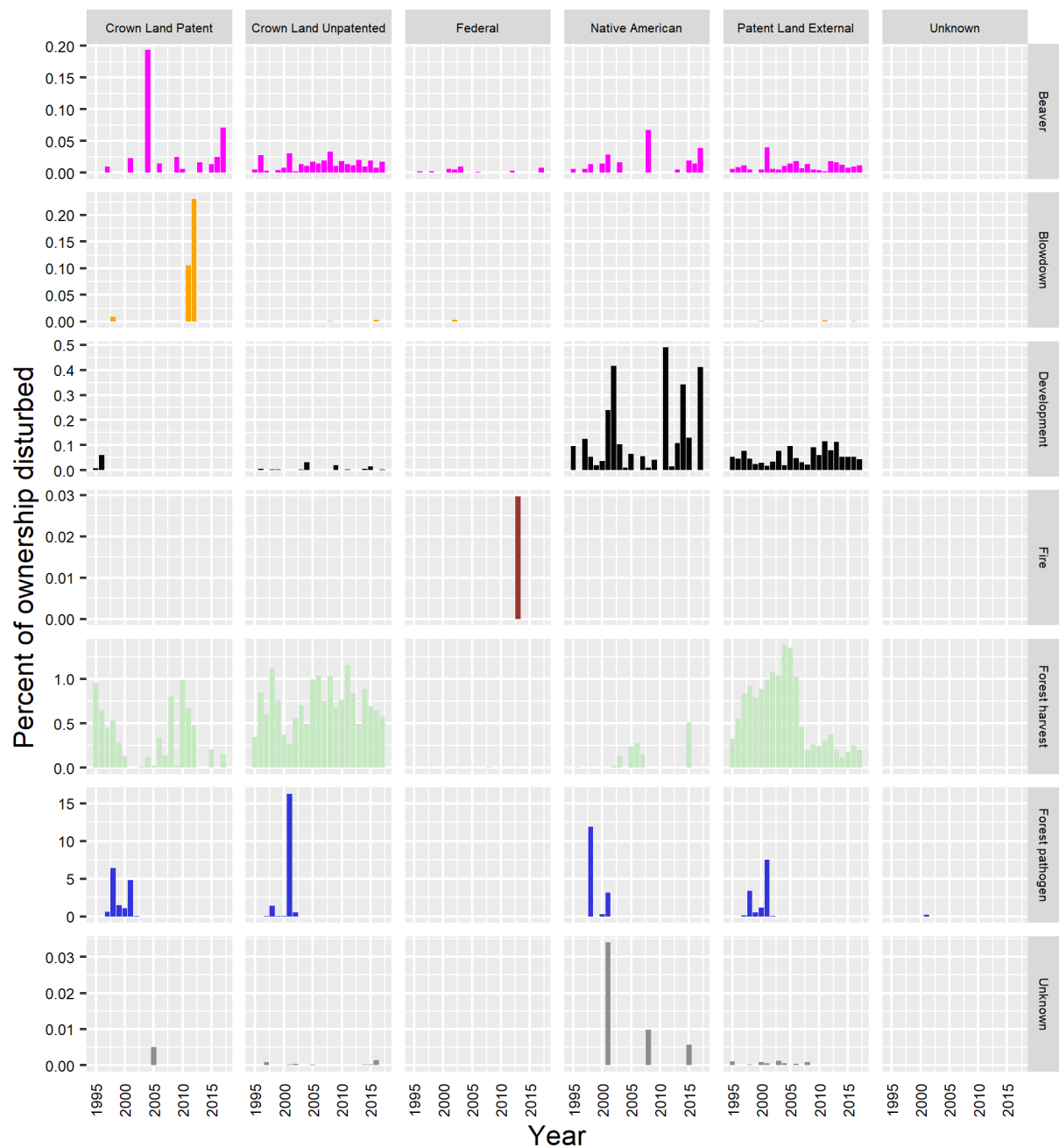


Figure 11. Percent of land disturbed within each watershed, by disturbance agent and year, 1995–2017. The upper and lower extents of the box indicate the 25th and 75th percentiles. Note: Y axis scale varies by disturbance agent.

Table 7. Total percent of land disturbed, by disturbance agent and ownership, 1995–2017. Note, this does not include forest pathogen.

Ownership	Percent land disturbed
Crown Land Patent	7.75
Crown Land Unpatented	17.02
Federal	0.08
Native American	4.38
Patent Land External	15.49
Unknown	0.00

Patch size

Not surprisingly, overall patch size is much larger outside the park (Figure 12). Outside the park, forest harvest disturbances were characterized by larger disturbances, with some reaching over 350 ha in size (Figure 12). There were also larger disturbances due to development, with the largest two being almost 125 ha in size. These two disturbances were the result of a gravel pit expansion north of Thunder Bay.

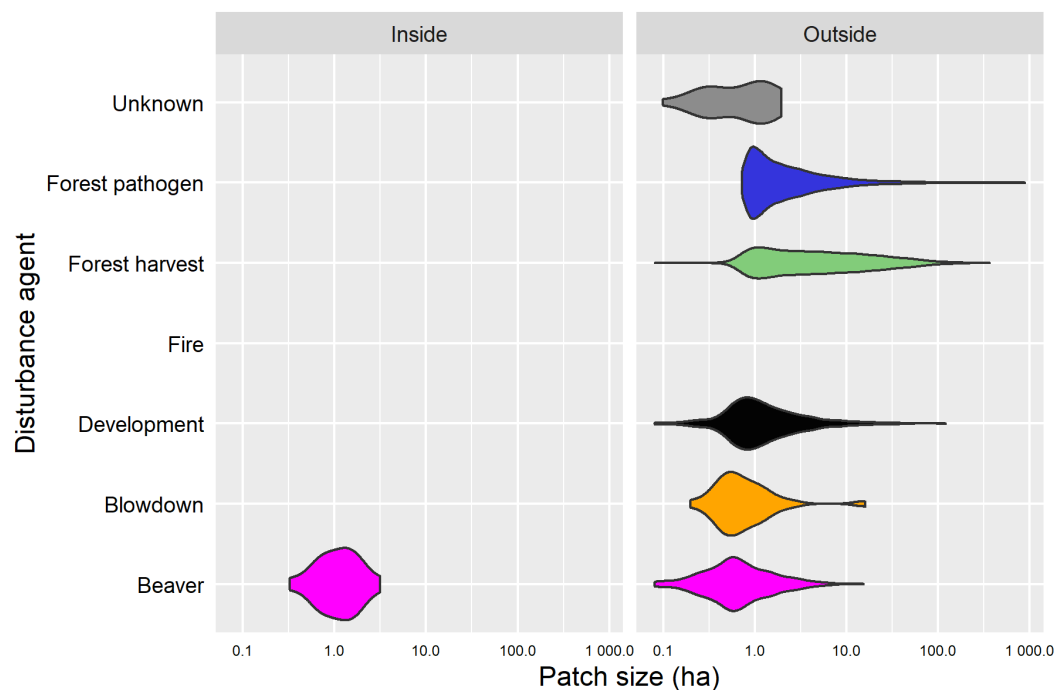


Figure 12. Violin plot displaying the patch size distribution of disturbances by disturbance agent inside and outside the park, 1995–2017. The height of the violin indicates larger numbers of patches at a given size, and the ends of the violin indicate the minimum and maximum patch size. Note: X axis is on log10 scale.

Comparison among GLKN parks

Compared to other parks monitored as part of this protocol, ISRO has low rates of disturbance inside the park (Figure 13). However, outside the park, ISRO has forest harvest disturbance rates similar to that of Apostle Islands National Lakeshore, Pictured Rocks National Lakeshore, Sleeping Bear Dunes National Lakeshore, and Voyageurs National Park. Rates of beaver disturbance outside the park were similar to those found outside Voyageurs National Park and were the second highest among network parks (Figure 13).

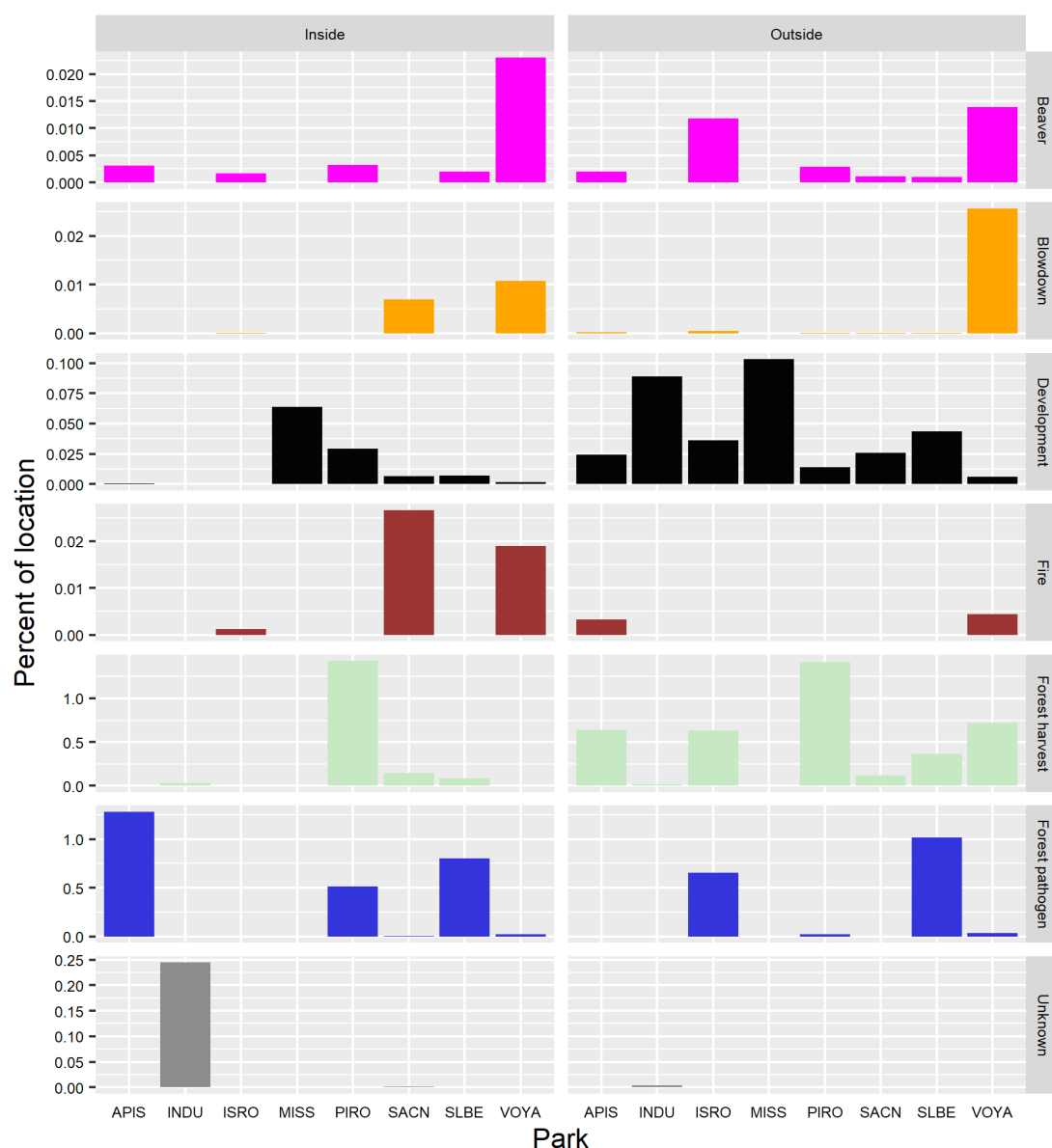


Figure 13. Yearly average percent of land disturbed inside and outside eight Great Lakes Network national parks, by disturbance agent, 1995–2017. Note: Y axis scale varies by disturbance agent. APIS=Apostle Islands, INDU=Indiana Dunes, ISRO=Isle Royale, MISS=Mississippi National River and Recreation Area, PIRO=Pictured Rocks, SACN=St. Croix National Scenic Riverway, SLBE=Sleeping Bear Dunes, VOYA=Voyageurs.

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Appendix A. Area Disturbed Inside Isle Royale National Park, 1995–2017.

Table A1. Area (in hectares) disturbed inside Isle Royale National Park during the analysis period (1995–2017).

Year	Area (ha) by Disturbance Agent						
	<i>Beaver</i>	<i>Blowdown</i>	<i>Development</i>	<i>Fire</i>	<i>Forest harvest</i>	<i>Forest pathogen</i>	<i>Unknown</i>
1995	0	0	0	0	0	0	0
1996	1	0	0	0	0	0	0
1997	0	0	0	0	0	0	0
1998	1	0	0	0	0	0	0
1999	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0
2001	3	0	0	0	0	0	0
2002	3	1	0	0	0	0	0
2003	5	0	0	0	0	0	0
2004	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0
2006	1	0	0	0	0	0	0
2007	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0
2012	2	0	0	0	0	0	0
2013	0	0	0	16	0	0	0
2014	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0
2017	4	0	0	0	0	0	0

Table A2. Area (in hectares) disturbed outside Isle Royale National Park during the analysis period (1995–2017).

Year	Area (ha) by Disturbance Agent						
	<i>Beaver</i>	<i>Blowdown</i>	<i>Development</i>	<i>Fire</i>	<i>Forest harvest</i>	<i>Forest pathogen</i>	<i>Unknown</i>
1995	21	0	116	0	1,219	0	2
1996	56	0	110	0	2,334	0	0
1997	30	0	167	0	2,584	421	1
1998	12	1	101	0	3,469	10,184	1
1999	6	0	56	0	2,688	1,330	0
2000	22	1	63	0	2,344	2,649	2
2001	128	0	53	0	2,419	38,415	3
2002	14	0	96	0	2,985	967	0
2003	29	0	170	0	3,115	0	3
2004	50	0	86	0	3,530	0	1
2005	53	0	204	0	4,158	0	1
2006	58	0	102	0	3,587	0	1
2007	40	0	71	0	1,975	0	0
2008	78	1	44	0	1,887	0	2
2009	27	0	219	0	1,469	0	0
2010	34	0	123	0	1,625	0	0
2011	24	12	271	0	2,265	0	0
2012	53	16	167	0	1,943	0	0
2013	63	0	242	0	1,095	0	0
2014	40	0	134	0	1,464	0	0
2015	46	0	141	0	1,359	3	1
2016	33	6	109	0	1,405	0	2
2017	55	0	117	0	1,209	0	0

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