



Landsat-based Monitoring of Landscape Dynamics at Apostle Islands National Lakeshore *1990–2018*

Natural Resource Data Series NPS/GLKN/NRDS—2022/1346



ON THE COVER

Photo of the southwest portion of Oak Island showing some of the area of blowdown that occurred in the park in the summer of 2020. Image from WorldView satellite.

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Alan A. Kirschbaum

National Park Service
Great Lakes Inventory and Monitoring Network
2800 Lakeshore Drive East
Ashland, Wisconsin 54806

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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 in 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 Apostle Islands National Lakeshore 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 Apostle Islands NL and varies slightly from the original report published in 2012 in terms of analysis area and the time period analyzed. The analysis area outside the park was expanded by including the entire Sand River, Fish Creek, White River, and Bad River watersheds. The time period analyzed has also increased by 23 years, from 2004–2009 (6 years) to 1990–2018 (29 years). Results of this updated analysis showed that disturbances inside the park due to forest pathogen defoliation affected the largest amount of land (91.31 ha), followed by blowdown (43.21 ha), with beaver and development being the only remaining disturbances detected inside the park (12.98 ha and 3.08 ha, respectively). Lands adjacent to the park in Bayfield, Ashland, and Iron counties, experienced far greater levels of disturbance, with forest pathogen (defoliation) accounting for half of the land disturbed outside the park (48,059 ha, or 1,657 ha per year). The second most prevalent disturbance agent outside the park was forest harvest, with 45,934 ha disturbed (average 1,583 ha per year) during the 29-year analysis period. Long-term monitoring of this analysis area will contribute to our understanding of how these disturbances may affect water quality of Lake Superior, spawning habitat in tributaries, and wildlife movement to the islands.

Introduction

Reported here are disturbances for Apostle Islands National Lakeshore (APIS) 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). The first report for APIS was published in 2012, which summarized disturbances for a smaller analysis area and shorter time period (Kirschbaum et al. 2012). Here, disturbances occurring between 1990 and 2018 (29 years) are summarized.

Methods

Study Area

The analysis was conducted inside and adjacent to Apostle Islands National Lakeshore (APIS). The analysis area extended into three counties in northern Wisconsin (Figure 1). In total 304,277 ha of land was monitored, of which 16,572 ha was land inside APIS. Included in the analysis area are five watersheds as defined by level 10 delineations of the National Hydrography Dataset's Hydrologic Unit Code (HUC) (nhd.usgs.gov) (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) (Figures 3 and 4).

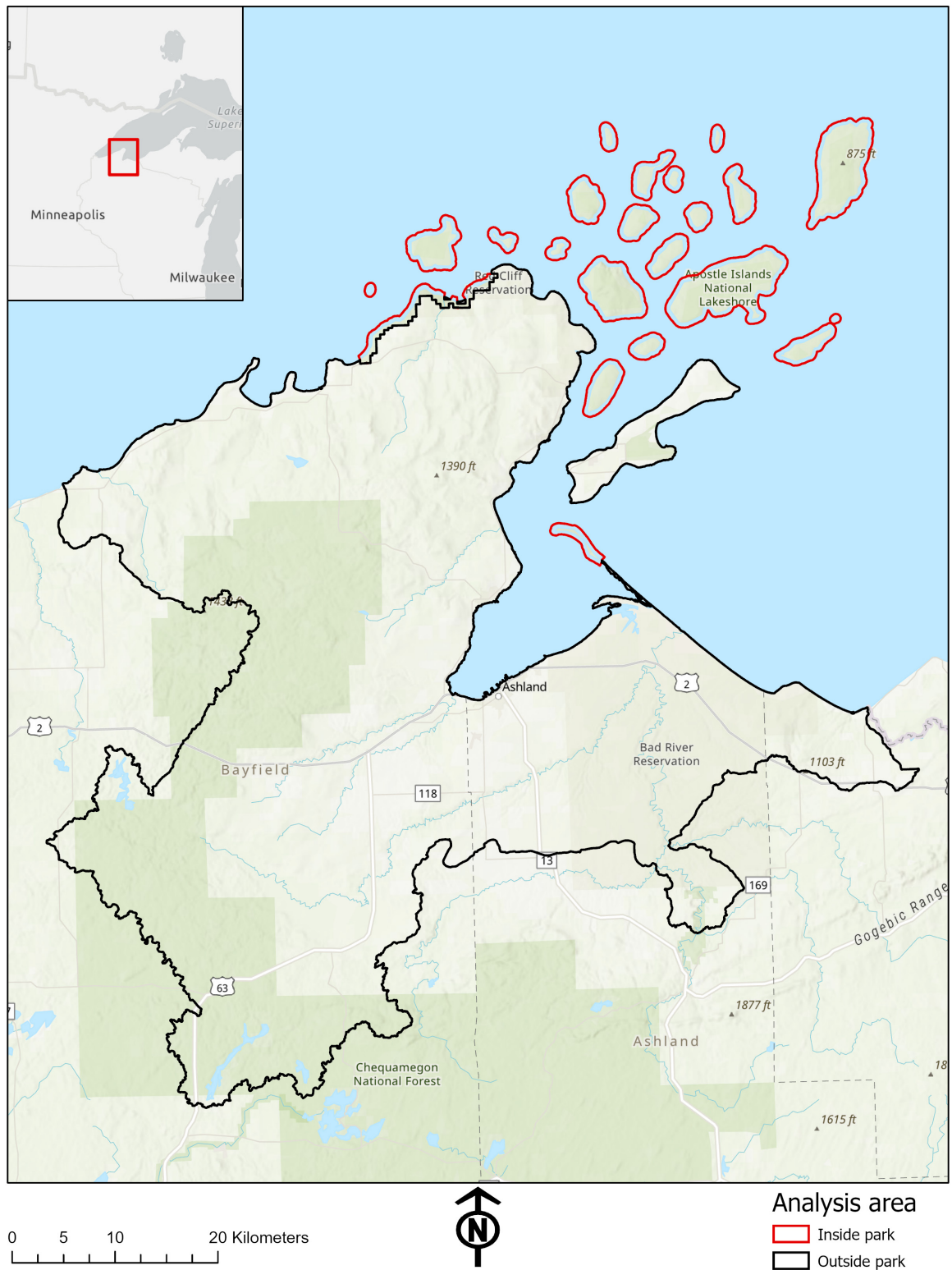


Figure 1. Analysis area for monitoring landscape dynamics in the greater Apostle Islands National Lakeshore ecosystem. Red outline indicates park extent and black outline indicates area monitored outside the park in Ashland, Bayfield, and Iron counties.

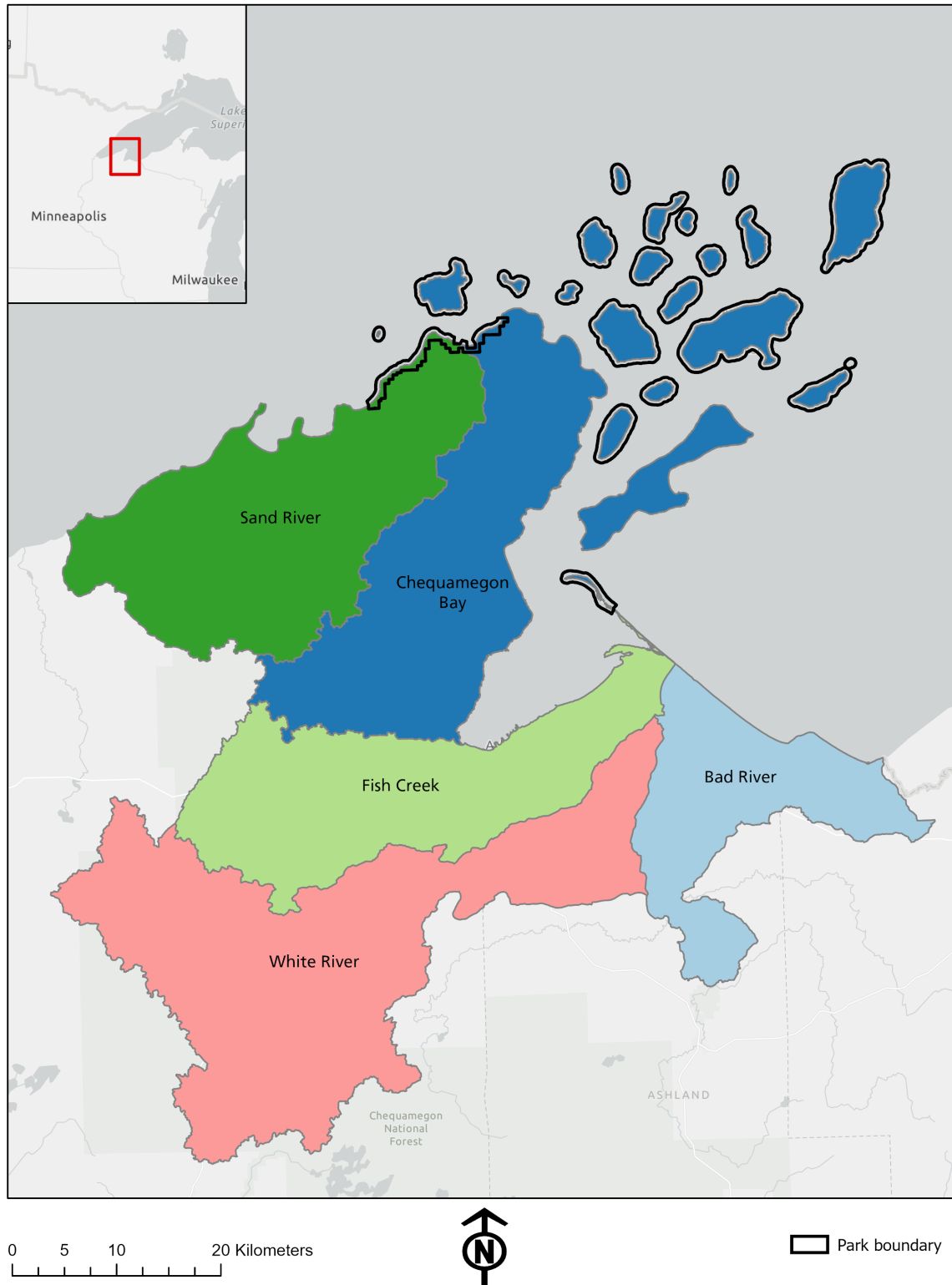


Figure 2. Labeled watersheds included in this analysis, as defined by level 10 Hydrologic Unit Codes (HUCs).

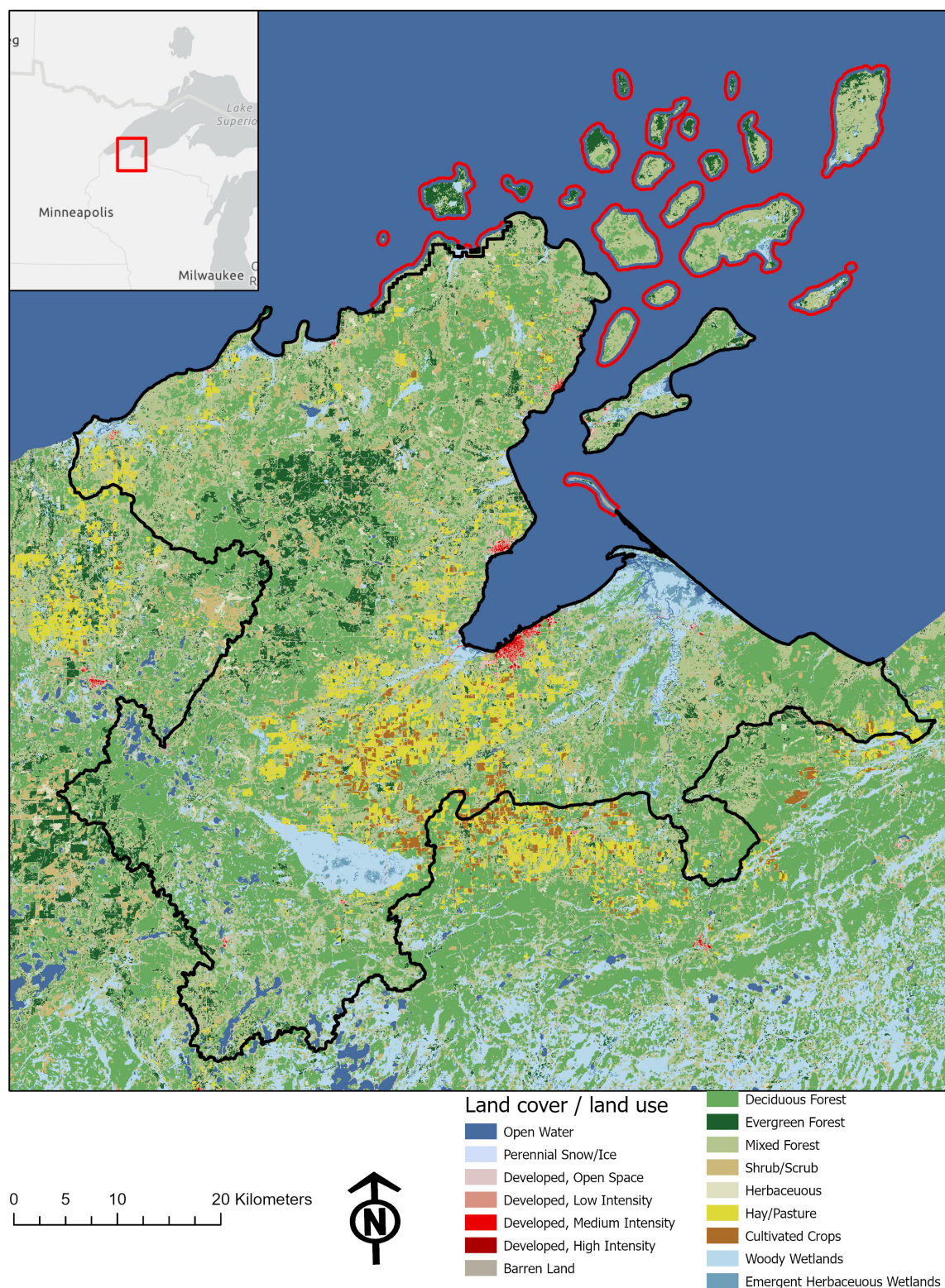


Figure 3. Land cover and land use classes in the analysis area, as mapped by the National Land Cover Database (Dewitz 2019).

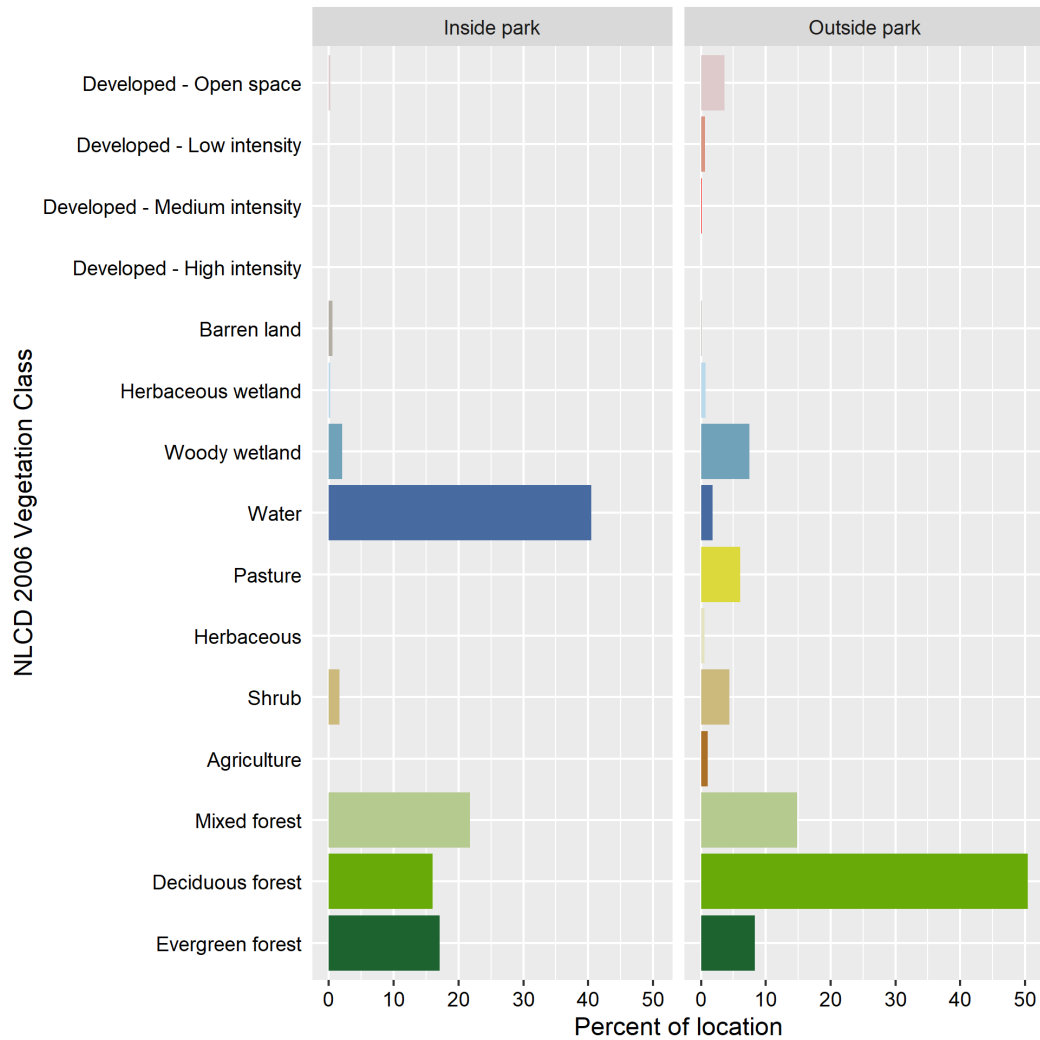


Figure 4. Percent of each land cover and land use class in the analysis area, as mapped by the National Land Cover Database (Dewitz 2019).

Ownership

Ownership within the analysis area was obtained from the Wisconsin Statewide Parcel Initiative (<https://www.sco.wisc.edu/parcels/data/>) (Figure 5). Most land was privately held (45%), followed by federal (27%), county (13%) and Native American (10%) (Table 1). The remaining 6% of land was in state and private industrial ownership. Federal ownership is split between the National Park Service and the U.S. Forest Service.

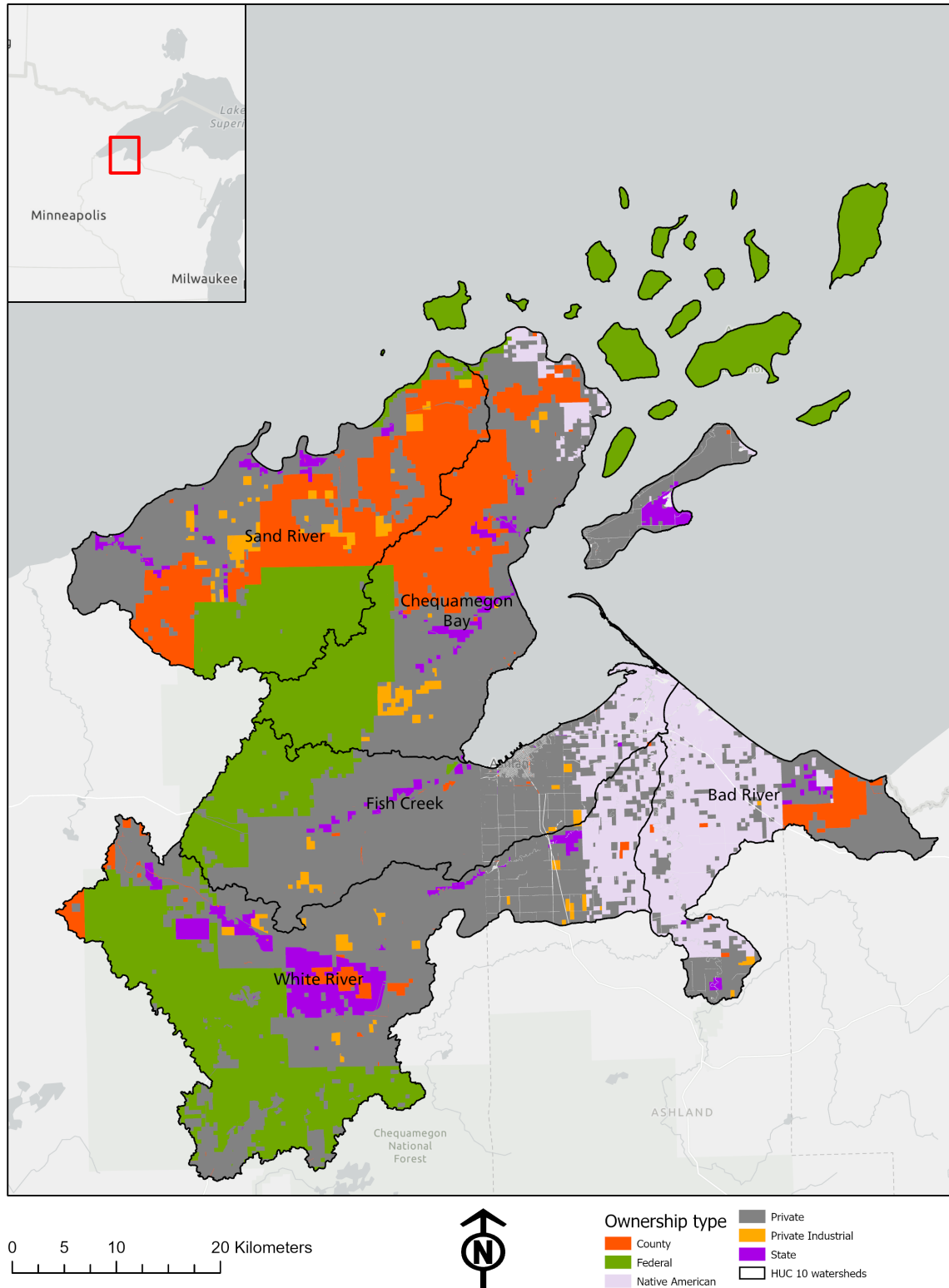


Figure 5. Ownership within the analysis area overlaid with HUC 10 watershed boundaries and labels. Ownership data was obtained from the Wisconsin Statewide Parcel Initiative (version 6).

Table 1. Ownership within the analysis area. Ownership data from the Wisconsin Statewide Parcel Initiative, version 6.

Ownership	Area (ha)	Percent of Land
County	40,072	13
Federal	80,405	27
Native American	31,290	10
Private	134,631	45
Private Industrial	5,345	2
State	10,651	4

Disturbance Detection Methodology

A set of processing and analysis steps collectively known as LandTrendr (Kennedy et al. 2010a, Kennedy et al. 2010b, Kennedy et al. 2012) were used. 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). Only changes are reported on in this analysis, where and when they occur.

To minimize effects of phenological variation, Landsat images between July and September of each year (1984–2018) were selected. 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. Therefore, an ensemble composite index (ENC) was used, 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

Every (census) disturbance polygon that was generated by LandTrendr was validated to remove commission errors (false positives) and at the same time determine the change agent. If a polygon spanned boundaries (watershed, ownership), the polygon with the majority of the polygon represented was attributed. 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). Up to ten change agents can be confidently distinguished during the validation process, but those ten were grouped into six for ease of reporting (Table 3). Disturbances known to have occurred but for which a change agent could not be attributed were classified as “unknown.” See Table B1 in Appendix B to view all fields filled out during the validation process.

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

High resolution (≤ 1 m) imagery (air photo and satellite) was used to determine whether changes had occurred. Much of the imagery used was from the National Agriculture Imagery Program (NAIP), with a pixel resolution of 1 m. Contextual information such as forest type, ownership, and drainage patterns were important for determining the disturbance agent and land cover classes. The entire Landsat image stack (1985–2018) for each prospective disturbance was also viewed, along with a graph of the reflectance values through time (1985–2018) of said disturbance.

In a GIS environment, utilizing high resolution imagery, ancillary datasets, and the Landsat imagery itself, a total of 34,234 LandTrendr-delineated disturbance polygons were validated, 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).

This 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

Maps presented below 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, the polygons for beaver, blowdown, fire, and development have been exaggerated. Due to the extremely large defoliation event that occurred in 2001, two maps of disturbances by agent are provided, one omitting the defoliation (Figure 6) and one including the defoliation (Figure 7). The defoliation event was caused by forest tent caterpillar and was well documented by the Wisconsin Department of Natural Resources (<https://dnr.wisconsin.gov/topic/foresthealth/forettent>). It does not appear to have caused any tree mortality. Excluding the defoliation event, the most widespread and ubiquitous change agent was forest harvest, found nearly everywhere outside the park and occurring more commonly in the heavily forested and closely managed lands on the Bayfield Peninsula (Figure 7). In the southern portion of the analysis area where agricultural land use is dominant, disturbances due to beaver and development were more common. Disturbance due to development activities were found throughout the analysis area but more prevalent outside the towns of Ashland, Washburn, and Bayfield. Inside the park, there was a very low level of disturbance overall (Figure 7). Of those that were detected, disturbances due to forest pathogen were the most common (Figure 7). The remaining disturbance agents found inside the park were blowdown, beaver, and development. Disturbances were detected on Sand, Oak, Stockton, Outer, Michigan, Basswood, and Hermit islands. A blowdown event in the summer of 2020 affected portions of Sand and Oak islands, but this was not detected during analysis because it was outside the analysis period. There do seem to be fewer disturbances occurring in the lower White River and Bad River watersheds in recent years (Figure 8).

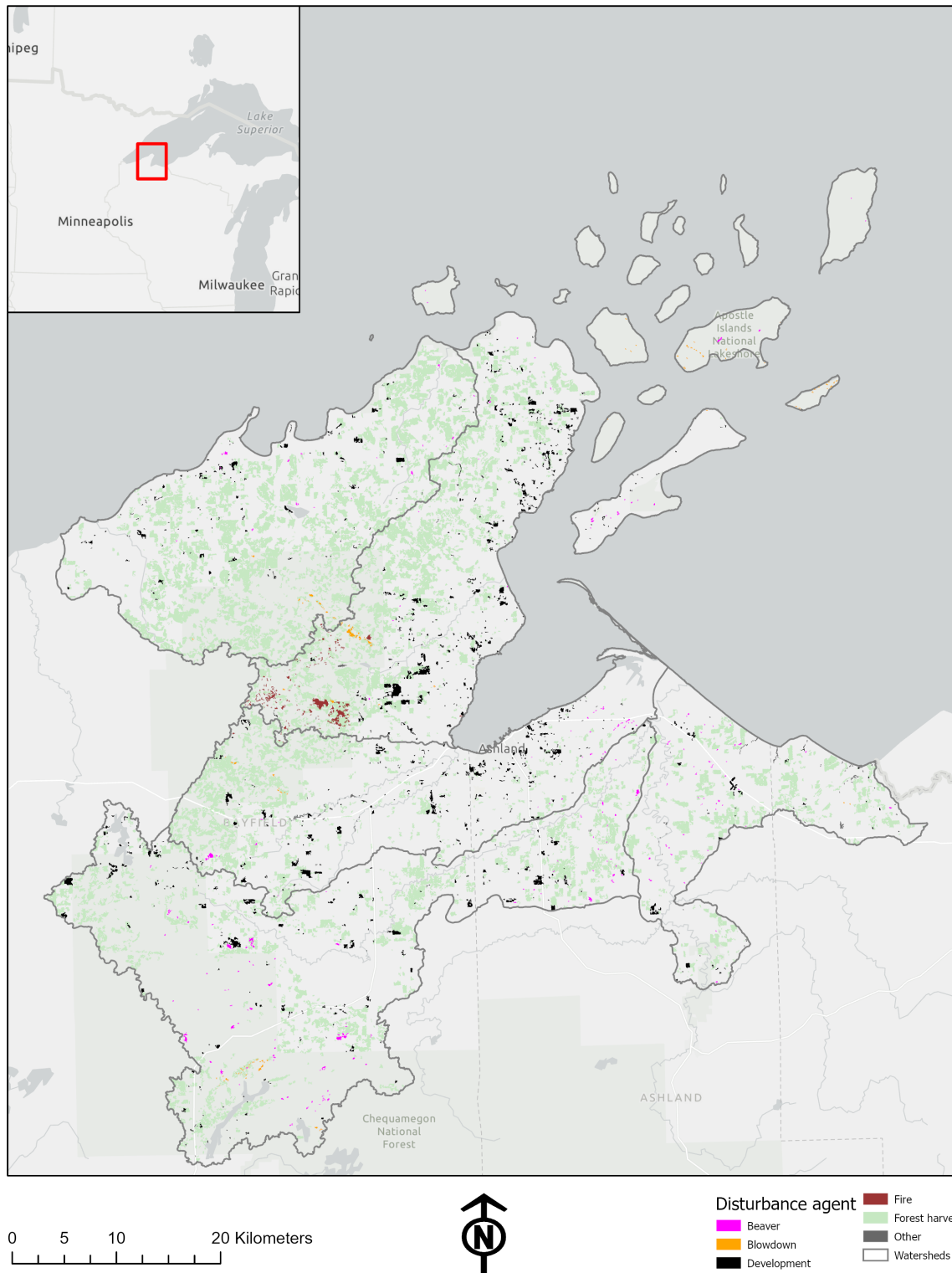


Figure 6. Spatial extent of disturbances within the analysis area for Apostle Islands National Lakeshore, by disturbance agent, with watershed boundaries overlaid. This map does not include the forest pathogen agent because its extent in one year (2001) overwhelms the other categories.

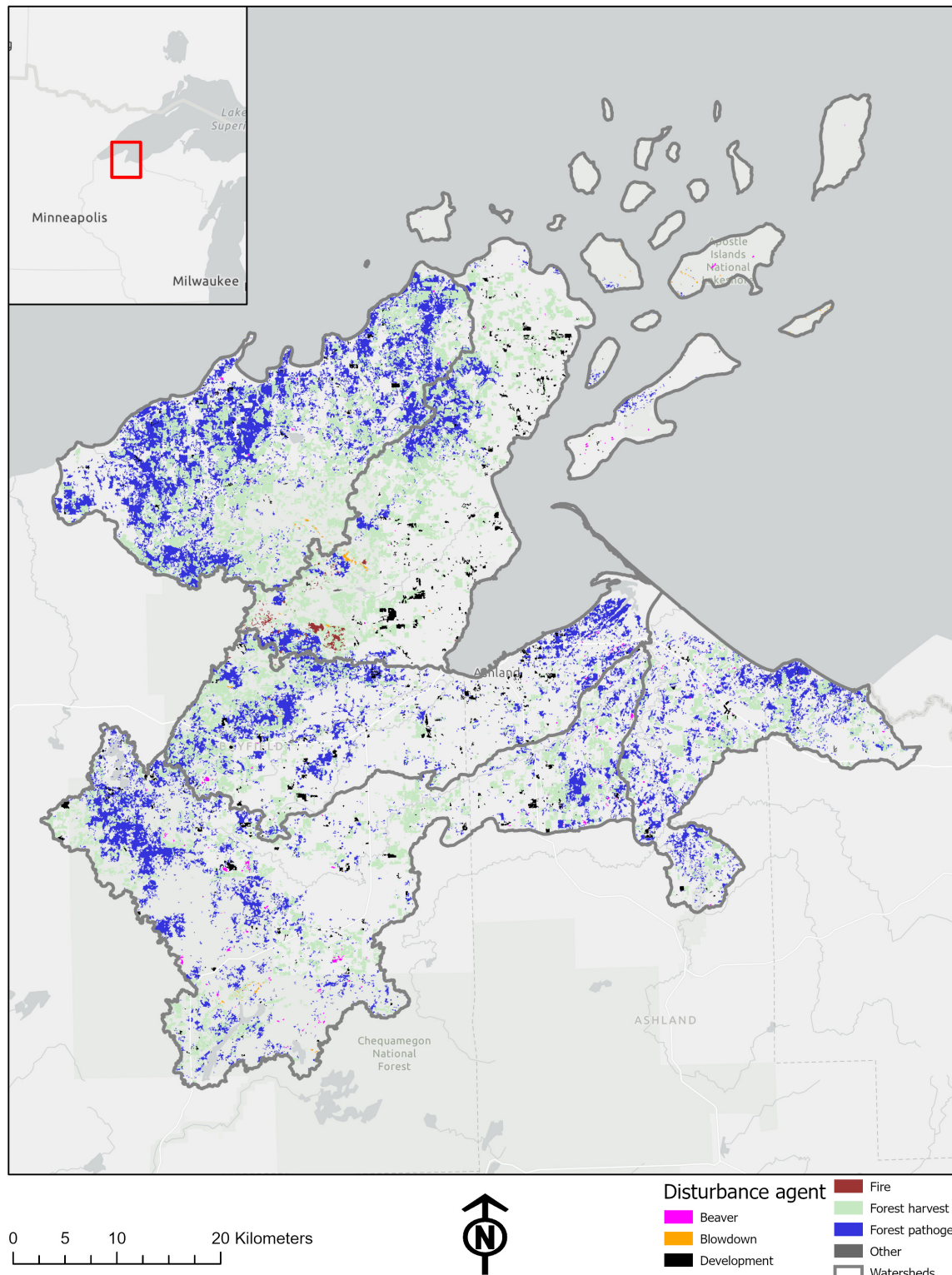


Figure 7. Spatial extent of disturbances within the analysis area for Apostle Islands National Lakeshore, by disturbance agent, with watershed boundaries overlaid. This map includes the forest pathogen agent, which is primarily accounted for by one extremely large defoliation event in 2001.

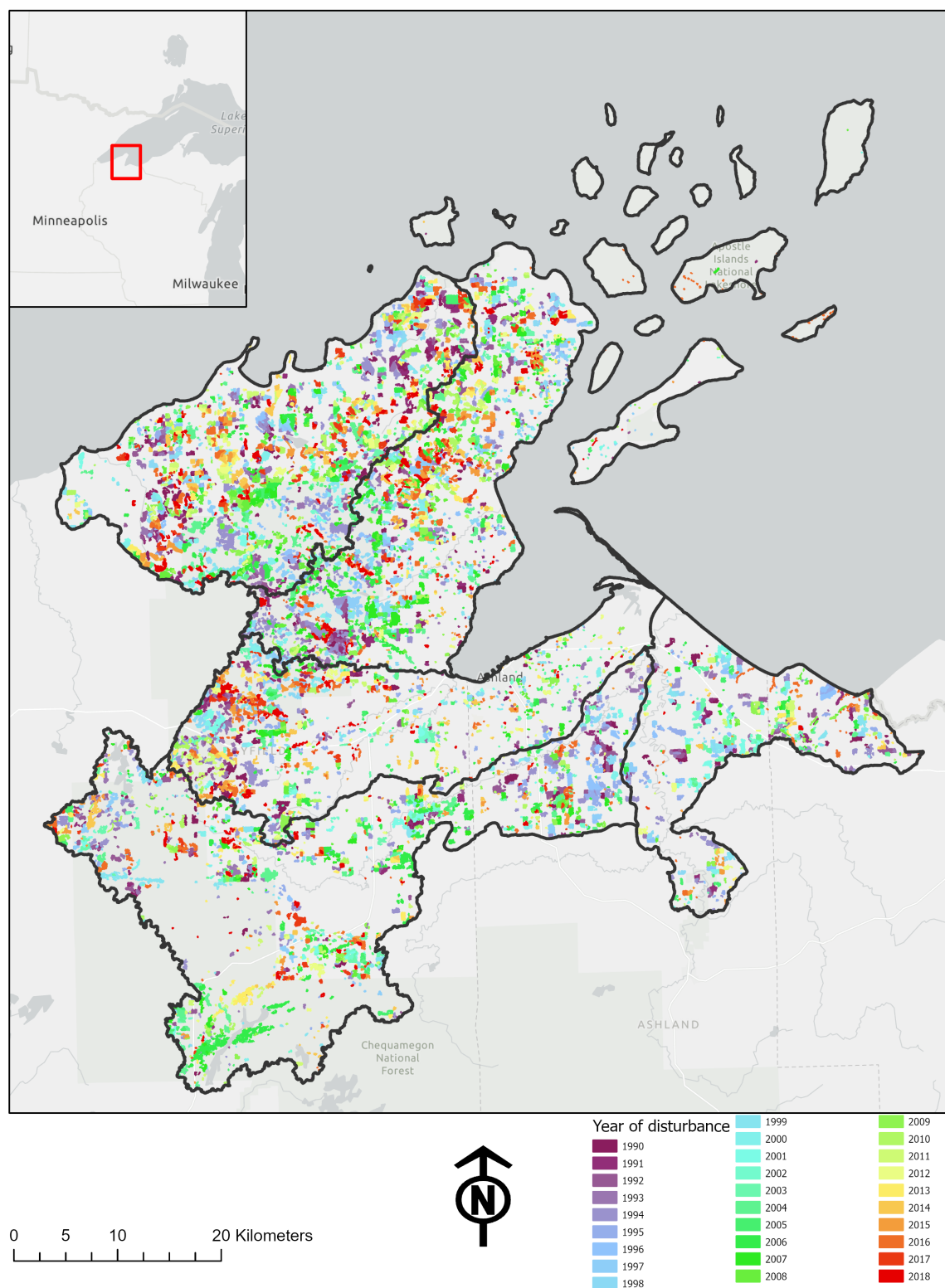


Figure 8. Spatial extent of disturbances within the analysis area for Apostile Islands National Lakeshore, identified by year of onset, with watershed boundaries overlaid. Polygon areas are exaggerated in this map to be large enough to be discerned at this scale. This map does not include the forest pathogen event (defoliation) of 2001.

Inside vs. outside the park

Inside the park boundary, forest pathogen disturbed the largest amount of land (0.55%, 91.31 ha) over the period, followed by blowdown (0.26%, 43.21 ha) (Figure 9 and Table 4). The blowdown event occurred in the summer of 2016 and affected Oak, Stockton, Michigan, and Basswood islands. Beaver disturbances were detected in multiple years, affecting almost 13 ha of land over the analysis period (Table 4). Lastly, development activity occurred within the park boundary at Little Sand Bay (Figure 6 and Table 4).

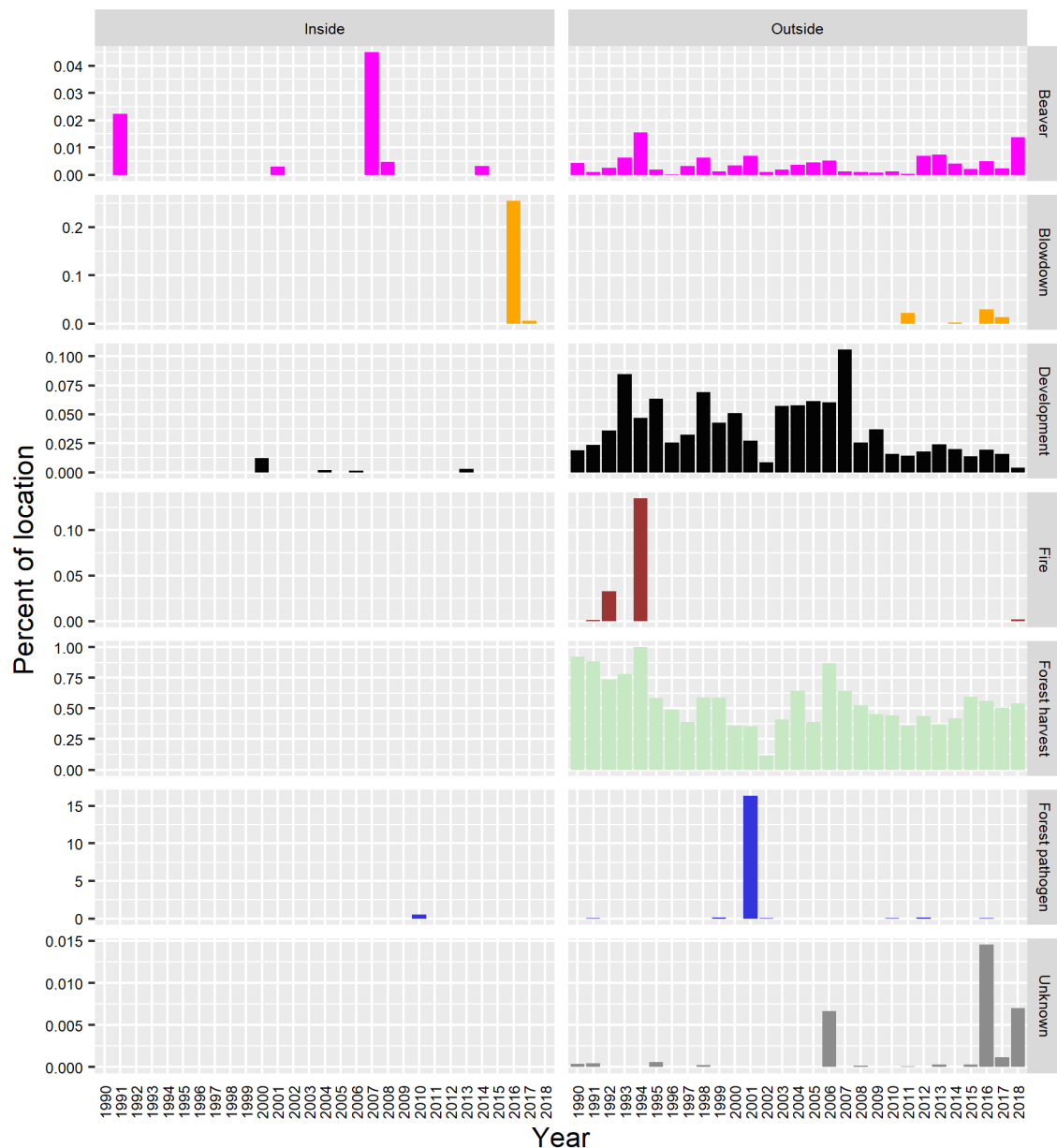


Figure 9. Percent of land disturbed inside and outside the park, by disturbance agent and year. Note: Y axis scale varies by disturbance agent.

Table 4. Total area (hectares) and percent of land disturbed *inside the park*, by disturbance agent, 1990–2018.

Disturbance Agent	Area (ha)	Percent Land Disturbed
Beaver	12.98	0.08
Blowdown	43.21	0.26
Development	3.08	0.02
Fire	0.00	0.00
Forest harvest	0.00	0.00
Forest pathogen	91.31	0.55
Unknown	0.00	0.00

Outside the park, disturbance due to forest pathogen (defoliation) affected the largest amount of land, with a total of just over 16% of land affected (Figure 9 and Table 5) and occurred almost exclusively in one year (2001). The disturbance agent that was the most prevalent through time was forest harvest. Land disturbed due to forest harvest totaled nearly 46,000 ha, or 15.97% (average 0.55% per year) of the land area outside the park (Table 5). The next most prevalent agent of change was development, which disturbed a total of just over 3,000 ha (average 107 ha/yr) during the analysis period (Table 5). Since 2008, the yearly average is 54 ha, half of the long-term average. Lastly, disturbances due to beaver activity were present in each year of the analysis period, although the overall percent of land disturbed was low (0.12% total land disturbed, 11.56 ha/yr) (Figure 9 and Table 5).

Table 5. Total area (hectares) and percent of land disturbed *outside the park*, by disturbance agent, 1990–2018.

Disturbance Agent	Area (ha)	Percent Land Disturbed
Beaver	335.25	0.12
Blowdown	194.01	0.07
Development	3,104.16	1.08
Fire	489.33	0.17
Forest harvest	45,934.62	15.97
Forest pathogen	48,059.25	16.70
Other	92.22	0.03

Watershed

There were five watersheds located within the study area (see Figure 2), with the park intersecting two of those (Sand and Chequamegon Bay). Of the watersheds, Sand River had the highest disturbance rates (25.32% 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. This watershed is largely comprised of public (county and federal) ownership types as well (see Figure 5). The watershed with the second highest disturbance rate was Chequamegon Bay. Forest harvest was again the major disturbance agent in this watershed with a higher rate of development disturbances than the Sand River watershed.

The remaining three watersheds (Bad River, Fish Creek, and White River) all experienced similar rates of disturbance (Figure 10, Table 6). In the Bad River watershed, an average of 213 ha of forest harvest occurred from 1990 through 2003. Since 2003 forest harvest has averaged 67 ha, roughly a third of the long-term average. The White River watershed experienced the most disturbance due to beaver (Figure 10) with most of the disturbances occurring in the upper reaches of the watershed (see Figure 6).

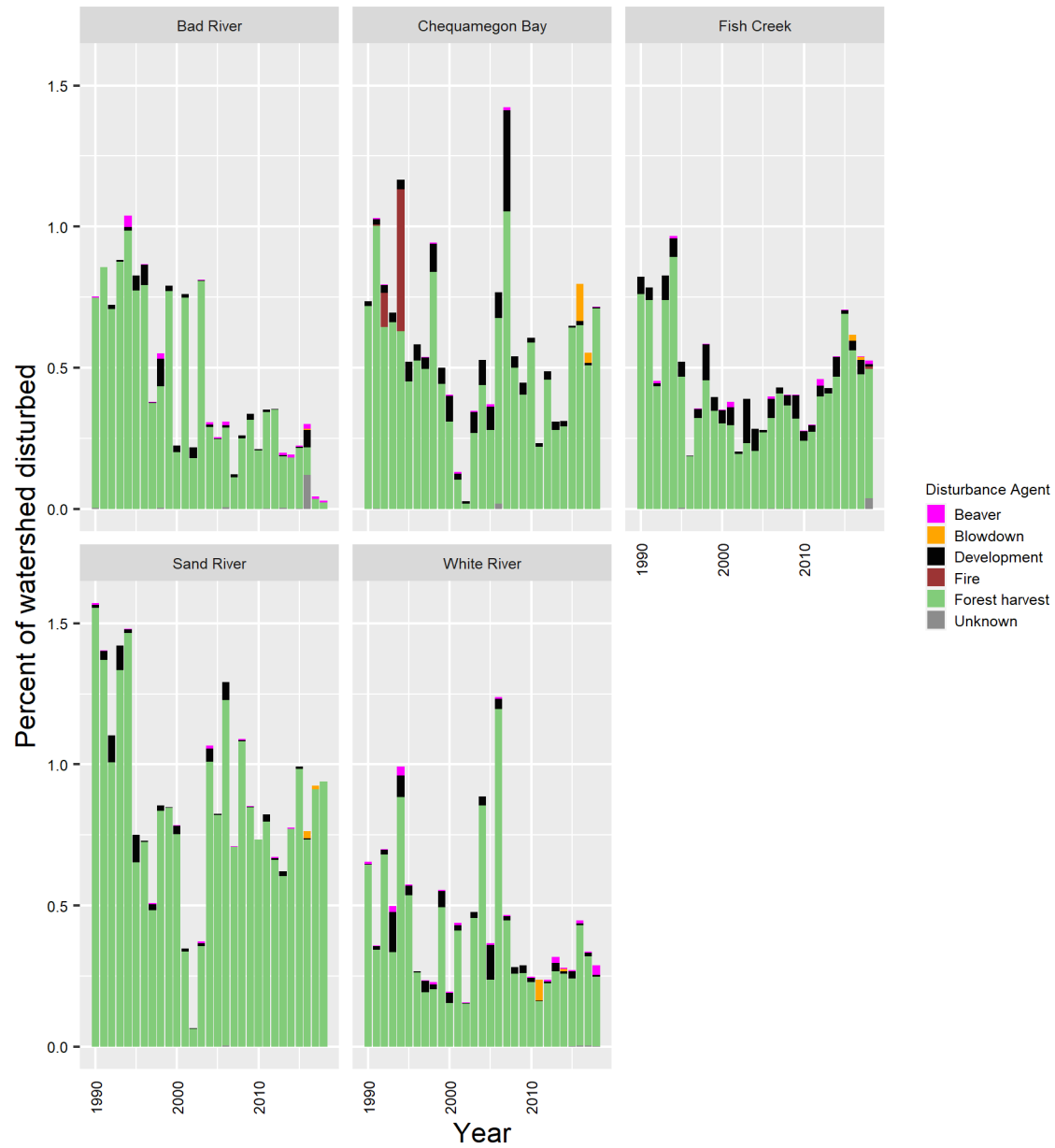


Figure 10. Percent of land disturbed within each watershed, by disturbance agent and year, 1990–2018.
Note: forest pathogen is not included in this figure.

Table 6. Total area and percentage of watershed disturbed, 1990–2018.

Watershed	Excluding Forest Pathogen		Including Forest Pathogen	
	Area (ha)	Percent	Area (ha)	Percent
Bad River	4,258.12	13.17	9,784.13	30.27
Chequamegon Bay	13,242.50	17.16	19,873.90	25.75
Fish Creek	7,001.53	13.81	14,766.72	29.12
Sand River	15,231.35	25.32	32,597.54	54.19
White River	10,475.36	12.52	21,337.12	25.50

Ownership

The ownership category experiencing the greatest percent of land disturbed was private industrial, with 40% of land in private industrial ownership being disturbed during the analysis period (Table 7 and Figure 11). Most of the disturbance in this ownership category was from forest harvest, which varied substantially through the analysis time period. County-owned lands experienced the next highest amount of disturbance, with a total of 31% of their land being disturbed during the analysis period, largely due to forest harvest (Figure 11 and Table 7). There was a lull in forest harvest activity in the late 1990s and early 2000s, but activity has increased more recently (Figure 11). Within the largest ownership type (Private), disturbance due to forest harvest was the most prominent, with development also being a consistent change agent, visible in nearly each year (Figure 11). Disturbances due to beaver were present in each ownership category and was most prevalent in the Native American category (Figure 11).

Table 7. Total percent of land disturbed, by disturbance agent and ownership, 1990–2018. Note, this does not include forest pathogen.

Ownership	Percent Land Disturbed
County	31.01
Federal	15.82
Native American	11.08
Private	13.95
Private Industrial	40.43
State	6.10

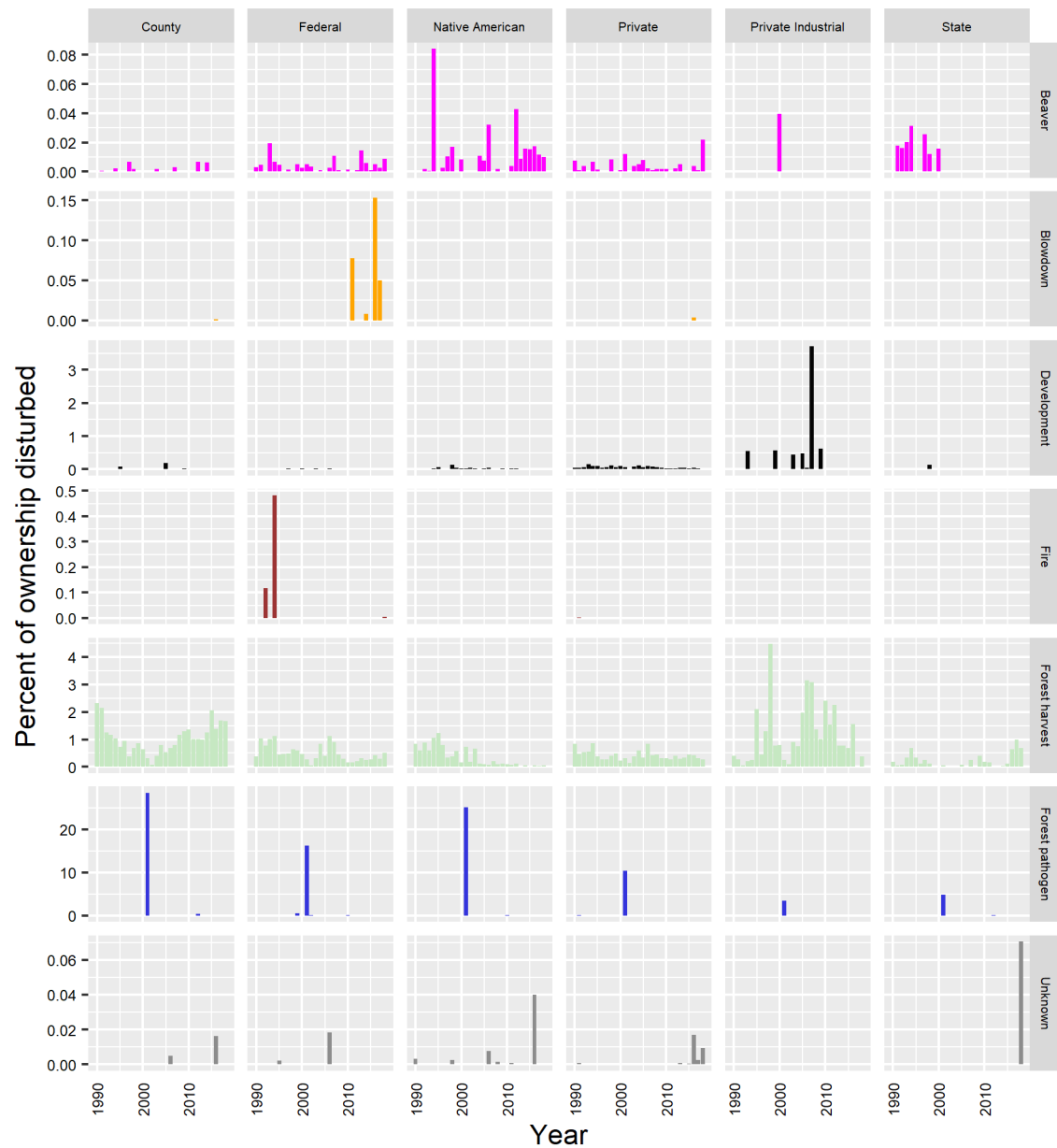


Figure 11. Percent of land disturbed within each ownership category, by disturbance agent and year, 1990–2018.

Patch size

Overall patch size is much larger outside the park versus inside the park (Figure 12). Outside the park, the forest pathogen disturbance in 2001 (defoliation) created multiple patches over 2,000 ha in size, with forest harvest disturbances creating the second largest patches (Figure 12). Forest harvest disturbances were also quite evenly distributed in sizes under 10 ha, with the largest patch being 200 ha in size (Figure 12). Inside the park, all disturbances except forest pathogen were smaller than 10 ha in size. The forest pathogen patches inside the park were also much smaller than those outside the park (Figure 12).

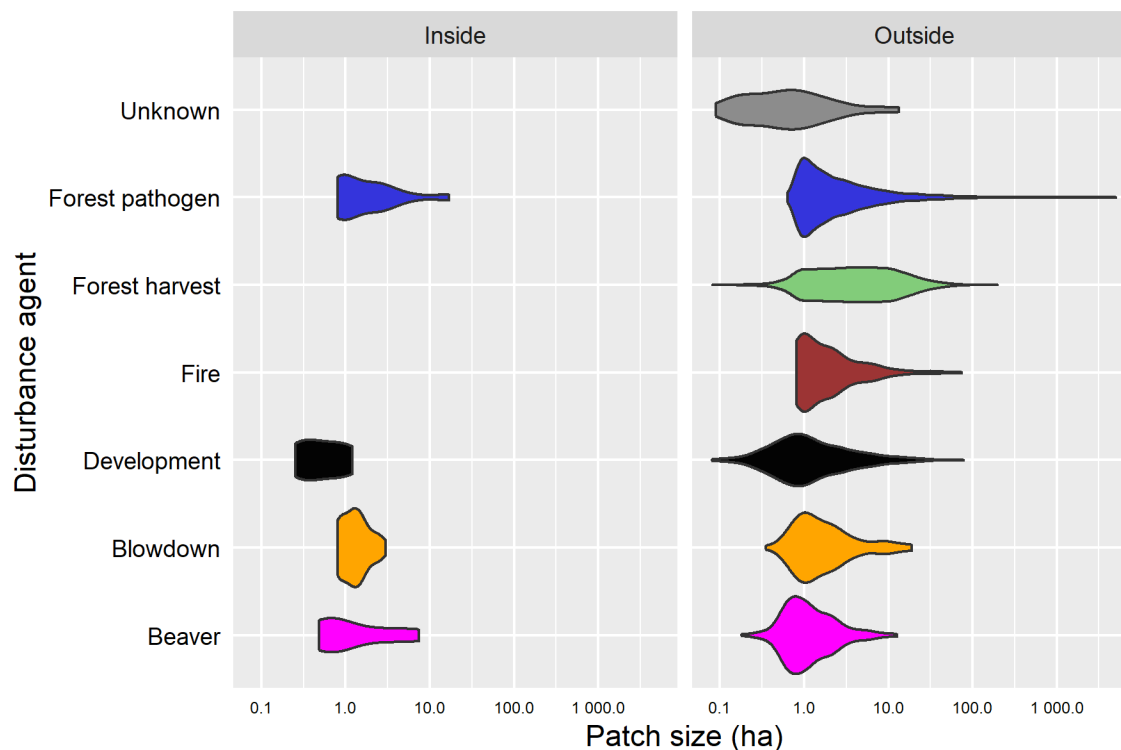


Figure 12. Violin plot displaying the patch size distribution of disturbances by disturbance agent inside and outside the park, 1990–2018. The height of the violin indicates larger numbers of patches at a given size, and the ends of the violin indicate the minimum and maximum patch size. Note: X axis is on log10 scale.

Comparison among GLKN parks

Compared to other network parks, APIS has similarly low rates of disturbance inside the park (Figure 13). The most common disturbances found inside GLKN parks tend to be beaver, blowdown, and forest pathogen. We are aware of a blowdown event that occurred inside APIS in the summer of 2020; however, this event fell outside the analysis period for this report. We have provided the park with additional high-resolution maps identifying the areas most affected to assist with management decisions. Outside the park, the disturbance regime (agents and rates) at APIS is similar to other northern Great Lakes parks (Isle Royale NP, Voyageurs NP, Pictured Rocks NL) in rates of disturbance due to beaver, development and forest harvest (Figure 13).

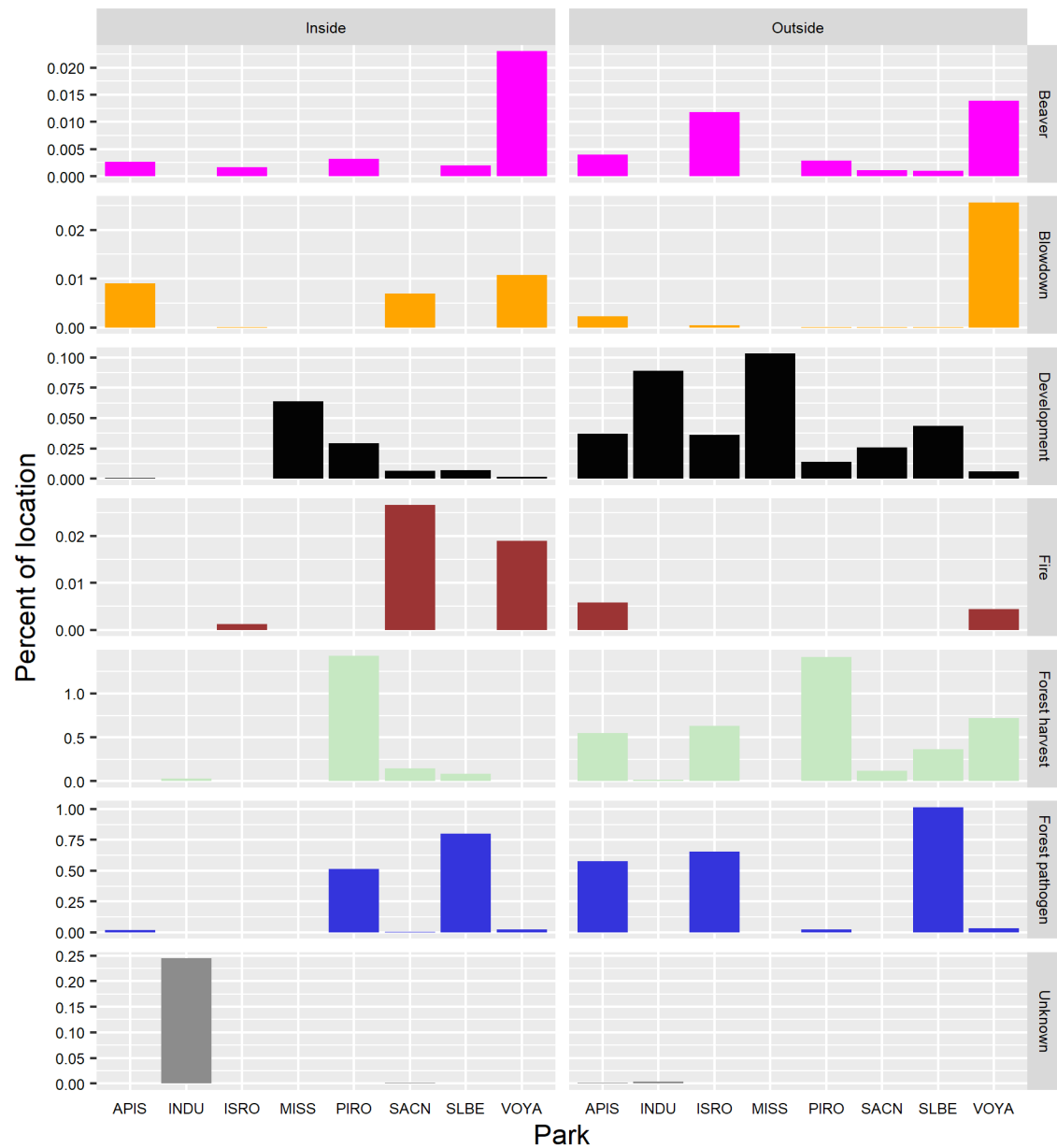


Figure 13. Yearly average percent of land disturbed inside and outside eight Great Lakes Network national parks, by disturbance agent, 1990–2018. Note: Y axis scale varies by disturbance agent. APIS=Apostle Islands, INDU=Indiana Dunes, ISRO=Isle Royale, MISS=Mississippi National River and Recreation Area, PIRO=Pictured Rocks, SACN=St. Croix National Scenic Riverway, SLBE=Sleeping Bear Dunes, VOYA=Voyageurs.

Conclusion

This data summary analysis revealed several points.

1. In the past 29 years, park lands have experienced low levels of landscape disturbances. This is similar to other parks in the Great Lakes Network (Kirschbaum and Gafvert 2013b, 2013a, 2014a, 2014b, 2017; Kirschbaum 2021). However, in the past five years, the park has experienced damage from two major wind events (2016 and 2020).
2. Forested areas on the Bayfield Peninsula under private, federal, and county ownerships are being intensively managed for forest harvest. A closer look at the harvest intensity levels (clearcut vs. partial harvest) and percent of each sub-watershed harvested might be useful in the future.
3. Development activities such as new roads and conversion to single family homes has been constant for the last 29 years and, if it continues, could alter nearshore environments. This category is unlike other disturbance agents in that it represents a permanent change in the land use, one that has been shown to affect water quality in streams, rivers, and lakes (Carey et al. 2011). This type of disturbance is cumulative and permanent, whereas a disturbance such as forest harvest is transitory—the land stays in a forested state, but is typically a younger, denser vegetation type.

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Appendix A. Area Disturbed in the Apostle Islands and Adjacent Analysis Area, 1990–2018.

Table A1. Area (in hectares) disturbed, by agent, inside Apostle Islands National Lakeshore and outside the park boundaries in the adjacent analysis area, 1990–2018.

Year	Disturbance Agent	Area Disturbed (ha)	
		<i>Inside</i>	<i>Outside</i>
1990	Beaver	0	13
1990	Blowdown	0	0
1990	Development	0	54
1990	Fire	0	0
1990	Forest harvest	0	2,655
1990	Forest pathogen	0	0
1990	Unknown	0	1
1991	Beaver	4	3
1991	Blowdown	0	0
1991	Development	0	68
1991	Fire	0	3
1991	Forest harvest	0	2,535
1991	Forest pathogen	0	145
1991	Unknown	0	1
1992	Beaver	0	8
1992	Blowdown	0	0
1992	Development	0	103
1992	Fire	0	94
1992	Forest harvest	0	2,121
1992	Forest pathogen	0	0
1992	Unknown	0	0

Table A1 (continued). Area (in hectares) disturbed, by agent, inside Apostle Islands National Lakeshore and outside the park boundaries in the adjacent analysis area, 1990–2018.

Year	Disturbance Agent	Area Disturbed (ha)	
		<i>Inside</i>	<i>Outside</i>
1993	Beaver	0	18
1993	Blowdown	0	0
1993	Development	0	243
1993	Fire	0	0
1993	Forest harvest	0	2,250
1993	Forest pathogen	0	0
1993	Unknown	0	0
1994	Beaver	0	45
1994	Blowdown	0	0
1994	Development	0	134
1994	Fire	0	388
1994	Forest harvest	0	2,879
1994	Forest pathogen	0	0
1994	Unknown	0	0
1995	Beaver	0	6
1995	Blowdown	0	0
1995	Development	0	182
1995	Fire	0	0
1995	Forest harvest	0	1,677
1995	Forest pathogen	0	0
1995	Unknown	0	2
1996	Beaver	0	1
1996	Blowdown	0	0
1996	Development	0	74
1996	Fire	0	0
1996	Forest harvest	0	1,412
1996	Forest pathogen	0	0
1996	Unknown	0	0

Table A1 (continued). Area (in hectares) disturbed, by agent, inside Apostle Islands National Lakeshore and outside the park boundaries in the adjacent analysis area, 1990–2018.

Year	Disturbance Agent	Area Disturbed (ha)	
		<i>Inside</i>	<i>Outside</i>
1997	Beaver	0	10
1997	Blowdown	0	0
1997	Development	0	93
1997	Fire	0	0
1997	Forest harvest	0	1,119
1997	Forest pathogen	0	0
1997	Unknown	0	0
1998	Beaver	0	18
1998	Blowdown	0	0
1998	Development	0	199
1998	Fire	0	0
1998	Forest harvest	0	1,691
1998	Forest pathogen	0	0
1998	Unknown	0	1
1999	Beaver	0	4
1999	Blowdown	0	0
1999	Development	0	123
1999	Fire	0	0
1999	Forest harvest	0	1,689
1999	Forest pathogen	0	424
1999	Unknown	0	0
2000	Beaver	0	10
2000	Blowdown	0	0
2000	Development	2	147
2000	Fire	0	0
2000	Forest harvest	0	1,039
2000	Forest pathogen	0	0
2000	Unknown	0	0

Table A1 (continued). Area (in hectares) disturbed, by agent, inside Apostle Islands National Lakeshore and outside the park boundaries in the adjacent analysis area, 1990–2018.

Year	Disturbance Agent	Area Disturbed (ha)	
		<i>Inside</i>	<i>Outside</i>
2001	Beaver	0	20
2001	Blowdown	0	0
2001	Development	0	78
2001	Fire	0	0
2001	Forest harvest	0	1,017
2001	Forest pathogen	0	47,082
2001	Unknown	0	0
2002	Beaver	0	3
2002	Blowdown	0	0
2002	Development	0	24
2002	Fire	0	0
2002	Forest harvest	0	336
2002	Forest pathogen	0	104
2002	Unknown	0	0
2003	Beaver	0	6
2003	Blowdown	0	0
2003	Development	0	164
2003	Fire	0	0
2003	Forest harvest	0	1,180
2003	Forest pathogen	0	0
2003	Unknown	0	0
2004	Beaver	0	11
2004	Blowdown	0	0
2004	Development	0	166
2004	Fire	0	0
2004	Forest harvest	0	1,857
2004	Forest pathogen	0	0
2004	Unknown	0	0

Table A1 (continued). Area (in hectares) disturbed, by agent, inside Apostle Islands National Lakeshore and outside the park boundaries in the adjacent analysis area, 1990–2018.

Year	Disturbance Agent	Area Disturbed (ha)	
		<i>Inside</i>	<i>Outside</i>
2005	Beaver	0	13
2005	Blowdown	0	0
2005	Development	0	176
2005	Fire	0	0
2005	Forest harvest	0	1,124
2005	Forest pathogen	0	0
2005	Unknown	0	0
2006	Beaver	0	15
2006	Blowdown	0	0
2006	Development	0	174
2006	Fire	0	0
2006	Forest harvest	0	2,499
2006	Forest pathogen	0	0
2006	Unknown	0	19
2007	Beaver	7	4
2007	Blowdown	0	0
2007	Development	0	304
2007	Fire	0	0
2007	Forest harvest	0	1,856
2007	Forest pathogen	0	0
2007	Unknown	0	0
2008	Beaver	1	3
2008	Blowdown	0	0
2008	Development	0	75
2008	Fire	0	0
2008	Forest harvest	0	1,518
2008	Forest pathogen	0	0
2008	Unknown	0	0

Table A1 (continued). Area (in hectares) disturbed, by agent, inside Apostle Islands National Lakeshore and outside the park boundaries in the adjacent analysis area, 1990–2018.

Year	Disturbance Agent	Area Disturbed (ha)	
		<i>Inside</i>	<i>Outside</i>
2009	Beaver	0	2
2009	Blowdown	0	0
2009	Development	0	106
2009	Fire	0	0
2009	Forest harvest	0	1,304
2009	Forest pathogen	0	0
2009	Unknown	0	0
2010	Beaver	0	3
2010	Blowdown	0	0
2010	Development	0	45
2010	Fire	0	0
2010	Forest harvest	0	1,276
2010	Forest pathogen	91	52
2010	Unknown	0	0
2011	Beaver	0	1
2011	Blowdown	0	62
2011	Development	0	41
2011	Fire	0	0
2011	Forest harvest	0	1,033
2011	Forest pathogen	0	0
2011	Unknown	0	0
2012	Beaver	0	20
2012	Blowdown	0	0
2012	Development	0	52
2012	Fire	0	0
2012	Forest harvest	0	1,255
2012	Forest pathogen	0	244
2012	Unknown	0	0

Table A1 (continued). Area (in hectares) disturbed, by agent, inside Apostle Islands National Lakeshore and outside the park boundaries in the adjacent analysis area, 1990–2018.

Year	Disturbance Agent	Area Disturbed (ha)	
		<i>Inside</i>	<i>Outside</i>
2013	Beaver	0	21
2013	Blowdown	0	0
2013	Development	1	69
2013	Fire	0	0
2013	Forest harvest	0	1,068
2013	Forest pathogen	0	0
2013	Unknown	0	1
2014	Beaver	1	12
2014	Blowdown	0	6
2014	Development	0	57
2014	Fire	0	0
2014	Forest harvest	0	1,201
2014	Forest pathogen	0	0
2014	Unknown	0	0
2015	Beaver	0	6
2015	Blowdown	0	0
2015	Development	0	40
2015	Fire	0	0
2015	Forest harvest	0	1,708
2015	Forest pathogen	0	0
2015	Unknown	0	1
2016	Beaver	0	14
2016	Blowdown	42	86
2016	Development	0	56
2016	Fire	0	0
2016	Forest harvest	0	1,617
2016	Forest pathogen	0	8
2016	Unknown	0	42

Table A1 (continued). Area (in hectares) disturbed, by agent, inside Apostle Islands National Lakeshore and outside the park boundaries in the adjacent analysis area, 1990–2018.

Year	Disturbance Agent	Area Disturbed (ha)	
		<i>Inside</i>	<i>Outside</i>
2017	Beaver	0	7
2017	Blowdown	1	39
2017	Development	0	45
2017	Fire	0	0
2017	Forest harvest	0	1,456
2017	Forest pathogen	0	0
2017	Unknown	0	3
2018	Beaver	0	40
2018	Blowdown	0	0
2018	Development	0	12
2018	Fire	0	4
2018	Forest harvest	0	1,560
2018	Forest pathogen	0	0
2018	Unknown	0	20

Appendix B. Fields Available in the Full Landscape Disturbance Dataset.

During validation, we fill out numerous fields that are not necessarily reflected in the data summary report series. This table identifies additional fields filled in during the validation process and a brief description of each. The more-detailed dataset is available upon request.

Table B1. Fields, and their descriptions, used to describe a disturbance during the validation process, but which are not reported on in this summary.

Field	Description
Year	Year of disturbance onset
Percent of polygon affected	Percent of polygon affected by any disturbance
Disturbance agent 1	A polygon could be comprised of multiple disturbance agents. We use this field to identify the first (and maybe only) disturbance agent.
Percent of polygon in disturbance agent 1	Percent of disturbed (affected) area due to disturbance agent one.
Percent cover remaining for disturbance agent 1	If the disturbance agent is forest harvest, this field is filled in. We estimate the percent cover (in 10% increments) of overstory remaining after the disturbance for disturbance agent one.
Disturbance agent 2	If multiple disturbance agents are present in the polygon, we identify the second disturbance agent.
Percent of polygon in disturbance agent 2	Percent of disturbed (affected) area due to disturbance agent two.
Percent cover remaining for disturbance agent 2	If the disturbance agent is forest harvest, this field is filled in. We estimate the percent cover (in 10% increments) of overstory remaining after the disturbance for disturbance agent two.
Disturbance agent 3	If multiple disturbance agents are present in the polygon, we identify the third disturbance agent.
Percent of polygon in disturbance agent 3	Percent of disturbed (affected) area due to disturbance agent three.
Percent cover remaining for disturbance agent 3	If the disturbance agent is forest harvest, this field is filled in. We estimate the percent cover (in 10% increments) of overstory remaining after the disturbance for disturbance agent three.
Start class 1	The starting land cover/land use class of the disturbed area. We allow up to three unique starting classes for each disturbed polygon. Class options are forest closed, forest semi-closed, forest open, shrub, herbaceous, pervious, impervious/vegetated, impervious, and water.
Start class 1 percent	Percent of the disturbed (affected) area in starting class one.
Start class 2	If multiple classes were disturbed, we identify the second class.

Table B1 (continued). Fields, and their descriptions, used to describe a disturbance during the validation process, but which are not reported on in this summary.

Field	Description
Start class 2 percent	Percent of the disturbed (affected) area in starting class two (if needed).
Start class 3	Same as start class 2
Start class 3 percent	Same as start class 2 percent
End class 1	The ending land cover/land use class of the disturbed area. This should reflect the immediate result of the disturbance and not the future condition of the area. Class options are the same as in the starting class options.
End class 1 percent	Percent of the disturbed (affected) area in ending class one.
End class 2	Same as end class 1
End class 2 percent	Same as end class 1 percent
End class 3	Same as end class 1
End class 3 percent	Same as end class 1 percent
Owner type	During validation we add ownership data from the best available source. Owner type is a higher-level ownership classification such as federal, county, state, and private.
Owner name	Owner name is a more detailed level of ownership such as National Park Service, Bayfield county, or Wisconsin Department of Natural Resources.
Watershed identifier	During validation we add the unique 12 digit watershed identifier, referred to as the Hydrologic Unit Code 12 (HUC12) from the USGS database.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525