



Landsat-Based Monitoring of Landscape Dynamics at Sleeping Bear Dunes National Lakeshore

1990–2021



Beech tree uprooted by the 2016 blowdown event within Sleeping Bear Dunes National Lakeshore.
NPS / A. KIRSCHBAUM

Landsat-based monitoring of landscape dynamics at Sleeping Bear Dunes National Lakeshore: 1990–2021

Science Report NPS/SR—2025/320

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Please cite this publication as:

Kirschbaum, A. A. 2025. Landsat-based monitoring of landscape dynamics at Sleeping Bear Dunes National Lakeshore: 1990–2021. Science Report NPS/SR—2025/320. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/2313944>

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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 Sleeping Bear Dunes 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 the park and differs slightly from the original report published in 2014 in terms of the time period analyzed, which increased by 26 years, from 2006–2011 (six years) to 1990–2021 (32 years). Results of this extended analysis showed that inside the park, the largest disturbance agent was blowdown which was an episodic event occurring in the late summer of 2016. There were also disturbances due to forest harvest, which in these cases were likely due to clearing trees for restoration activities. There were also instances of forest die-off due to forest pathogens, likely the result of emerald ash borer and/or beech bark disease. Lands outside the park experienced far greater levels of disturbance, with forest harvest being the most prevalent disturbance agent, affecting 4.96% of the land outside the park (298 ha annually). Outside the park, development was very prevalent, disturbing a total of 2.3% of the land (138 ha annually). Long-term monitoring of this analysis area will contribute to our understanding of how these disturbances may affect water quality, wildlife corridors, and pressures on the natural resources within the surrounding watersheds of Sleeping Bear Dunes National Lakeshore.

Acknowledgments

The author would like to acknowledge the work and contribution of Katelynn Roberts, who validated 22,329 Sleeping Bear Dunes National Lakeshore polygons during the mild winter of 2024 and produced all maps in the report.

Introduction

Monitoring changes in land cover and land use has long been recognized as an important part of monitoring landscape processes (Cohen and Goward 2004). Data obtained from disturbance detection and monitoring have been used in ecosystem modeling of carbon (Law et al. 2004, Turner et al. 2006, Potapov et al. 2009, Powell et al. 2010); for mapping fire extent, severity, and recovery (Veraverbeke et al. 2010, Chen et al. 2011, Meigs et al. 2011); for evaluating policy effects on land use (Kennedy et al. 2012); and for modeling the effects of disturbances on watershed characteristics (Eshleman et al. 2009, Deel et al. 2012).

Previous landscape dynamics studies in the region have focused on large-scale changes in land cover and land use using moderate resolution imagery such as Landsat (30-m pixels). Wolter et al. (2006) examined land use and land cover change in the U.S. Great Lakes basin for one time period (1992–2001) using two generations of the National Land Cover Dataset (NLCD). The study found that 2.5% of the watershed experienced change, with forest and agriculture categories experiencing the largest declines in area (approximately 2.3%). In addition, 49.3% of the changes were transitions from undeveloped to developed land, with the greatest percentage of the overall watershed change occurring within 0–10 km of the shoreline. More recently, Stueve et al. (2011) investigated the amount of disturbance in the Lake Superior and Lake Michigan basins from 1985–2008 using Vegetation Change Tracker (VCT). They found that 4.0% of the land (0.26%/yr) in the lower Lake Superior basin was disturbed between 1985 and 1999, and 2.9% of the land (0.32%/yr) was disturbed from 2000 through 2008. This study was performed on an extremely large scale, providing less information on smaller subunits of the Lake Superior watershed.

In northeastern Minnesota, White and Host (2003, 2008) used General Land Office (GLO) survey data and aerial photography from the 1930s, 1970s, and 1990s to quantify forest disturbance frequency and spatial patterns. They found an increase in fire frequency from the pre-settlement period (1860–1890) to the period between 1910 and 1940, followed by a decrease in fire frequency, which was replaced by increases in timber harvest rates. Wolter and White (2002) focused on forest cover type transitions and landscape structural changes in the same area using Landsat imagery from 1990 to 1995 and found that, of the mature forested area, 4.2% (0.79%/yr) was harvested, flooded, or burned five years later. When comparing disturbances among timber management status (managed vs. unmanaged) in each of the ownership types, the highest annual rates of mature forest area changing to early successional forests occurred within the private industrial category (3.6%). The lowest rates of conversion were found on federal lands (0.17%), with county lands being the next least disturbed land type (0.22%).

Brown (2003) investigated the relationship and trends in land use and forest cover on private parcels in the upper Midwest (the northern forested regions of Minnesota, Wisconsin, and Michigan) from 1970 to 1990 and found that land development increased in all 106 counties. In addition, the percentage of land in agriculture declined between the 1980s and 1990 but held steady in some counties when observed over the entire period (1970s to 1990). This could reflect the conversion of previously cleared forest lands for agriculture back to a forested cover type. In four national forests in

northern Wisconsin and Michigan, a separate study (Stueve et al. 2011) focused on studying “intermediate” wind disturbances, those not generally studied due partially to the fact that they are not easily detected with most remote sensing techniques. They found that these disturbances rivaled the amount of land disturbed by large, infrequent disturbances (e.g., fires or extreme wind events).

Landscape perturbations produce ripple effects in multiple natural processes. Fitzpatrick et al. (1999) studied the effect of the major shift in land cover and land use in northern Wisconsin watersheds since the late 1800s and saw large changes in the sedimentation load and flow dynamics. Verry et al. (1983) studied the effect of forest composition within watersheds and how this affected the spring runoff events. He found that forested watersheds comprised of mixed age forest helped buffer the spring runoff events. Also, resulting effects of landscape disturbances such as fragmentation and land cover changes have been found to affect (both positively and negatively) the abundance of rare and endangered species; biodiversity and habitat for birds, amphibians, and other animals; water quality; and in-stream habitat for fish (Ward 1998, With 2002, Fahrig 2003).

Because landscape disturbances can affect a broad range of natural resources, being cognizant of what is happening in and around Sleeping Bear Dunes National Lakeshore will help inform resource managers at the park about pressures affecting the areas under their jurisdiction. Many landscape dynamics studies have been performed in the upper Great Lakes region, but there is a lack of this type of research in the Sleeping Bear Dunes National Lakeshore vicinity. In addition, due to the culture of research conducted by many colleges and universities, many of these studies are supported by one-time funding (“soft money”) from governments and organizations; thus, they are often limited to a duration of only two or three years. This is one of the many reasons the NPS Inventory and Monitoring program was developed: to provide consistent, long-term monitoring of ecologically significant parameters affecting national park lands.

Reported here are disturbances for Sleeping Bear Dunes National Lakeshore (SLBE) 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. 2010b). The first report for SLBE (Kirschbaum and Gafvert 2014) summarized disturbances for a six-year period (2006–2011). This report summarizes disturbances occurring over 32 years (1990–2021).

Methods

Analysis Area

The analysis was conducted inside and adjacent to Sleeping Bear Dunes National Lakeshore (SLBE; Figure 1) in northwestern lower Michigan. The analysis area extended into seven watersheds that could potentially influence the park (Figure 2). Watersheds were defined by level-10 delineations of the National Hydrography Dataset's Hydrologic Unit Code (HUC) (nhd.usgs.gov) (Figure 2). In total 215,844 ha of land was monitored, of which 23,879 ha was land inside SLBE. Land cover within the analysis area was dominated by the forested class, followed by crops and wood wetlands, as classified in the U.S. by the 2021 National Land Cover Database (NLCD) (Dewitz 2023) (Figures 3 and 4). Ownership within the analysis area is largely in the Unknown class, which is typically private lands (Figure 5 and Table 1). Federal and state owned lands are the next two largest ownership types within the analysis area.

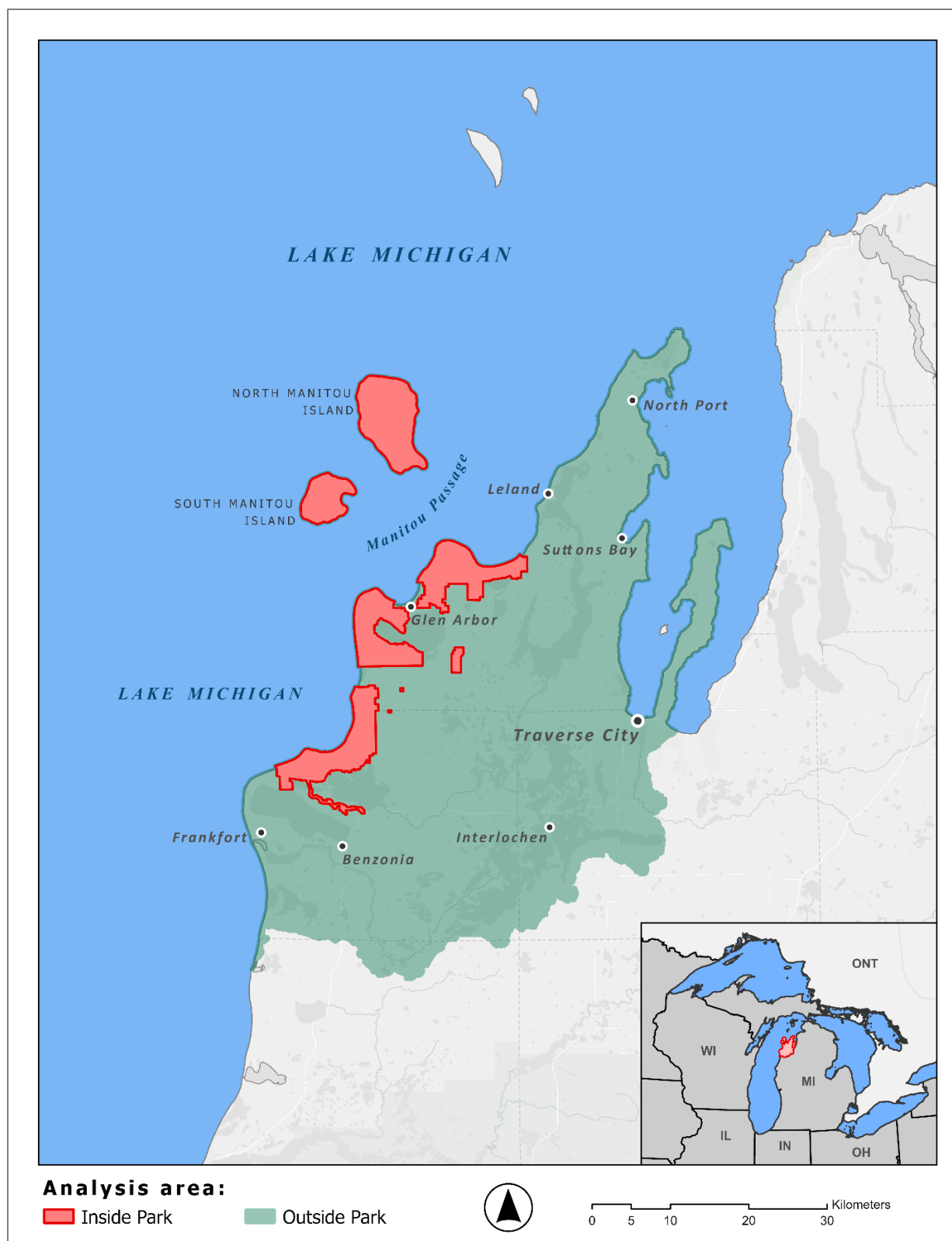


Figure 1. Analysis area for monitoring landscape dynamics in the greater Sleeping Bear Dunes National Lakeshore ecosystem. Green indicates area monitored outside the park in additional watersheds.

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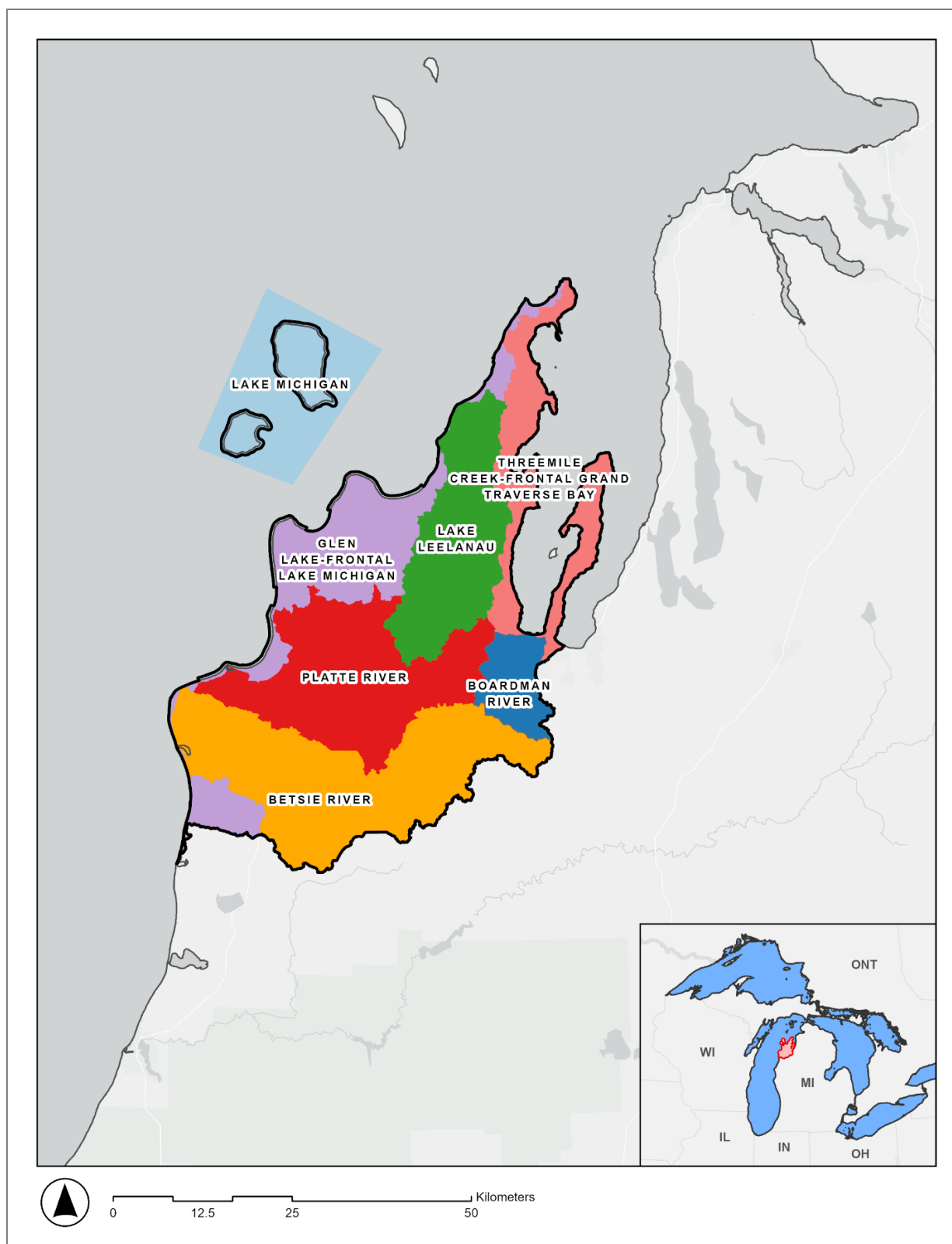


Figure 2. Labeled watersheds included in this analysis, as defined by level 10 Hydrologic Unit Codes (HUCs).

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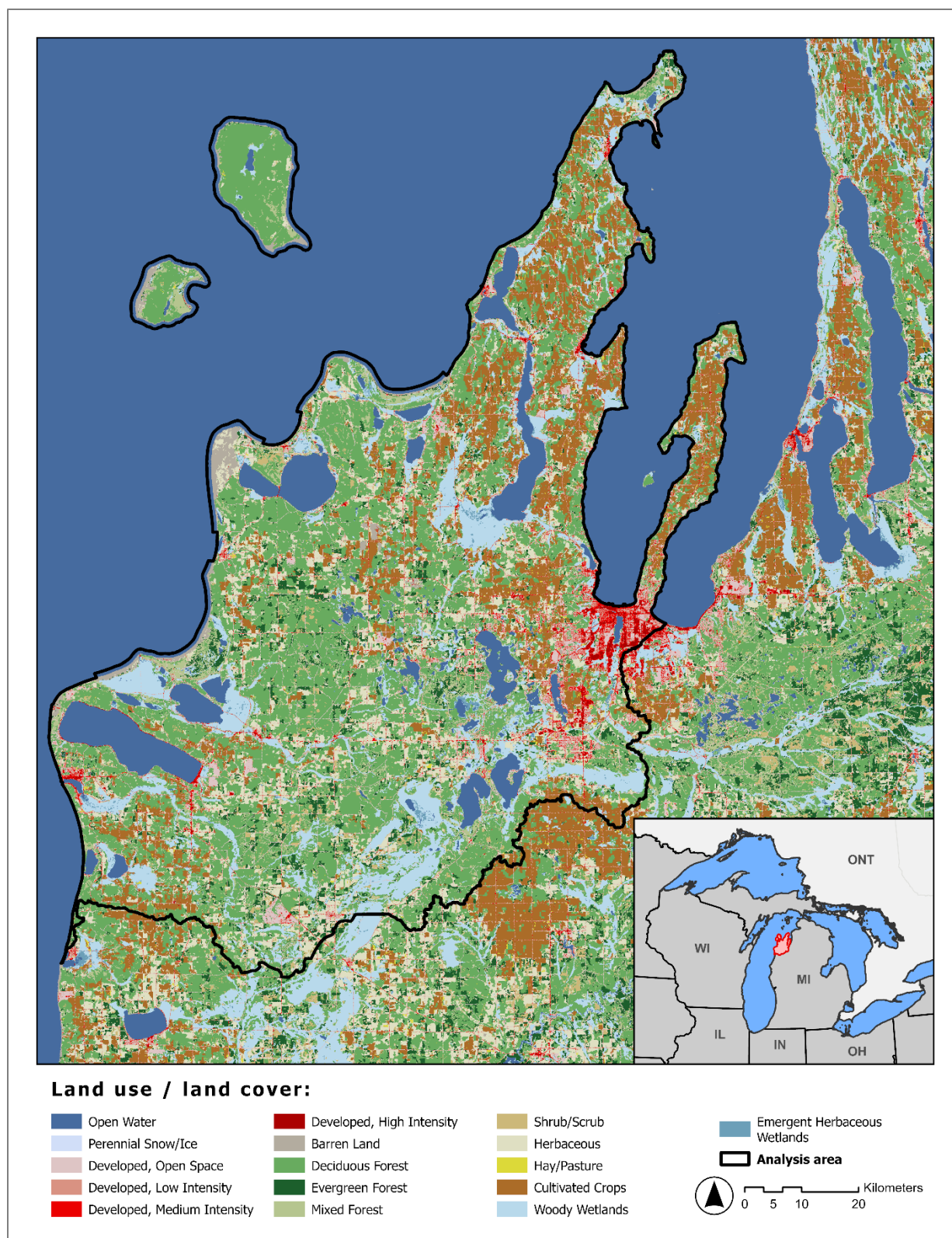


Figure 3. Land cover and land use classes in the analysis area, as mapped by the National Land Cover Database (Dewitz 2023).

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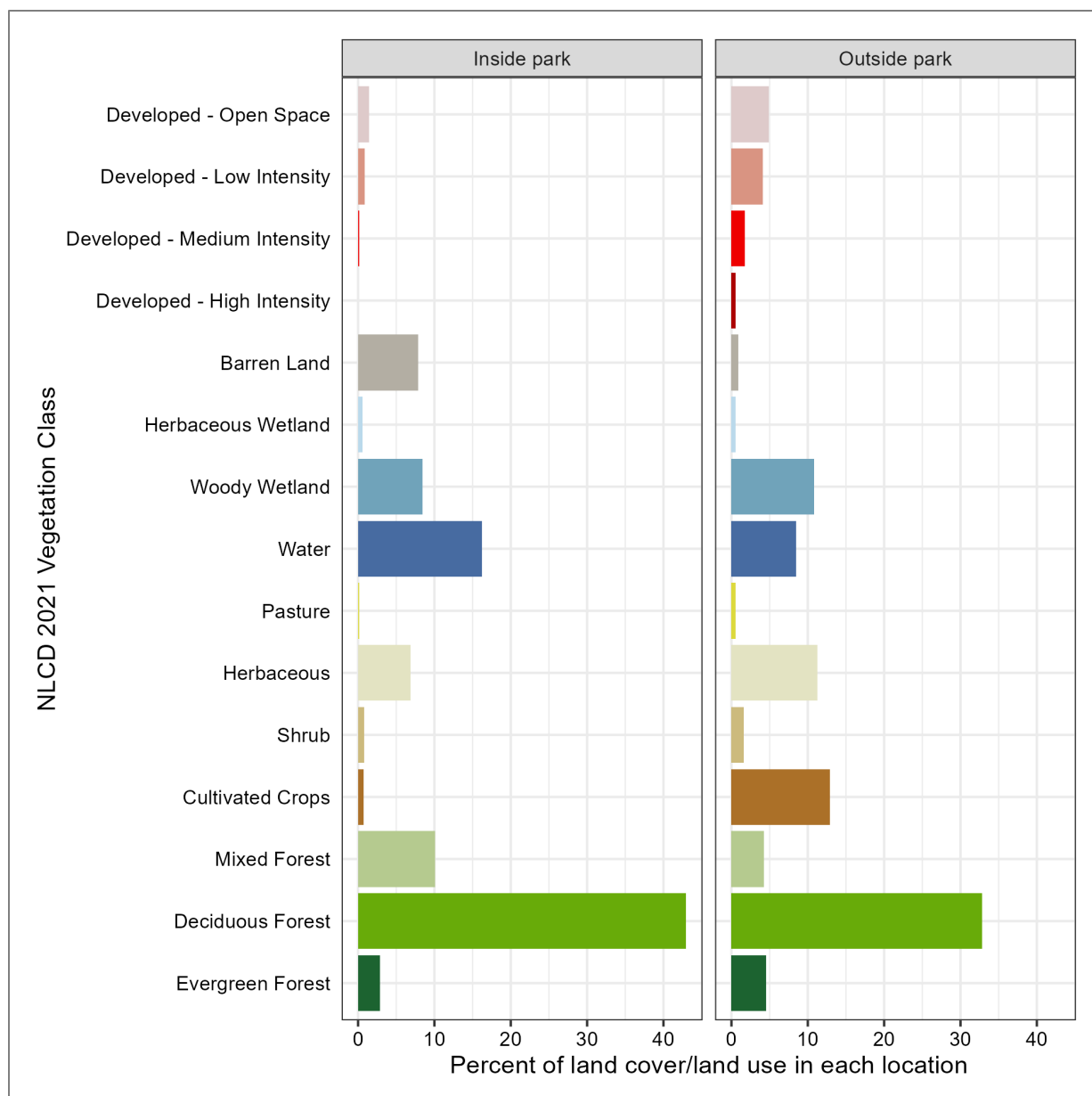


Figure 4. Percent of each land cover and land use class in the analysis area, as mapped by the National Land Cover Database (Dewitz 2023).

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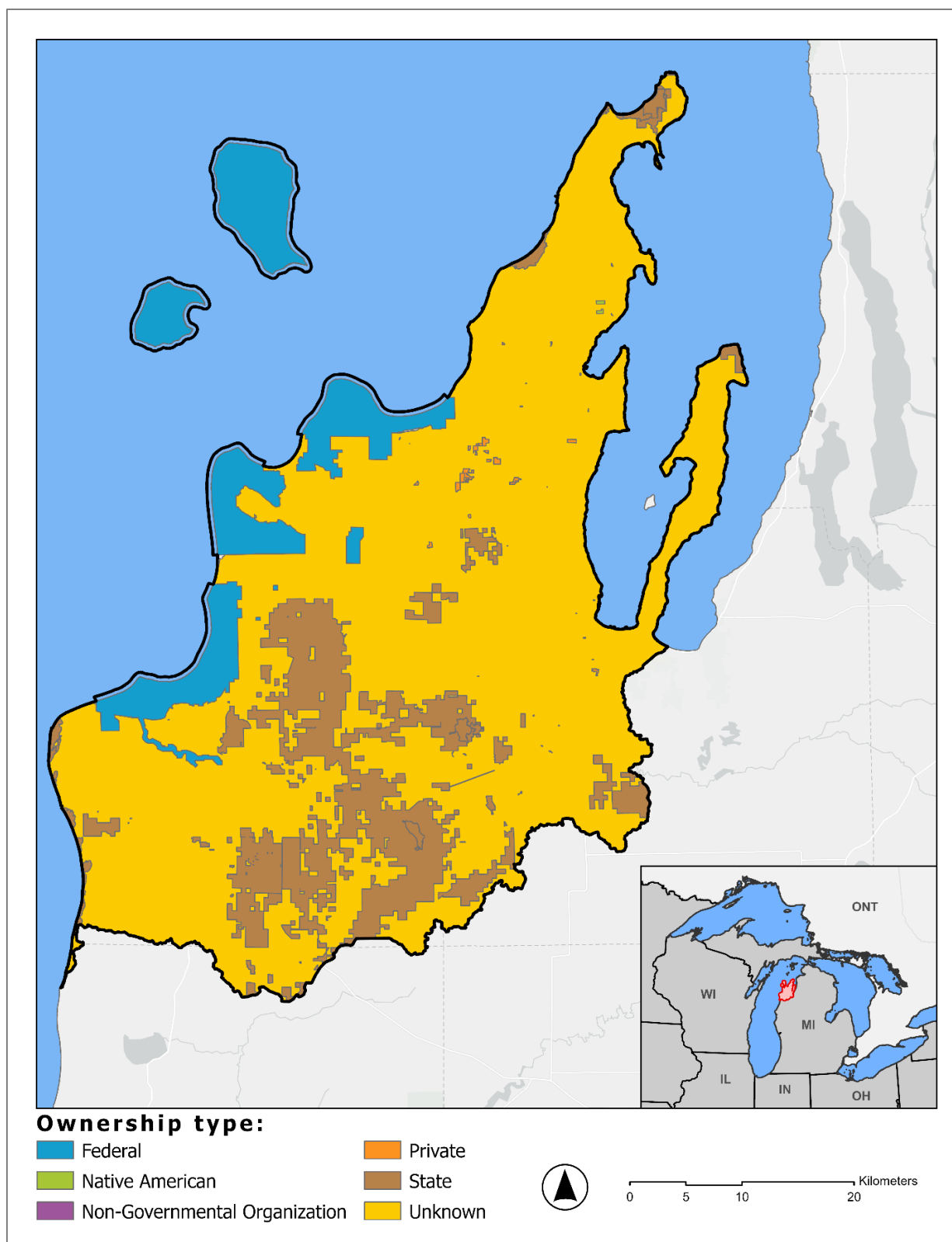


Figure 5. Ownership within the analysis area. Ownership data was obtained from the Michigan Gap Analysis Program.

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Table 1. Ownership within the analysis area. Ownership data from the Michigan Gap Analysis Program.

Ownership	Area (ha)	Percent of Land
City	490.13	0.23
County	640.52	0.30
Federal	22725.87	10.47
Native American	370.74	0.17
Other Public	4635.86	2.14
Unknown	157,122.94	72.40
State	31001.37	14.28

Disturbance Detection Methodology

A set of processing and analysis steps collectively known as LandTrendr (Kennedy et al. 2010b, 2010a) 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 in this analysis, where and when they occur.

To minimize effects of phenological variation, Landsat images between July and September of each year (1985–2021) 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, as identified 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 option. 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 is 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 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 attribute with the majority of the polygon represented was chosen. Validation of possible disturbances followed details given in Kirschbaum and Gafvert (2014) 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.” All fields filled out during the validation process are listed in Appendix A.

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 air photos 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
Beaver	Beaver
Blowdown	Blowdown
Development	Agriculture, development
Fire	Fire
Forest harvest	Forest harvest categories light, moderate, and heavy
Forest pathogen	Insect/disease defoliation and mortality
Other	Other

High-resolution (≤ 5 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 (1985–2021) for each prospective disturbance was also viewed, along with a graph of the reflectance values through time (1985–2021) of said disturbance.

In a GIS environment, using high-resolution imagery, ancillary datasets, and the Landsat imagery itself, a total of 22,329 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 2021 National Land Cover Database (Dewitz 2023).

This validation workflow corroborates what has been shown in past studies (Antonova et al. 2011, Cohen et al. 2018), 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 on private land) or because the evidence (e.g., insect/disease, low level forest harvests) has been masked by time (Antonova et al. 2011, Cohen et al. 2018).

Results

Disturbance Agent Summaries

Maps of Disturbances

Maps presented below show the location of disturbances in the analysis area by disturbance agent (Figure 6) and by year (Figure 7). The most widespread and ubiquitous change agent was forest harvest, found nearly everywhere outside the park, but most prominently and most heavily concentrated in the southern half of the study area (Figure 6). Disturbances due to development were also widespread (Figure 6) and constant (Figures 7) through time and space. Inside the park, the most notable disturbance was the blowdown event in the Alligator Hill area (Figure 6). This event did affect other areas of the park, but to a much lesser degree.

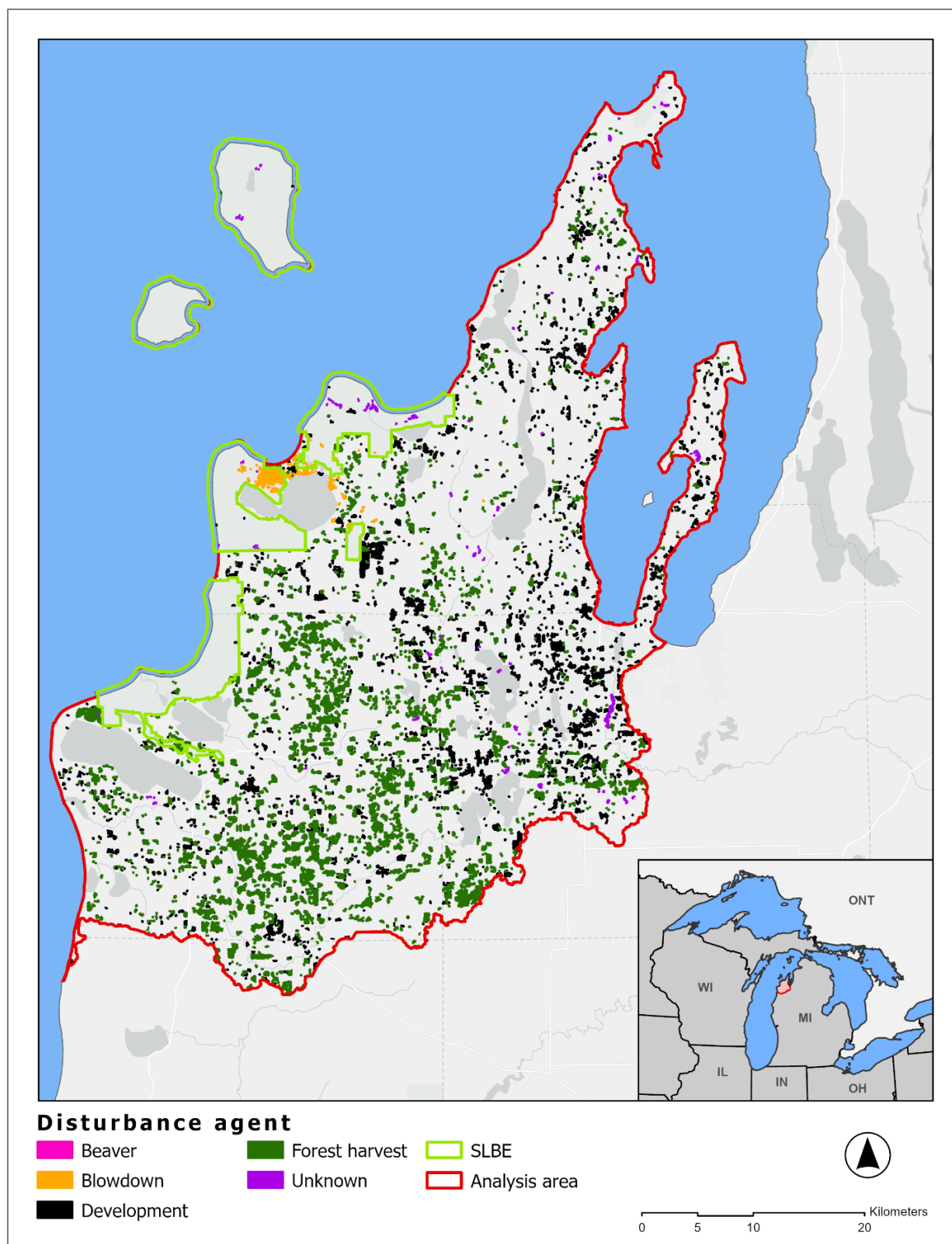


Figure 6. Spatial extent of disturbances, by disturbance agent, within the analysis area for Sleeping Bear Dunes National Lakeshore, 1990–2021.

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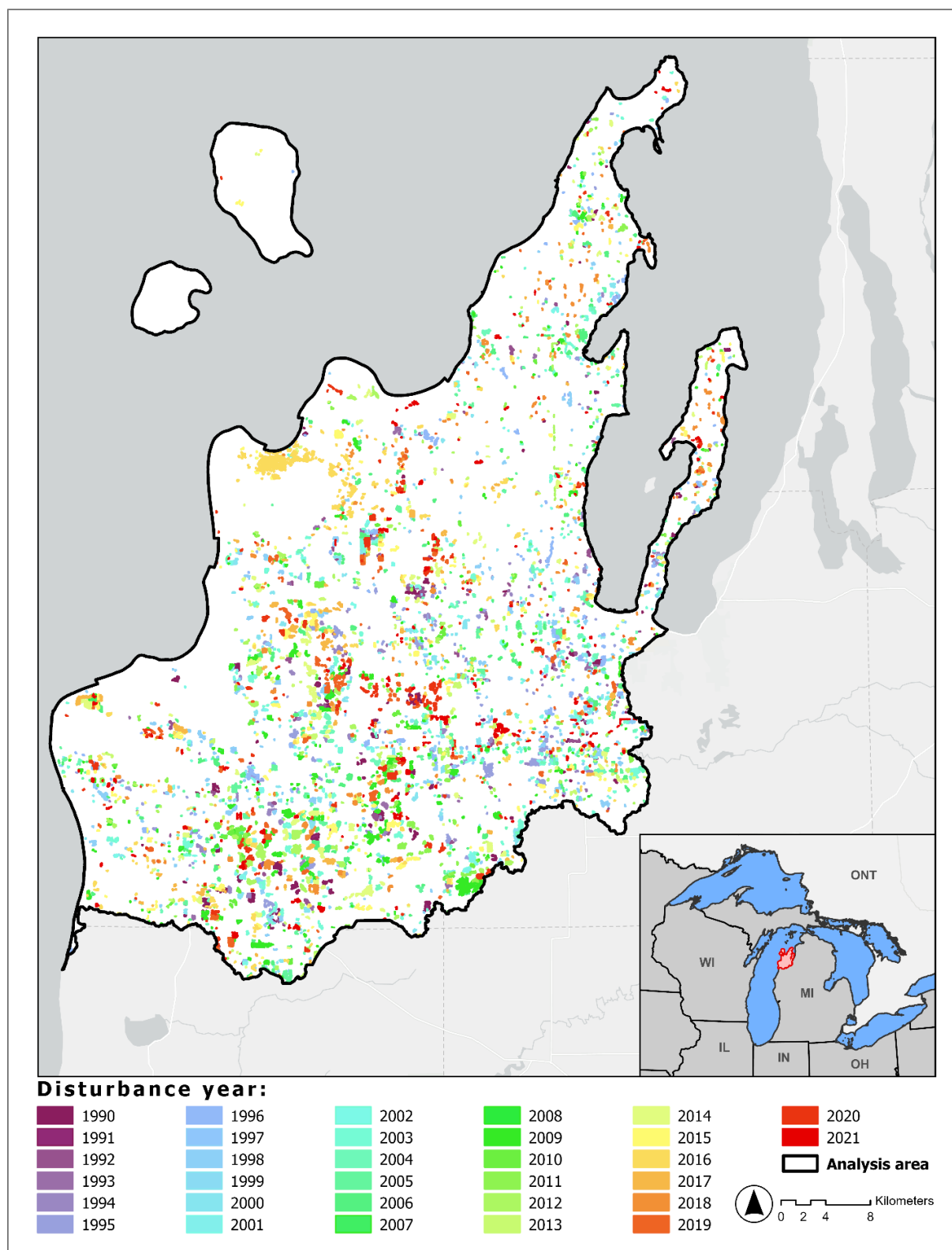


Figure 7. Spatial extent of disturbances, identified by year of onset, within the analysis area for Sleeping Bear Dunes National Lakeshore, 1990–2021.

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Inside vs. Outside the Park

Inside the park boundary, disturbances due to the blowdown event in 2015 represented the largest amount of land affected (1.68%, 400.32 ha) over the period, followed by forest pathogens (0.21%, 49.76 ha) and forest harvest disturbances (0.20%, 47.3 ha) (Figure 8 and Table 4). The blowdown event occurred in August 2015, however due to how the base imagery (Landsat) is collected and mosaicked, this analysis did not detect it until 2016.

Outside the park, disturbances due to forest harvest were the most prevalent, occurring every year of the analysis period (Figure 8) and averaging 297.93 ha/year (Table 4). The next most prevalent disturbance agent outside the park was development, which affected 2.31%, or 4,443.39 ha, of land.

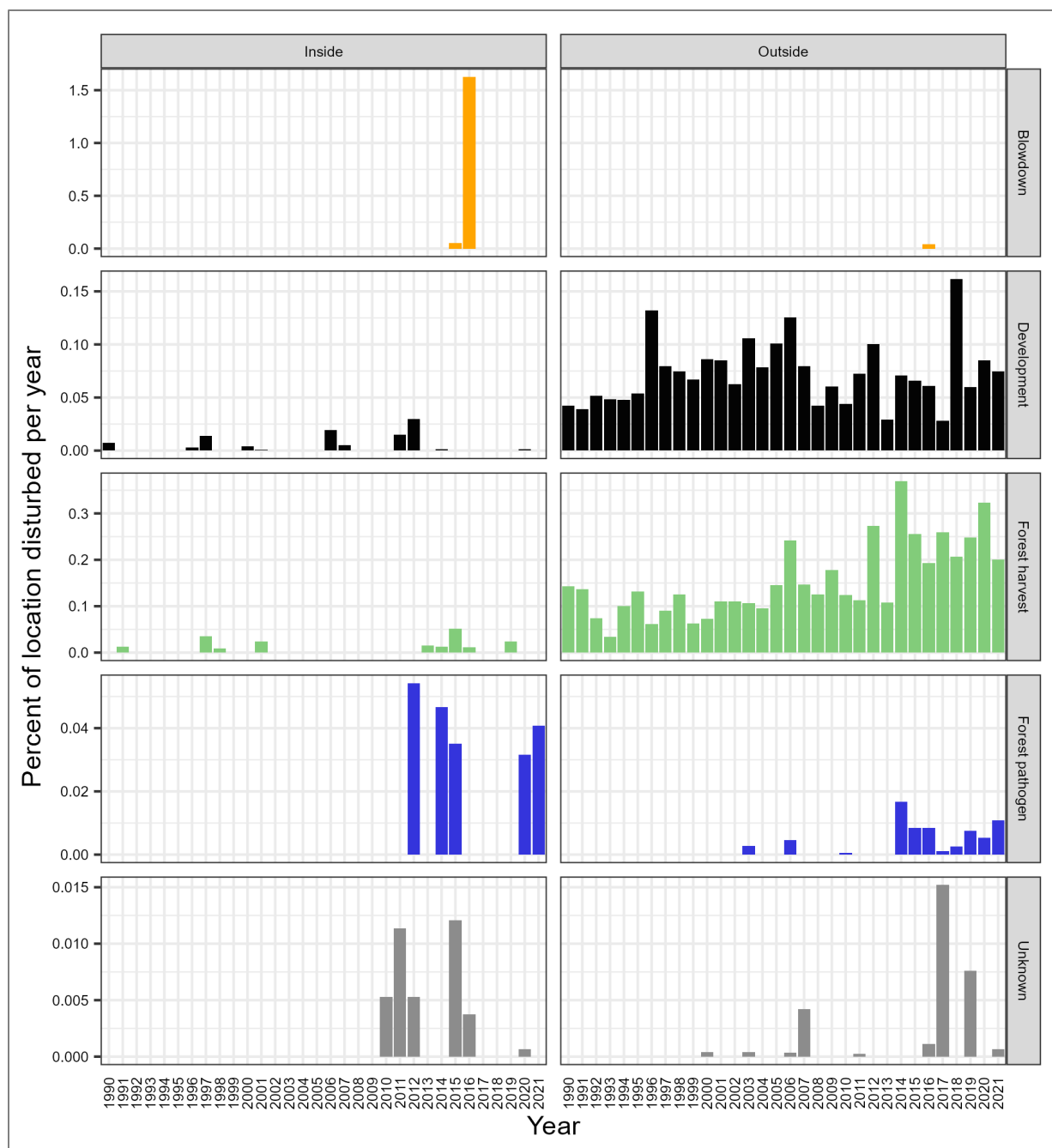


Figure 8. Percent of land disturbed inside and outside the park, by disturbance agent and year, 1990–2021. Note: Y-axis scale varies by disturbance agent.

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Table 4. Total percent and area (hectares) disturbed inside and outside the park, by disturbance agent, 1990–2021.

Disturbance Agent	Inside Park		Outside Park	
	Area (ha)	Percent Land Disturbed	Area (ha)	Percent Land Disturbed
Blowdown	400.32	1.68	84.39	0.04
Development	24.1	0.10	4443.39	2.31
Forest harvest	47.3	0.20	9533.77	4.97
Forest pathogen	49.76	0.21	131.82	0.07
Unknown	9.17	0.04	57.88	0.03

Watershed

There were seven watersheds located within the study area (see Figure 2). Of the watersheds, Betsie River had the highest disturbance rates (10.40% of the land in the watershed disturbed) during the analysis period (Figure 9 and Table 5), with the majority of disturbances resulting from forest harvest (Table 6). The Boardman River watershed experienced the next highest level of disturbance (9.26% of the land in the watershed disturbed), with development being the largest agent of change (Figure 9 and Table 6). Spatially, development occurred in the watersheds located along the shorelines and near Traverse City (Figure 6). The two southerly watersheds (Betsie and Platte Rivers) were largely characterized by disturbances due to forest harvest (Figure 9).

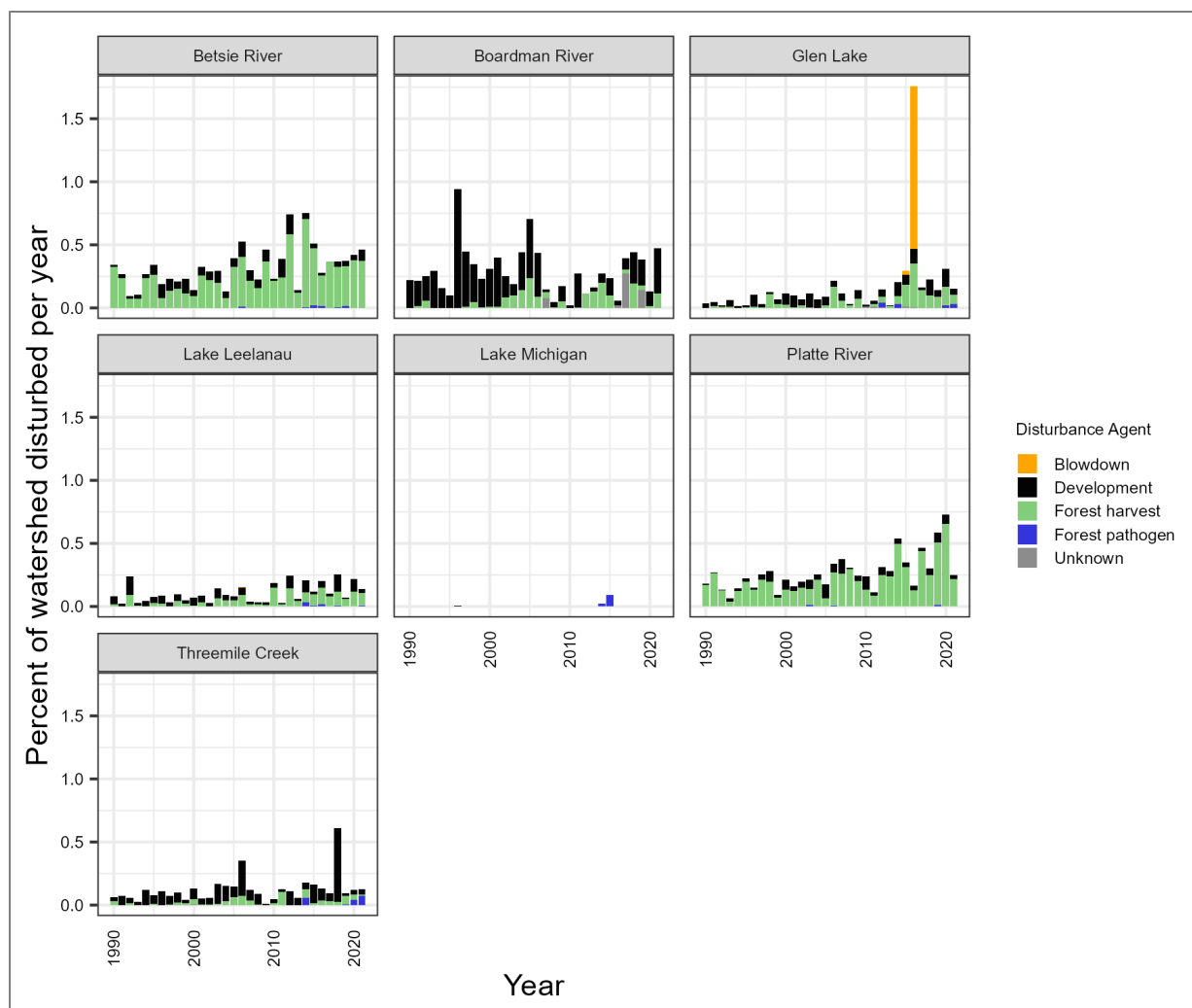


Figure 9. Percent of land disturbed within each watershed, by disturbance agent and year, 1990–2021.
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Table 5. Total area and percentage of watershed disturbed, 1990–2021.

Watershed	Area (ha)	Percent
Betsie River	5904.52	10.40
Boardman River	964.98	9.26
Glen Lake	1858.46	5.10
Lake Leelanau	1097.72	3.37
Lake Michigan	9.87	0.12
Platte River	3961.66	8.58
Threemile Creek	984.70	3.88

Table 6. Total area and percentage of watershed disturbed, by disturbance agent, 1990–2021.

Watershed	Disturbance Agent	Land Disturbed (ha)	Percent Land Disturbed
Betsie River	Development	1145.59	2.02
Betsie River	Forest harvest	4721.49	8.32
Betsie River	Forest pathogen	37.44	0.07
Boardman River	Development	719.97	6.91
Boardman River	Forest harvest	191.51	1.84
Boardman River	Unknown	53.51	0.51
Glen Lake	Blowdown	483.05	1.32
Glen Lake	Development	660.80	1.81
Glen Lake	Forest harvest	660.23	1.81
Glen Lake	Forest pathogen	44.45	0.12
Glen Lake	Unknown	9.93	0.03
Lake Leelanau	Blowdown	1.67	0.01
Lake Leelanau	Development	517.25	1.59
Lake Leelanau	Forest harvest	551.21	1.69
Lake Leelanau	Forest pathogen	25.66	0.08
Lake Leelanau	Unknown	1.94	0.01
Lake Michigan	Development	0.68	0.01
Lake Michigan	Forest harvest	0.20	<0.00
Lake Michigan	Forest pathogen	9.00	0.11
Platte River	Development	684.02	1.48
Platte River	Forest harvest	3256.25	7.05
Platte River	Forest pathogen	20.48	0.04
Platte River	Unknown	0.90	<0.00
Threemile Creek	Development	739.20	2.91
Threemile Creek	Forest harvest	200.17	0.79
Threemile Creek	Forest pathogen	44.55	0.18
Threemile Creek	Unknown	0.78	<0.00

Ownership

State land experienced the greatest percent of land disturbed (15.45%) during the analysis period (Table 7), most resulting from forest harvest. Native American land experienced the next highest amount of disturbance (11.47% of land), also largely due to forest harvest (Table 7), though there was a very small (<0.2%) proportion of Native American land within the analysis area.

Table 7. Total percent of land disturbed, by ownership, 1990–2021.

Ownership	Percent Land Disturbed
County	10.65
Federal	2.57
Native American	11.47
Other public	1.97
Unknown	6.10
State	15.45

Patch Size

The disturbances due to blowdown were the largest in size (Figure 10). However, this disturbance was caused by one event that mainly occurred inside the park in the Alligator Hill area. Forest harvests, which were the most prevalent disturbance agent, exhibited similar patch size characteristics both inside and outside the park boundary (Figure 10).

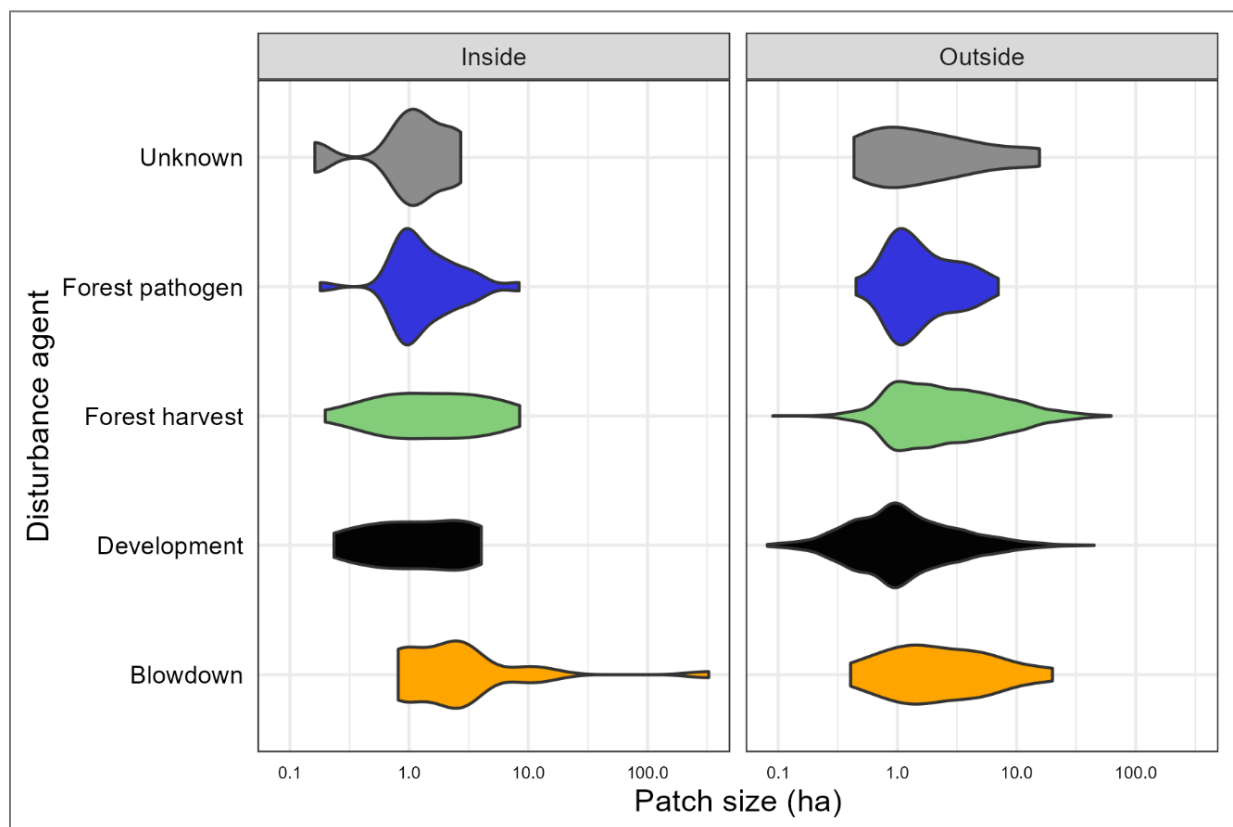


Figure 10. Violin plot displaying the patch size distribution of disturbances, by disturbance agent, inside and outside Sleeping Bear Dunes National Lakeshore, 1990–2021. The height of the violin indicates larger numbers of patches at a given size, and the ends of the violin indicate the minimum and maximum patch size. Note: X-axis is on log10 scale.

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Comparison Among GLKN Parks

Compared to other network parks, the disturbance regime inside and outside SLBE is unique (Figure 11). There is a concentration of development occurring near Traverse City, and up into both the Old Mission and Leelanau Peninsulas. South of these areas, disturbances are largely due to forest harvest. Like many other parks, we see the highest concentration of development along shorelines and population centers. The disturbance regime of SLBE most closely resembles that of SACN which has a mix of urban, agriculture, and forest dominated landscapes (Figure 11).

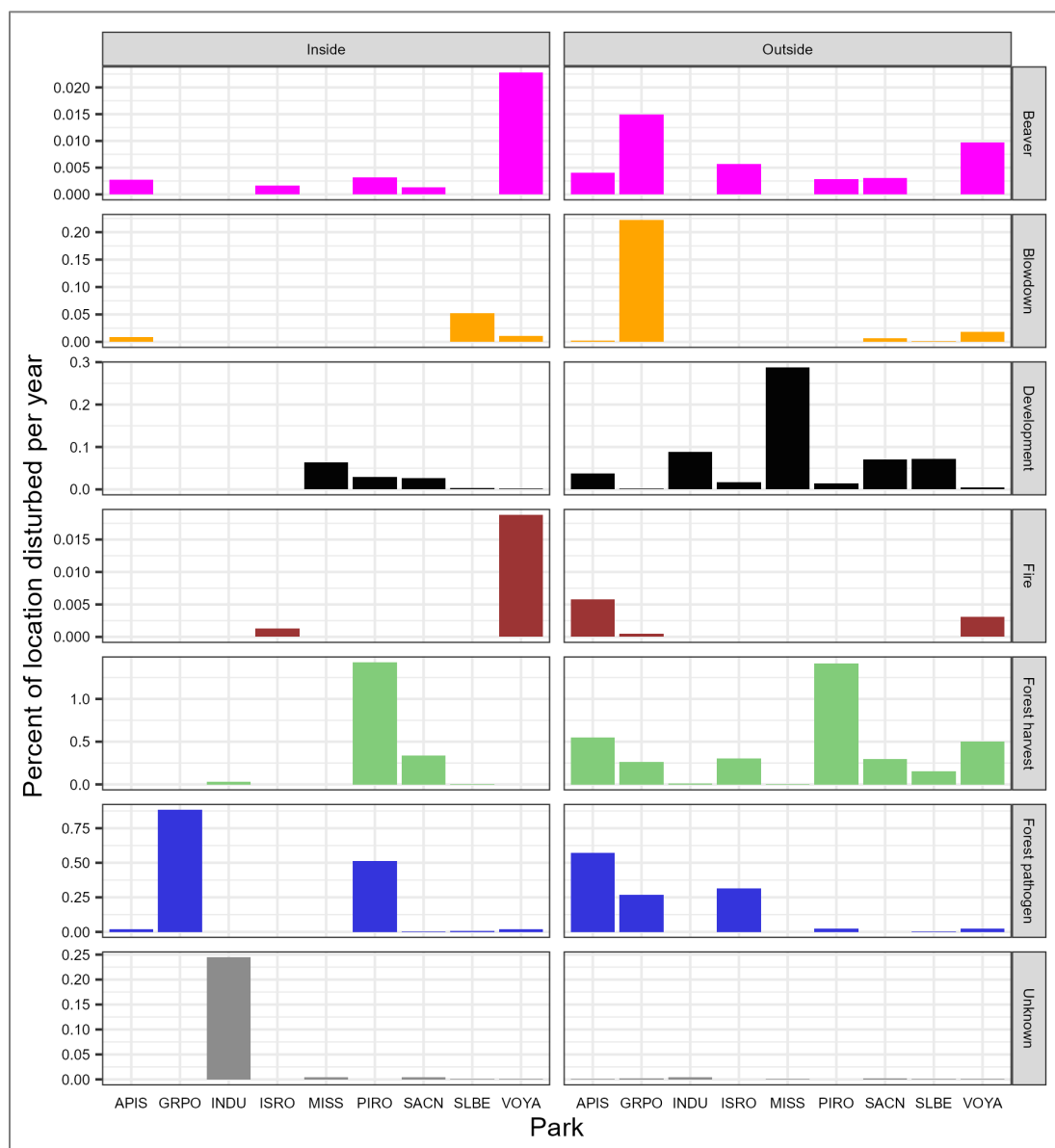


Figure 11. Yearly average percent of land disturbed inside and outside eight Great Lakes Network national parks, by disturbance agent, 1990–2021. Note: Y-axis scale varies by disturbance agent. APIS=Apostle Islands, INDU=Indiana Dunes, ISRO=Isle Royale, MISS=Mississippi National River and Recreation Area, PIRO=Pictured Rocks, SACN=St. Croix National Scenic Riverway, SLBE=Sleeping Bear Dunes, VOYA=Voyageurs.

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

During validation, we fill out numerous fields that are not necessarily reflected in the report series. Table 8 identifies additional fields filled in during the validation process and a brief description of each. The more detailed dataset is available upon request.

Table 8. 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.
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

Table 8 (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
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. Private ownership is difficult to definitively identify, so it is in the “Unknown” category.
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.

Appendix B. Map Series of Disturbances within the Sleeping Bear Dunes Analysis Area.

Figures 12 through 16 are detailed maps of disturbances in the analysis area.

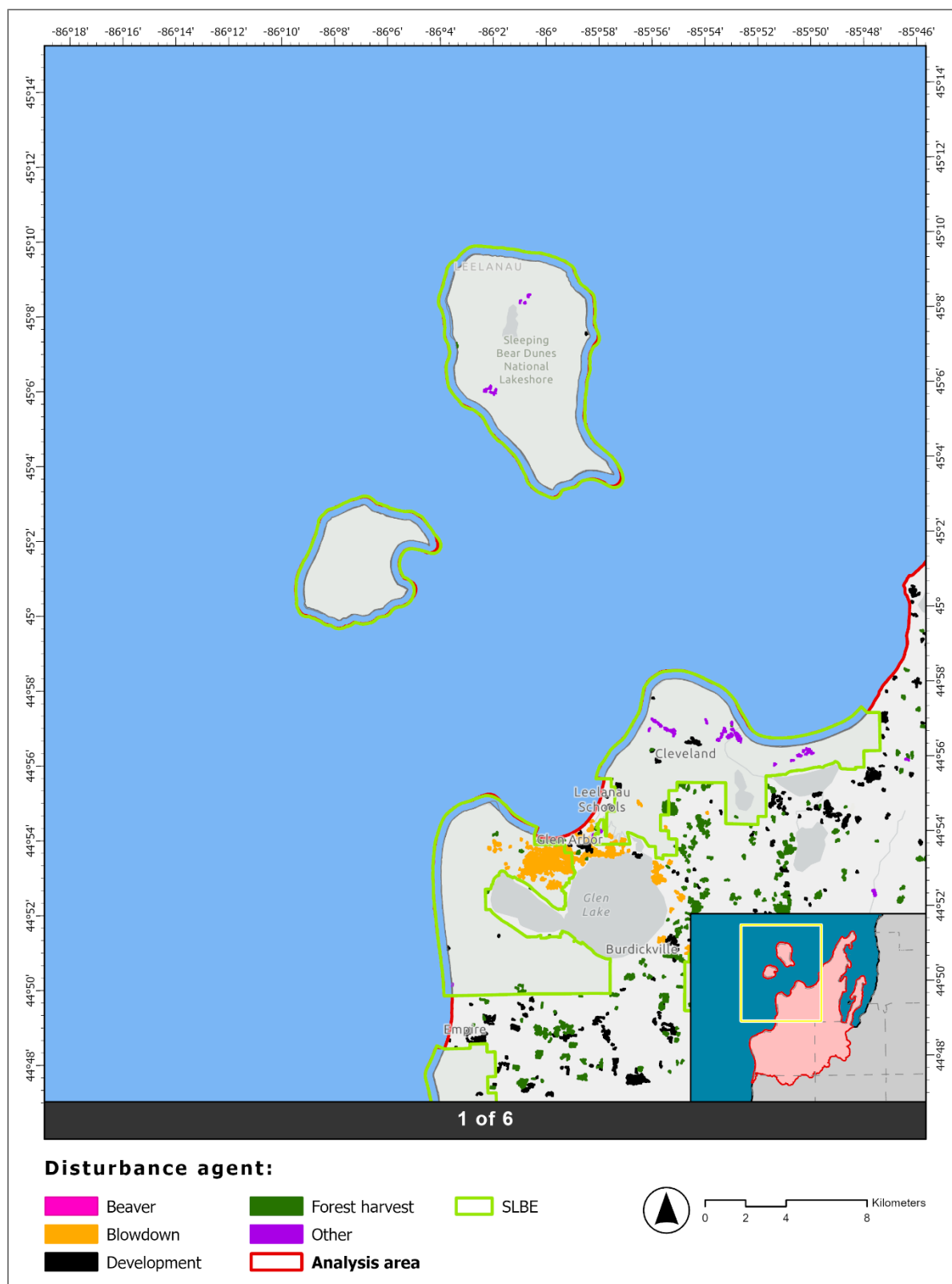


Figure 12. Disturbances in the northern portion of Sleeping Bear Dunes National Lakeshore including North and South Manitou Islands, 1990–2021.

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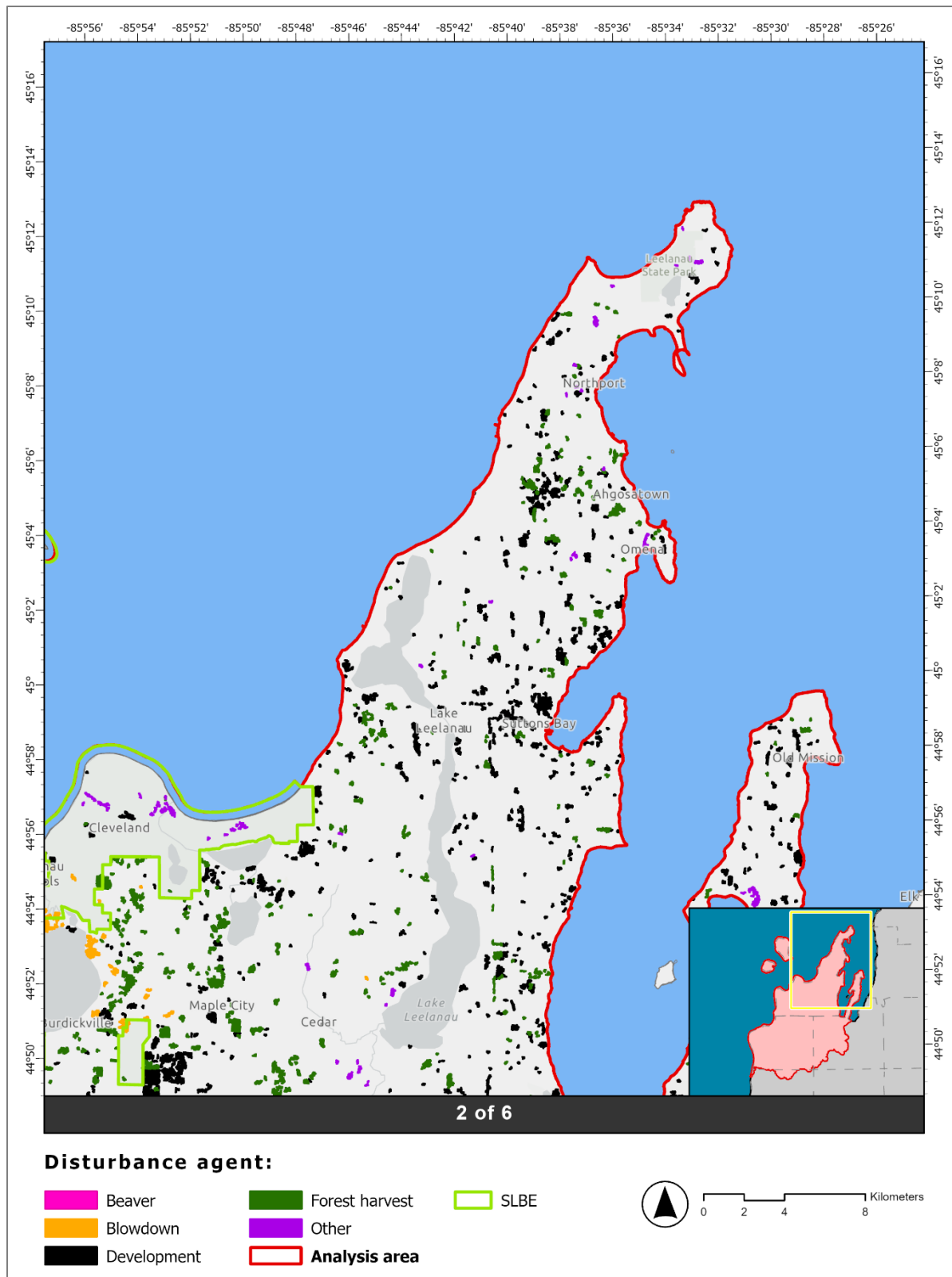


Figure 13. Disturbances in the Leelanau Peninsula portion of the study area near Leland and Lake Leelanau, 1990–2021.

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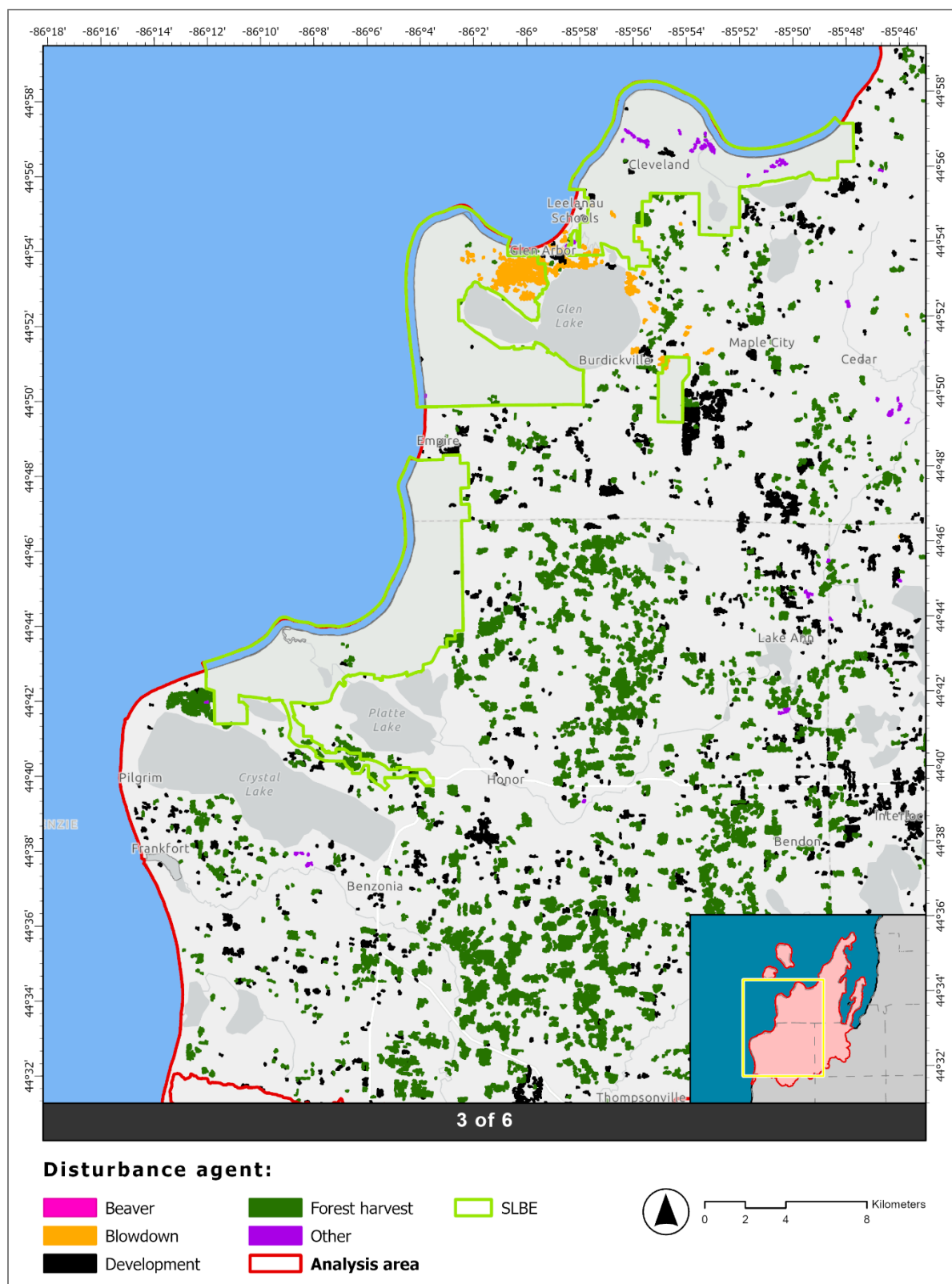


Figure 14. Disturbances in the southwest portion of the study area including the southern portion of Sleeping Bear Dunes National Lakeshore and east to Interlochen, 1990–2021.

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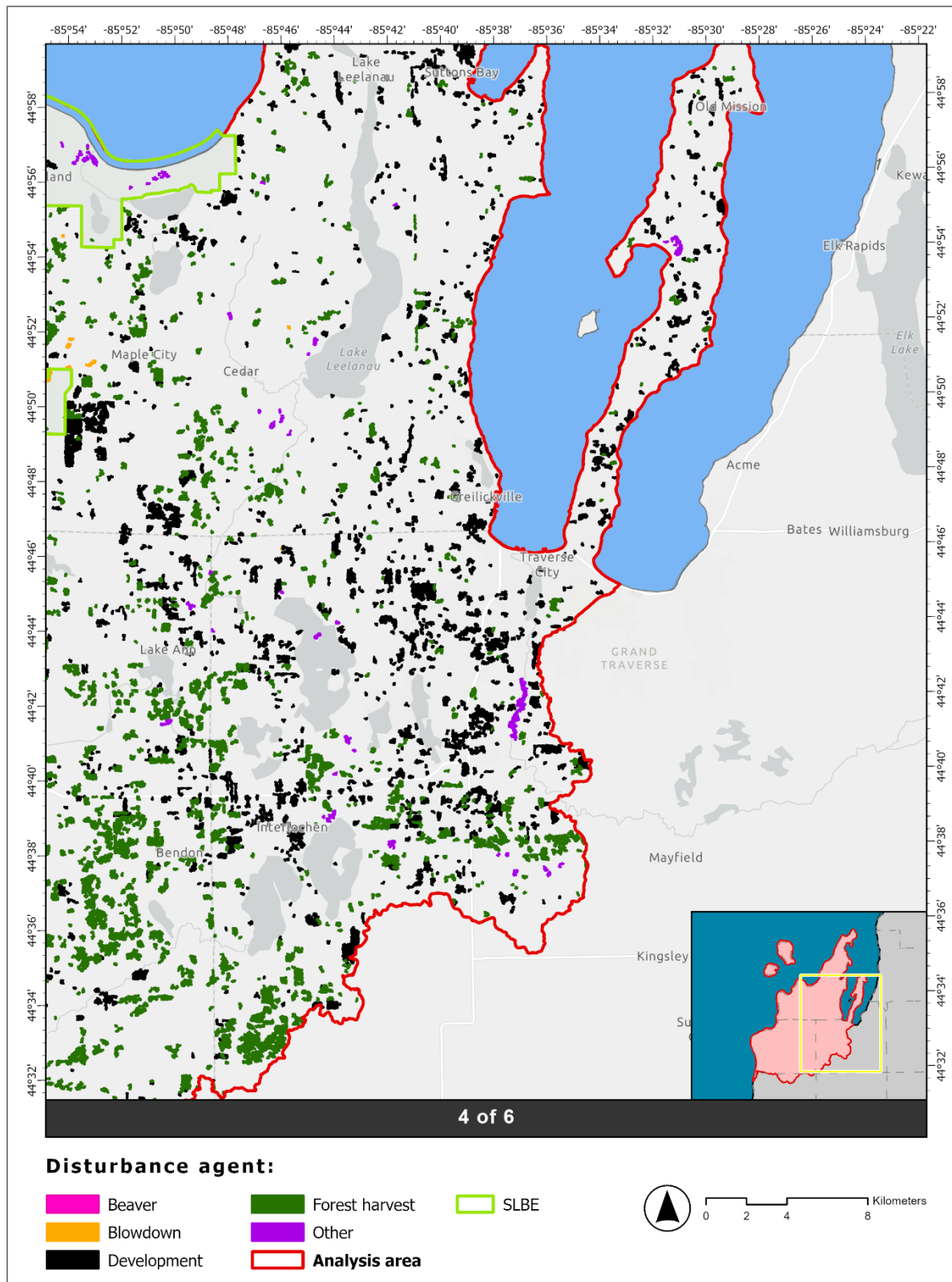


Figure 15. Disturbances in the eastern portion of the study area that includes the Old Mission Peninsula, Traverse City, and Interlochen, 1990–2021.

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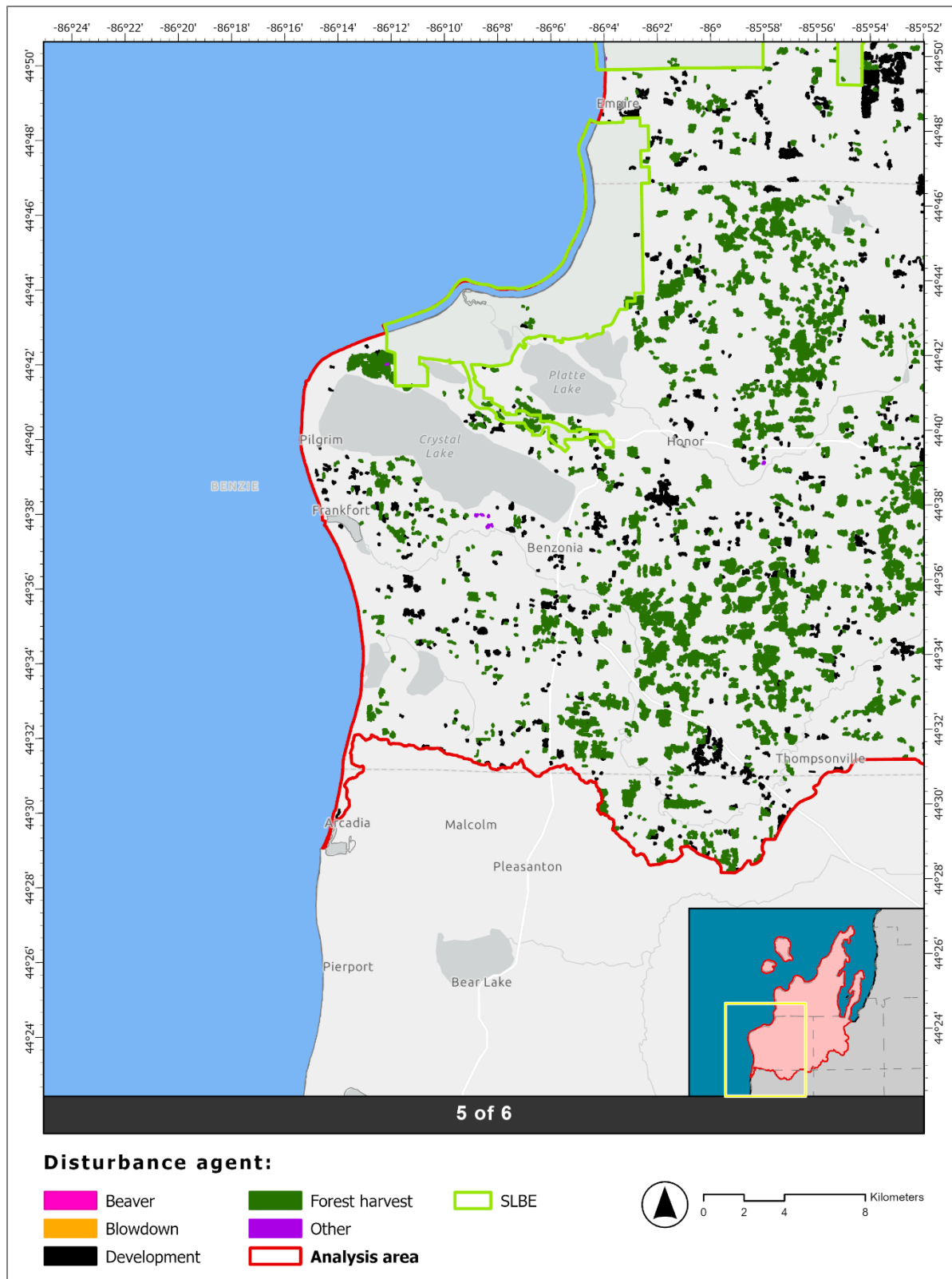


Figure 16. Disturbances in the southwestern portion of the study area near Crystal Lake and Platte River, 1990–2021.

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National Park Service
U.S. Department of the Interior



Science Report NPS/SR—2025/320
<https://doi.org/10.36967/2313944>

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