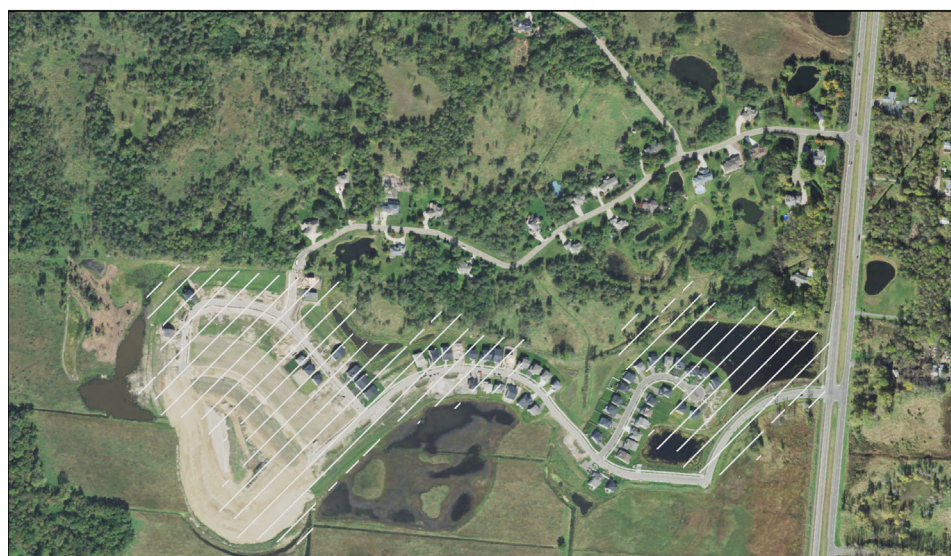




Landsat-based Monitoring of Landscape Dynamics at Mississippi National River and Recreation Area *1990–2019*

Natural Resource Data Series NPS/GLKN/NRDS—2022/1383



ON THE COVER

Aerial imagery showing expanding development activity in the Rice Creek watershed. Top image is from 2013 and the bottom image is from 2017.

Imagery from the National Agriculture Imagery Program.

Landsat-based Monitoring of Landscape Dynamics at Mississippi National River and Recreation Area

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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 Mississippi National River and Recreation Area 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 varies slightly from the original report published in 2013 in terms of the time period analyzed, which increased from six to 30 years (23 years difference). The period 2005–2010 was analyzed in 2013; this report encompasses 1990–2019. Results of this extended analysis showed that disturbances due to development activities affected the largest amount of land inside the park (307 ha total, or 10.23 ha annually). Lands in the area outside the park experienced far greater levels of disturbance, with development accounting for 99% of the disturbances and affecting 8.66% of the land (14,686 ha total, or 489.53 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 heat island effect of the Mississippi River corridor in the Twin Cities area.

Introduction

Reported here are disturbances for Mississippi National River and Recreation Area (MISS) 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 MISS was published in 2013, which summarized disturbances for a shorter time period (Kirschbaum and Gafvert 2013a). Here, disturbances occurring between 1990 and 2019 (30 years) are summarized.

Methods

Study Area

The analysis was conducted inside and adjacent to Mississippi National River and Recreation Area (MISS). The analysis area extended into three sub watersheds (Figures 1 and 2). In total 185,690 ha of land was monitored, of which 16,085 ha was land inside MISS. Included in the analysis area are three 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 split among developed, agriculture, and forest, as classified in the U.S. by the 2006 National Land Cover Database (NLCD) (Fry et al. 2011) (Figures 3 and 4).

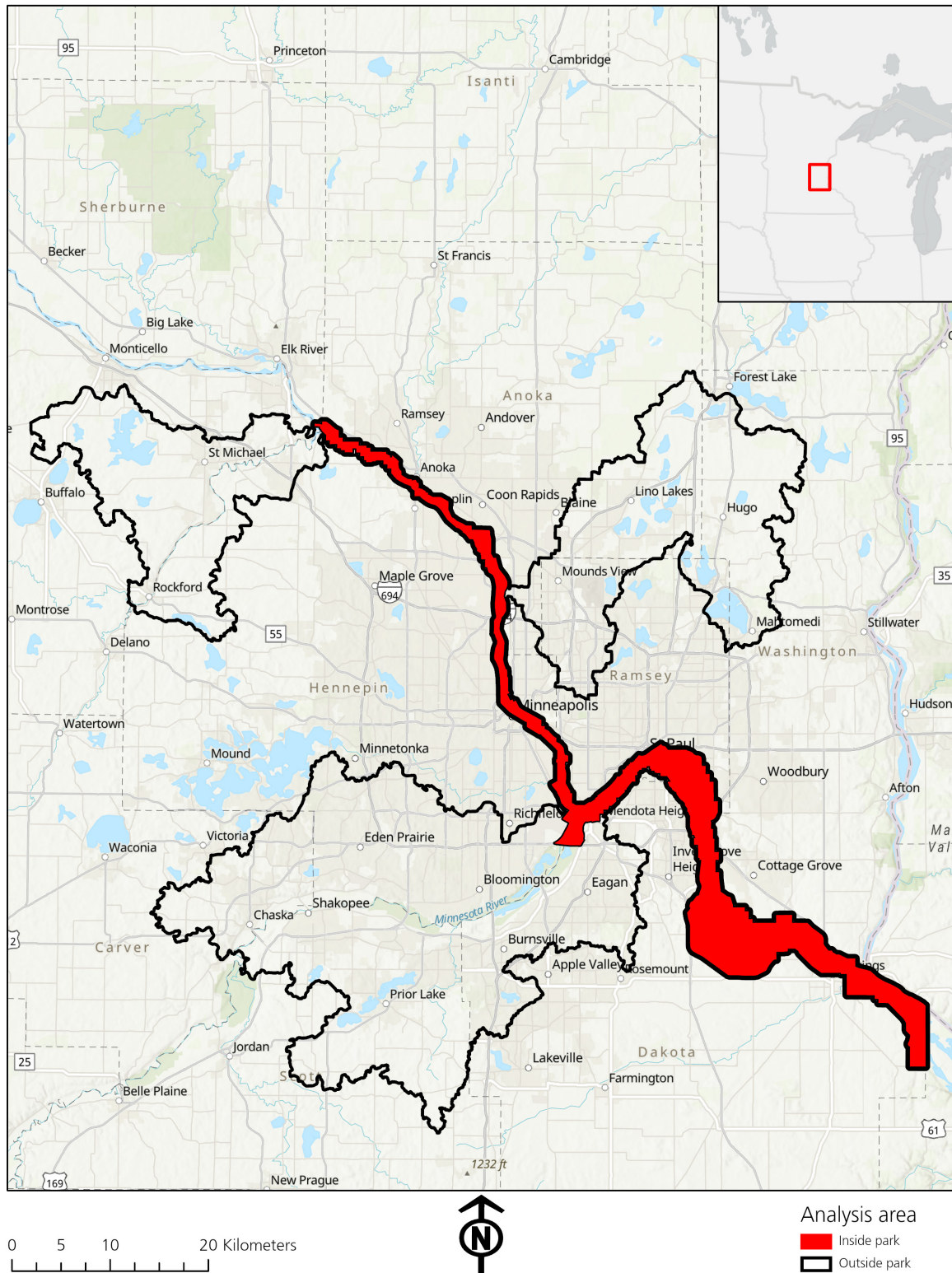


Figure 1. Analysis area for monitoring landscape dynamics in the greater Mississippi National River and Recreation Area ecosystem. Red outline indicates park extent and black outline indicates area monitored outside the park in three additional watersheds.

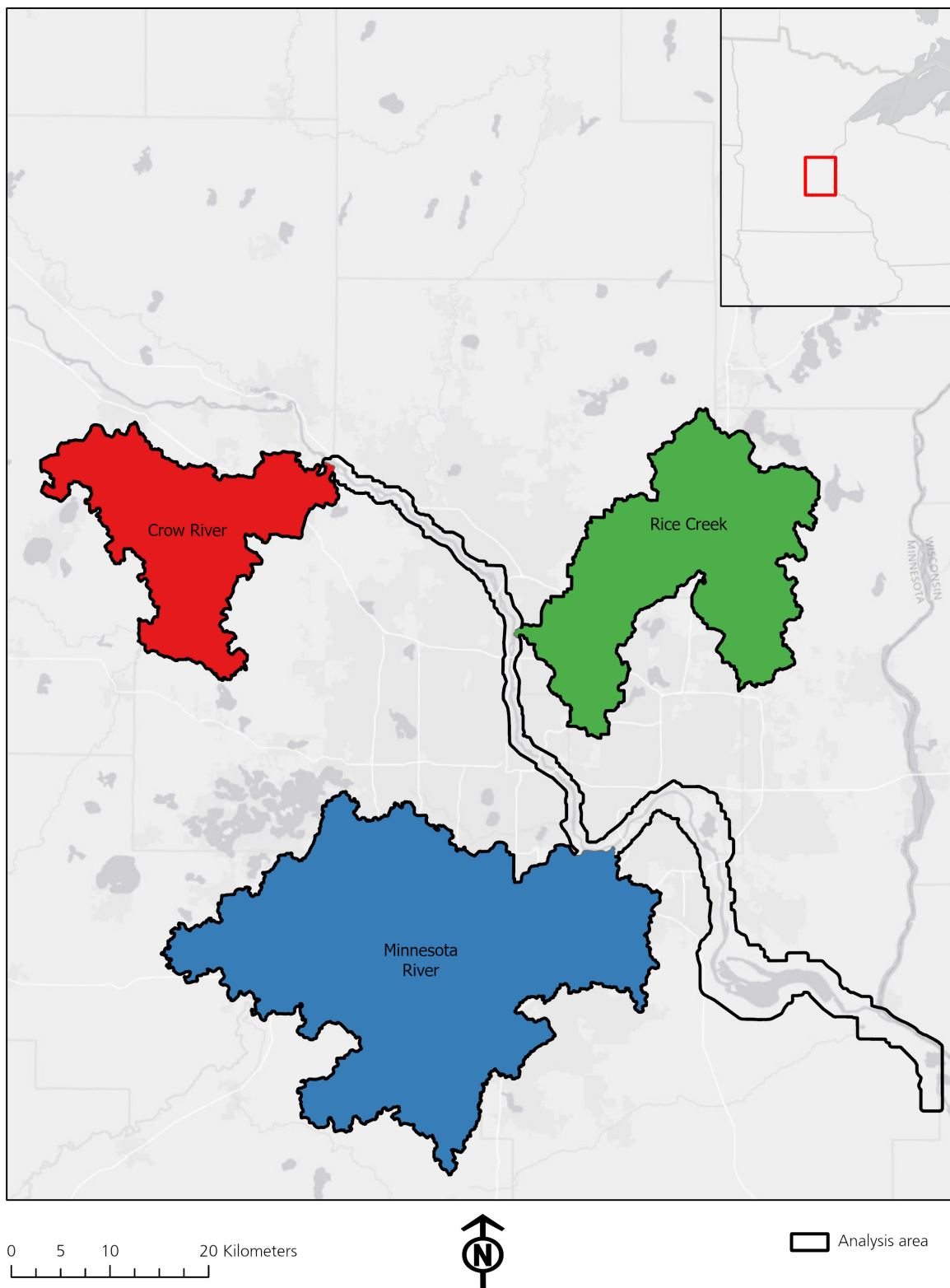


Figure 2. Labeled watersheds included in this analysis, as defined by level 10 Hydrologic Unit Codes (HUCs).

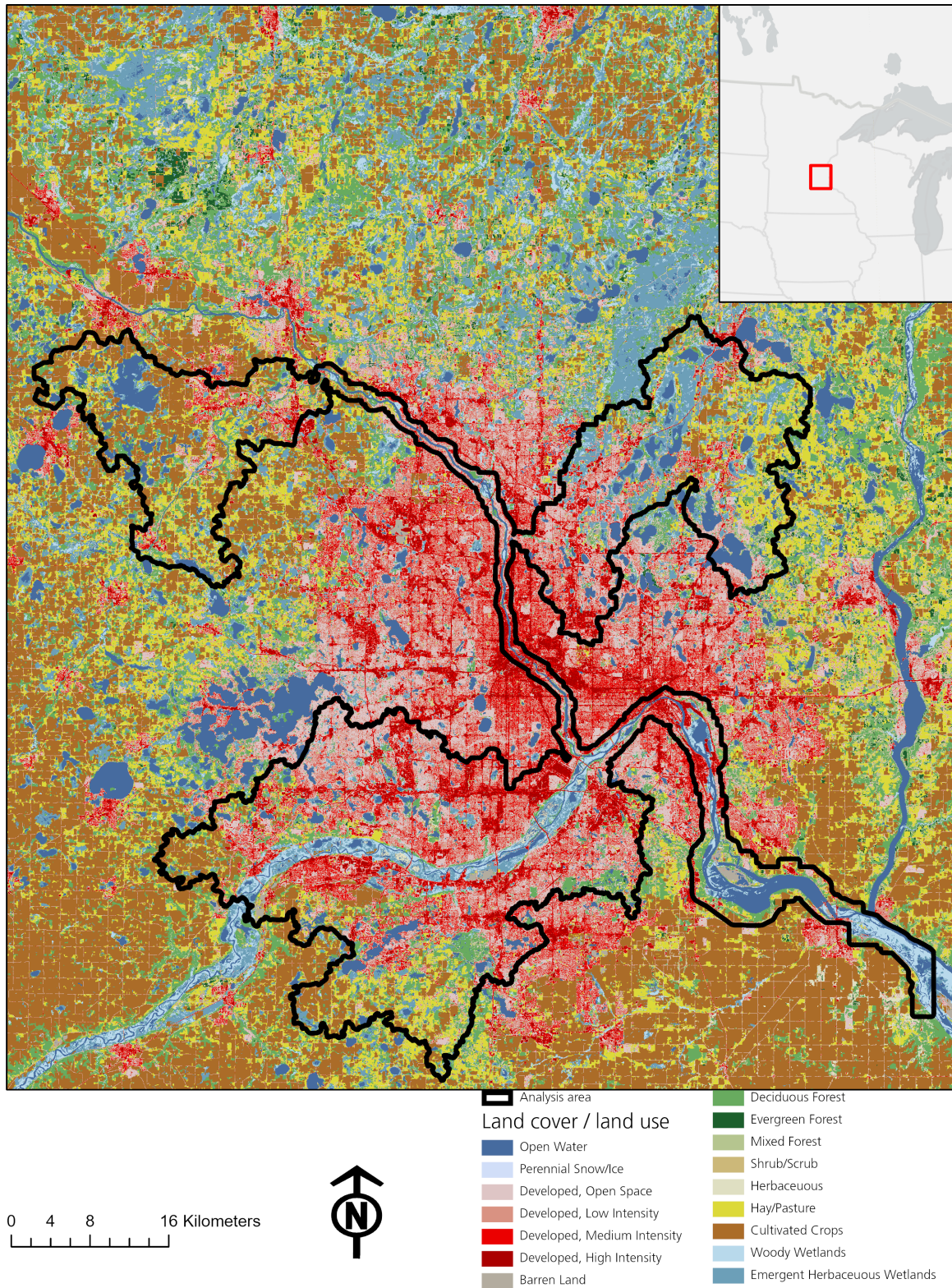


Figure 3. Land cover and land use classes in the analysis area, as mapped by the National Land Cover Database (Dewitz and U.S. Geologic Survey 2021).

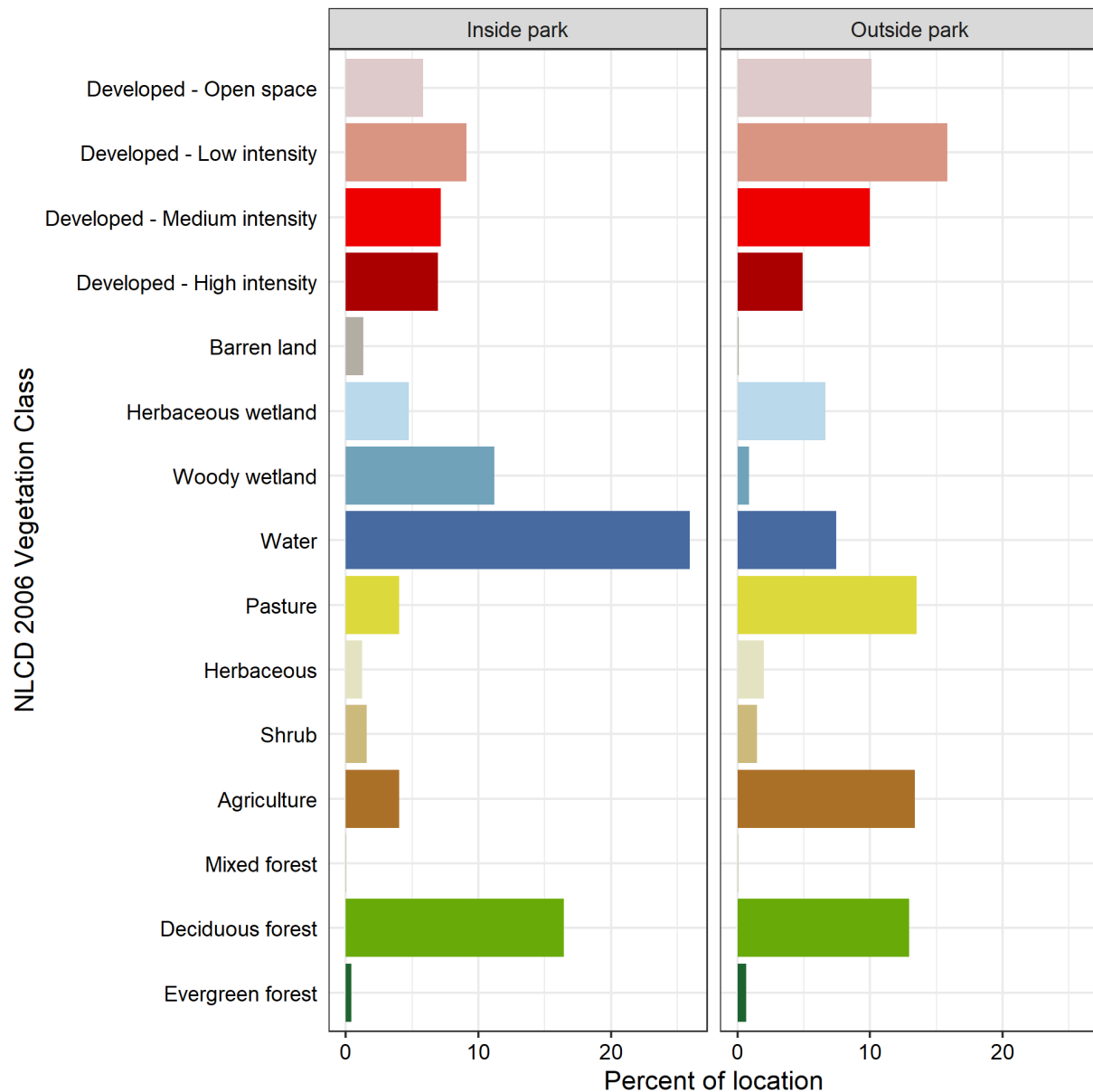


Figure 4. Percent of each land cover and land use class in the analysis area, as mapped by the National Land Cover Database (Dewitz and U.S. Geologic Survey 2021).

Ownership

Ownership within the analysis area was obtained from the Wisconsin Statewide Parcel Initiative (<https://www.sco.wisc.edu/parcels/data/>) and from the MN Gap Analysis Program (https://gdrs.dnr.state.mn.us/gdrs/data/pub/us_mn_state_dnr/plan_gap_stewardship_2008.zip) (Figure 5). Most land was privately held (90%), followed by county (5%), state (3%) and federal (2%) (Table 1).

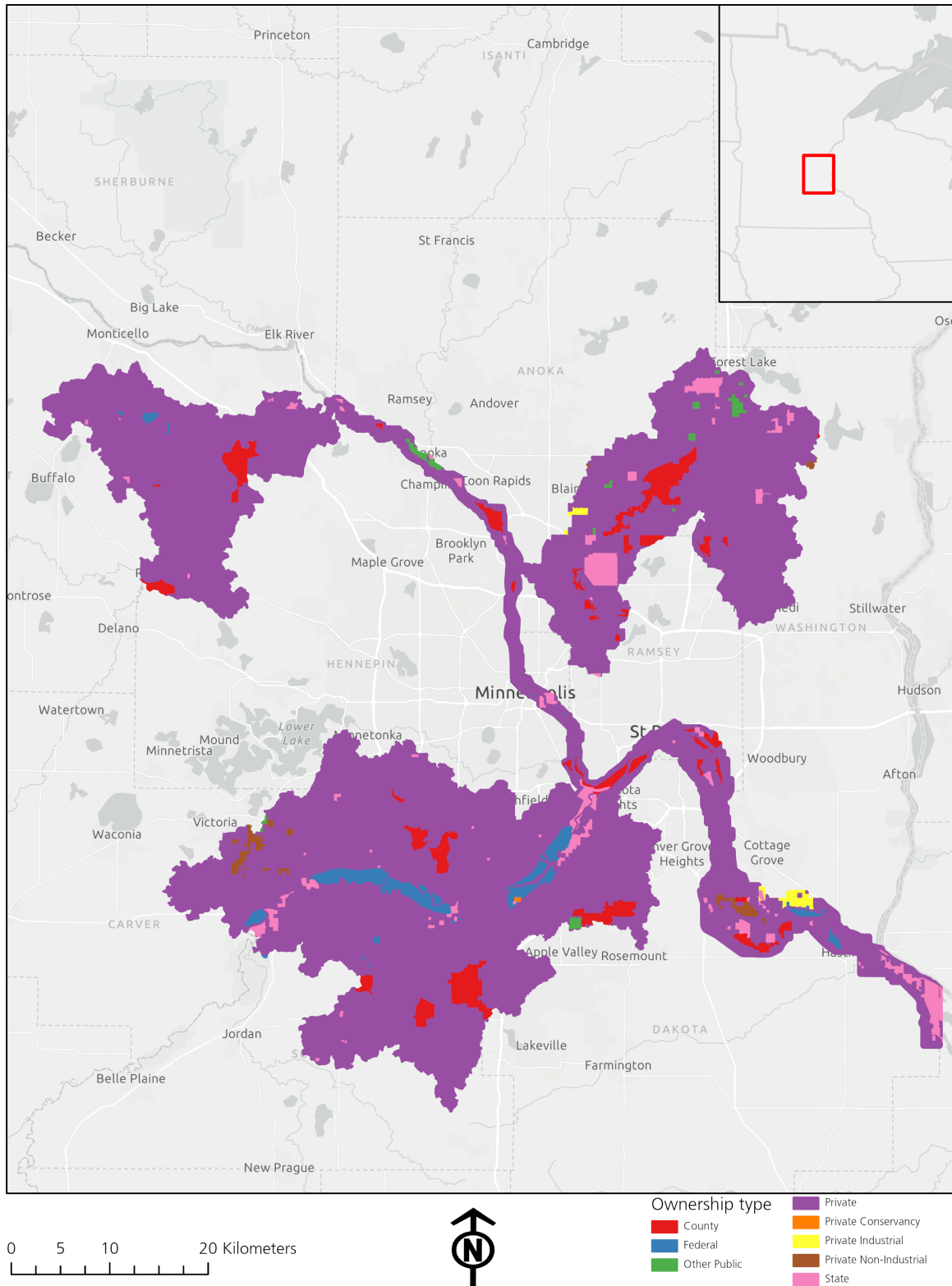


Figure 5. Ownership within the analysis area. Ownership data was obtained from the Wisconsin Statewide Parcel Initiative (version 6) and the Minnesota Gap Analysis Program.

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

Ownership	Area (ha)	Percent of land
County	8,781.2	4.73
Federal	3,355.7	1.81
State	5,278.5	2.84
Other Public	943.1	0.51
Private Industrial	630.9	0.34
Private	165,442.6	89.09
Private Non-Industrial	1,238.4	0.67
Private Conservancy	42.0	0.02

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 A1 in Appendix A to view all fields filled out during the validation process.

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 (1985–2019) 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.

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

Disturbance agent	Description and means of identification
Insect/disease (mortality)	Disturbances in the overstory due to insects or diseases that result in tree mortality.
Unknown	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
Unknown	Unknown

In a GIS environment, utilizing high resolution imagery, ancillary datasets, and the Landsat imagery itself, a total of 21,807 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 on private land) 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 (Figure 6) and by year (Figure 7). The most widespread and ubiquitous change agent was development, found nearly everywhere in the analysis area, but most prominently in the western portion of the Minnesota River watershed (Figure 6). The first two decades of the analysis time period show the largest level of development that tapered off since 2010 (Figures 7 and 8).

Inside the park, there was a very low level of disturbance overall (Figure 6). Of those that were detected, disturbances due to development were the most common (Figure 8). The remaining disturbance agents found inside the park were unknown and forest harvest.

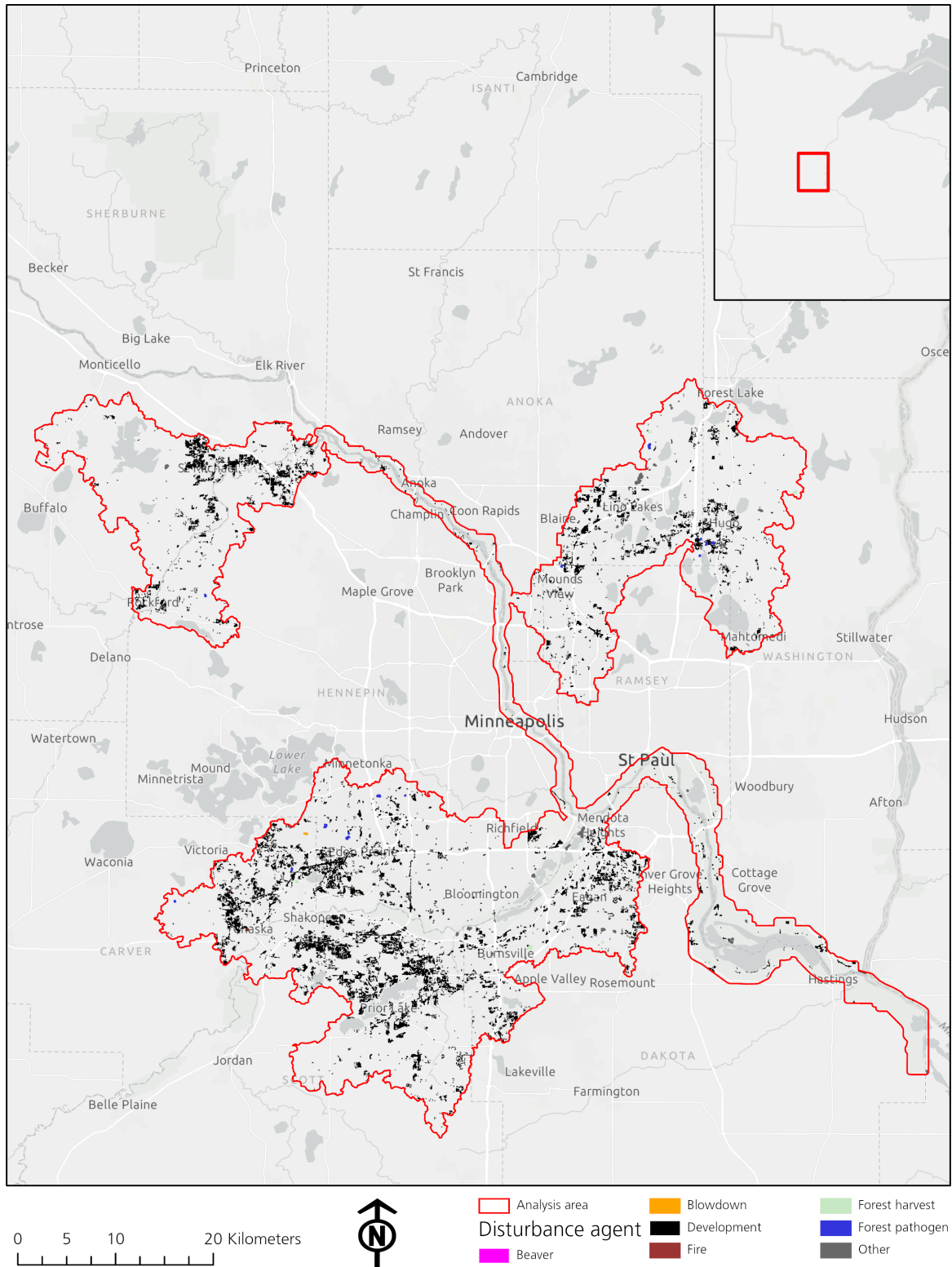


Figure 6. Spatial extent of disturbances within the analysis area for Mississippi National River and Recreation Area, by disturbance agent, with watershed boundaries overlaid.

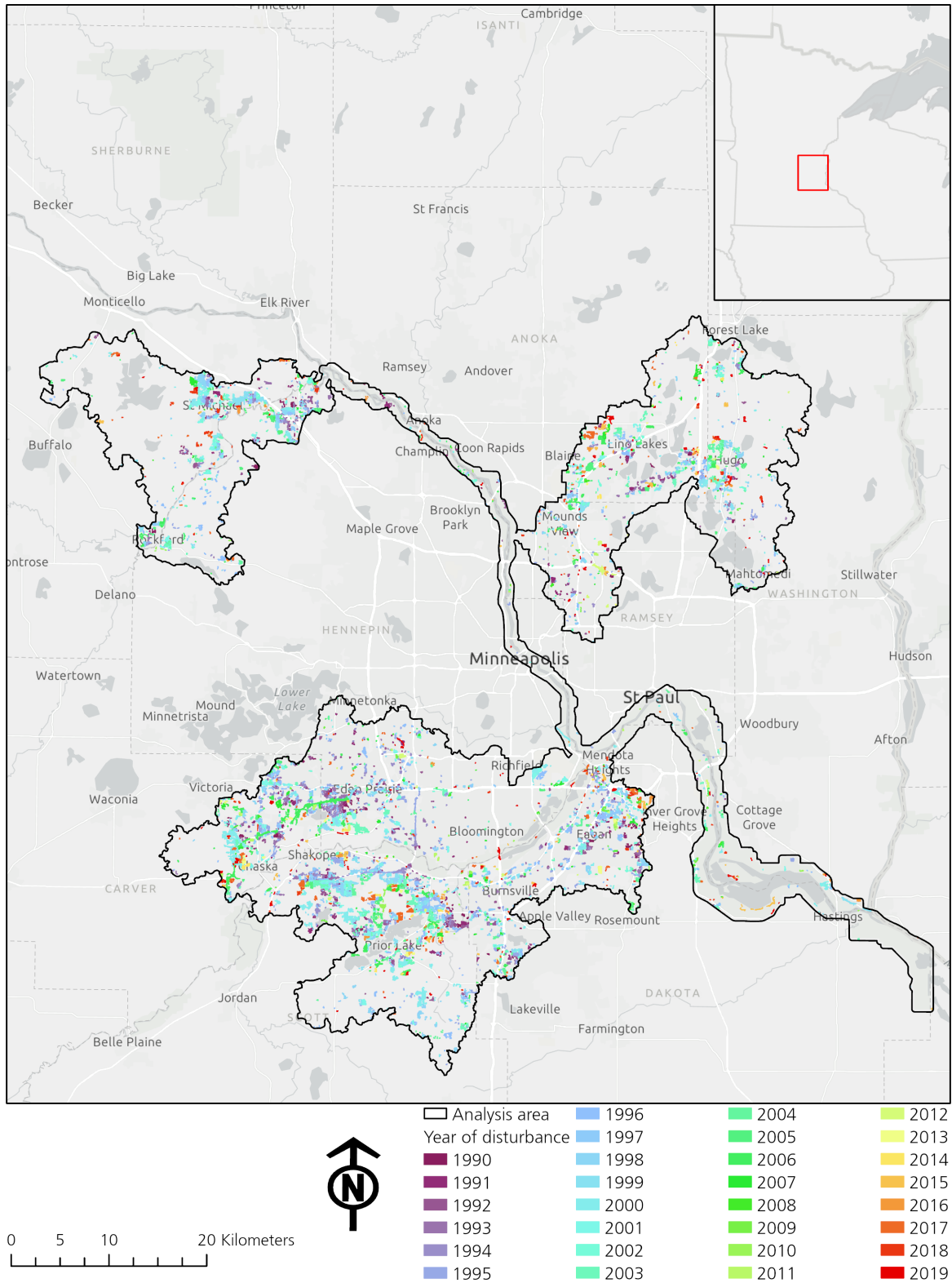


Figure 7. Spatial extent of disturbances within the analysis area for Mississippi National River and Recreation Area, identified by year of onset, with watershed boundaries overlaid.

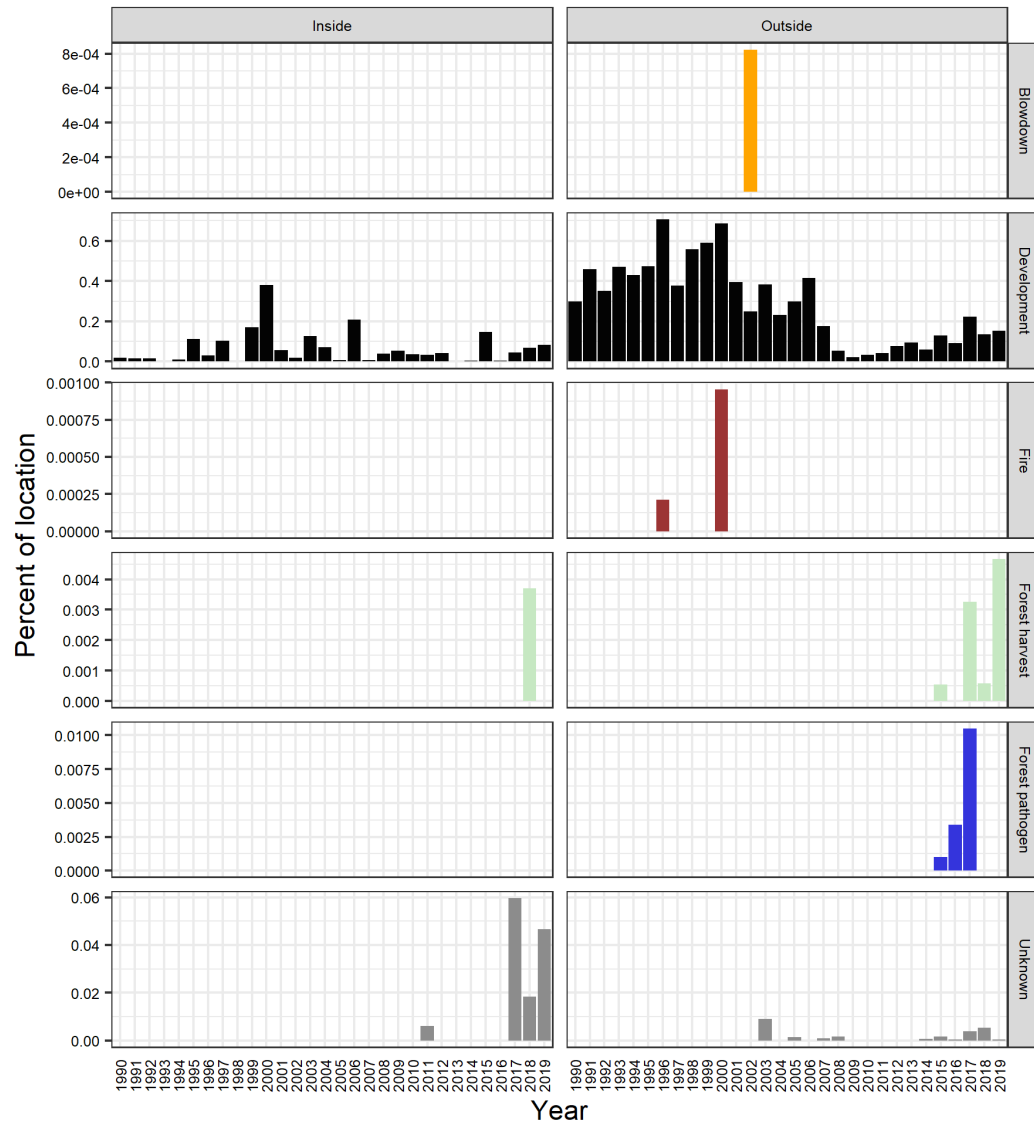


Figure 8. Percent of land disturbed inside and outside the park, by disturbance agent and year, 1990–2019. Note: Y axis scale varies by disturbance agent.

Inside vs. outside the park

Inside the park boundary, development activities disturbed the largest amount of land (1.91%, 307.67 ha) over the period, followed by unknown disturbances (0.26%, 43.21 ha) and forest harvest (Figure 8 and Table 4).

Outside the park, disturbances due to development were the most prevalent, occurring every year of the analysis (Figure 8) and averaged 506 ha during the analysis period (Table 4). There is also a drop in development generally corresponding with the 2008 housing market crash. Other disturbance agents present outside the park included blowdown, fire, forest harvest, forest pathogen, and unknown totaling 0.05% of land disturbed.

Table 4. Total percent and area (hectares) disturbed by disturbance agent during analysis period, inside and outside the park.

Disturbance agent	Inside park Area (ha)	Inside park Percent land disturbed	Outside park Area (ha)	Outside park Percent land disturbed
Beaver	0	0	0	0
Blowdown	0	0	1.4	<0.01
Development	307.67	1.91	14,686.14	8.66
Fire	0	0	1.98	<0.01
Forest harvest	0.59	0	15.35	0.01
Forest pathogen	0	0	25.27	0.01
Unknown	21.04	0.13	42.24	0.02

Watershed

There were three watersheds located within the study area (see Figure 2). Of the watersheds, Minnesota River had the highest disturbance rates (10.76% of the land in the watershed disturbed) during the analysis period (Figure 9 and Table 5). Spatially, most development occurred in the western edge of the watershed (Figure 6). The Crow River watershed experienced the next highest level of disturbance (7.57% of the land in the watershed disturbed), again nearly all disturbance the result of development activities (Figure 9 and Table 6) occurring in the Albertville and Rogers areas. Lastly, the Rice Creek watershed experienced the lowest amount of disturbance (6.15 percent of the land in the watershed disturbed) with the disturbances being equally distributed throughout the watershed. As with other watersheds, ~99% of the disturbances were due to development activities. In all watersheds the amount disturbed followed the same relative pattern, with development peaking just prior to 2008 with a large decline in 2009 then steadily increasing since 2009.

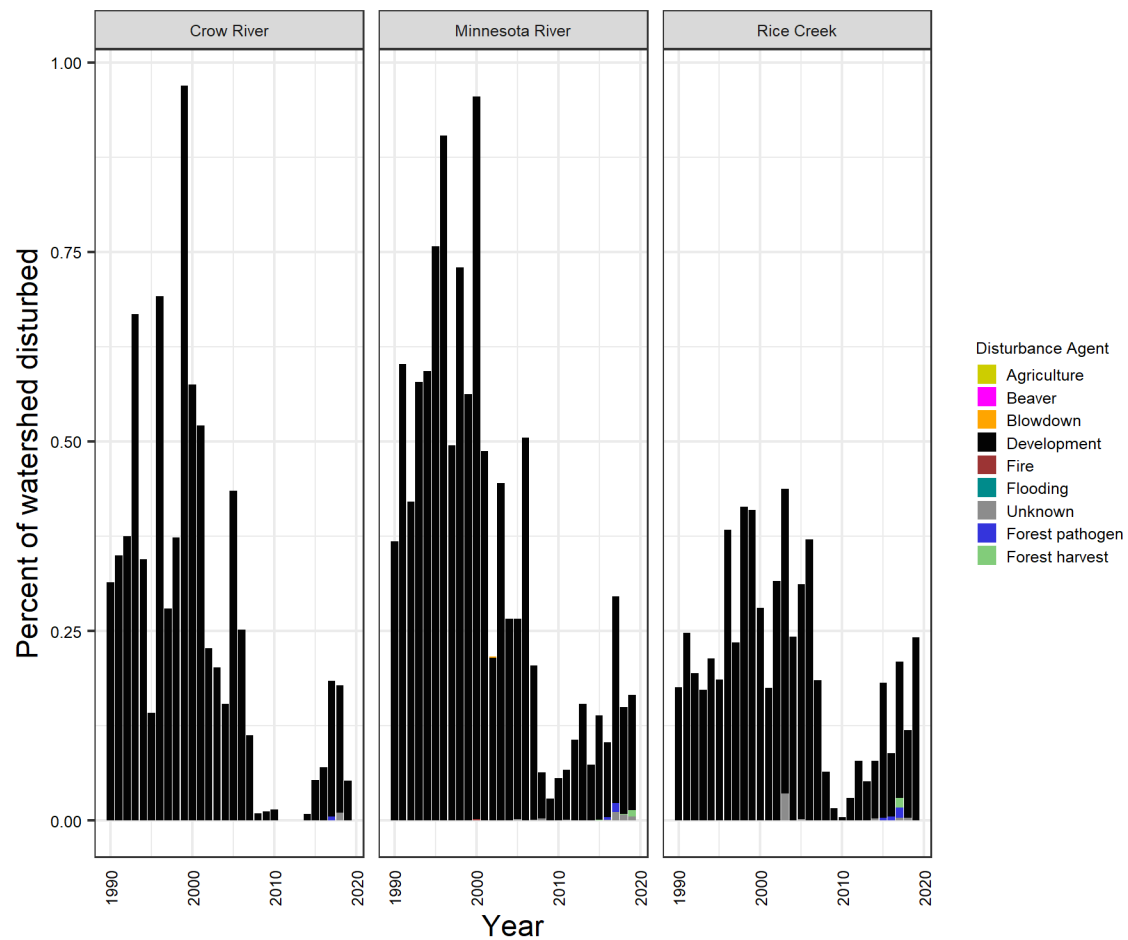


Figure 9. Percent of land disturbed within each watershed, by disturbance agent and year, 1990–2019.

Table 5. Total area and percentage of watershed disturbed, 1990–2019.

Watershed	Area (ha)	Percent
Crow River	2,315.24	7.57
Minnesota River	9,630.27	10.76
Rice Creek	2,635.03	6.12

Table 6. Total area and percentage of watershed disturbed by disturbance agent, 1990–2019.

Watershed	Area (ha)	Hectare land disturbed	Percent land disturbed
Crow River	Blowdown	0	0
Crow River	Development	2,310.59	7.56
Crow River	Fire	0	,0
Crow River	Forest harvest	0	0
Crow River	Forest pathogen	1.54	0.01
Crow River	Unknown	3.11	0.01
Minnesota River	Blowdown	1.40	<0.00
Minnesota River	Development	9,574.33	10.69
Minnesota River	Fire	1.98	<0.00
Minnesota River	Forest harvest	9.81	0.01
Minnesota River	Forest pathogen	14.26	0.02
Minnesota River	Unknown	28.50	0.03
Rice Creek	Blowdown	0	0
Rice Creek	Development	2,598.96	6.03
Rice Creek	Fire	0	0
Rice Creek	Forest harvest	5.54	0.01
Rice Creek	Forest pathogen	9.48	0.02
Rice Creek	Unknown	21.06	0.05

Ownership

The ownership category experiencing the greatest percent of land disturbed was private, with 8.88% of land in private ownership being disturbed during the analysis period (Table 7 and Figure 10). Most of the disturbance in this ownership category was from development, which peaked in 2008, dropped, and has been slowly increasing since 2009. Land categorized as “Other public lands”

experienced the next highest amount of disturbance, with a total of 4.55% of their land being disturbed during the analysis period, largely due to development (Table 7 and Figure 10). The remaining ownership categories had disturbances totaling 7% of land disturbed throughout the analysis period, with development being the dominant disturbance agent (Table 7 and Figure 10).

Table 7. Total percent of land disturbed, by ownership, 1990–2019.

Ownership	Percent land disturbed
County	1.55
Federal	1.49
Other Public	4.55
Private	8.88
Private Industrial	0.79
Private Non-Industrial	2.97
State	2.73

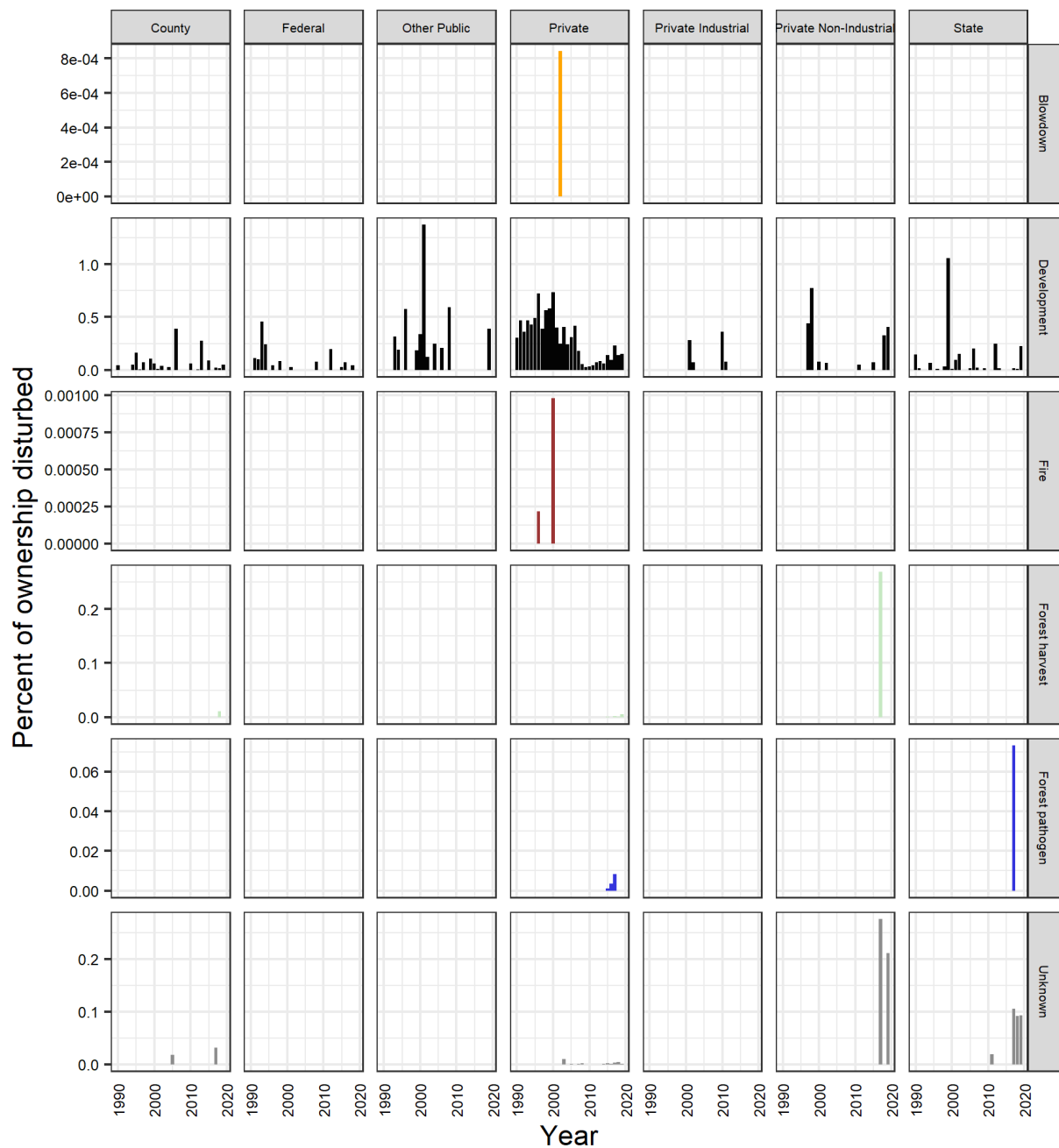


Figure 10. Percent of land disturbed within each ownership category, by disturbance agent and year, 1990–2019.

Patch size

Overall patch size of the dominant disturbance agent (development) inside and outside the park was relatively small, with most of the patches being less than 10 ha in size (Figure 11). Because there were so few disturbances besides development, the patch size data for remaining disturbance agents is minimal.

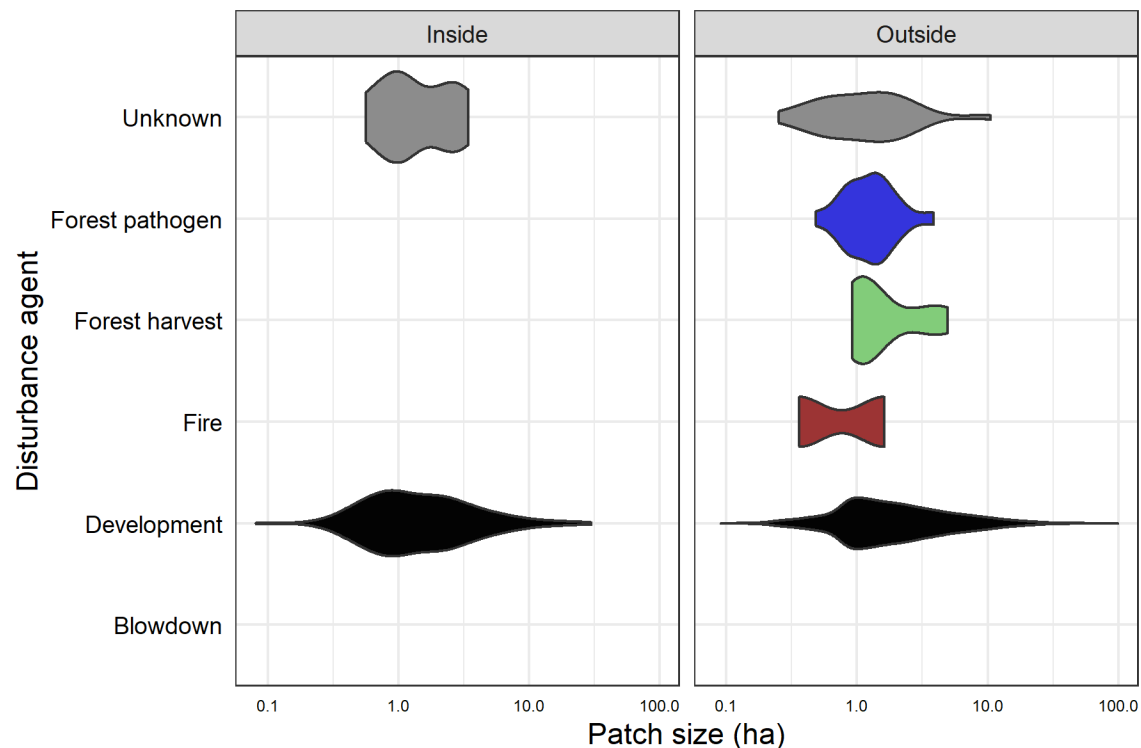


Figure 11. Violin plot displaying the patch size distribution of disturbances by disturbance agent inside and outside the park, 1990–2019. The height of the violin indicates larger numbers of patches at a given size, and the ends of the violin indicate the minimum and maximum patch size. Note: X axis is on log10 scale.

Comparison among GLKN parks

Compared to other network parks, the disturbance regime of the MISS study area is unique (Figure 12). Of all parks it has the highest percent of disturbance due to development. It is the also the only park where development is the largest agent of change. The most common disturbances found inside GLKN parks tend to be beaver, blowdown, and forest pathogen. None of these were found inside the park at MISS, but given this park is located in a highly urbanized environment, it is not surprising that development activities dominate the landscape. During the polygon validation, we often noticed buildings and parking lots associated with a developed area were torn down and redeveloped. This suggests there will continue to be a low level of ongoing development, even if it is simply re-developing the same parcels of land. It was also noteworthy to see the very abrupt decline in development that coincided with the 2008 housing market crash (see Figure 8).

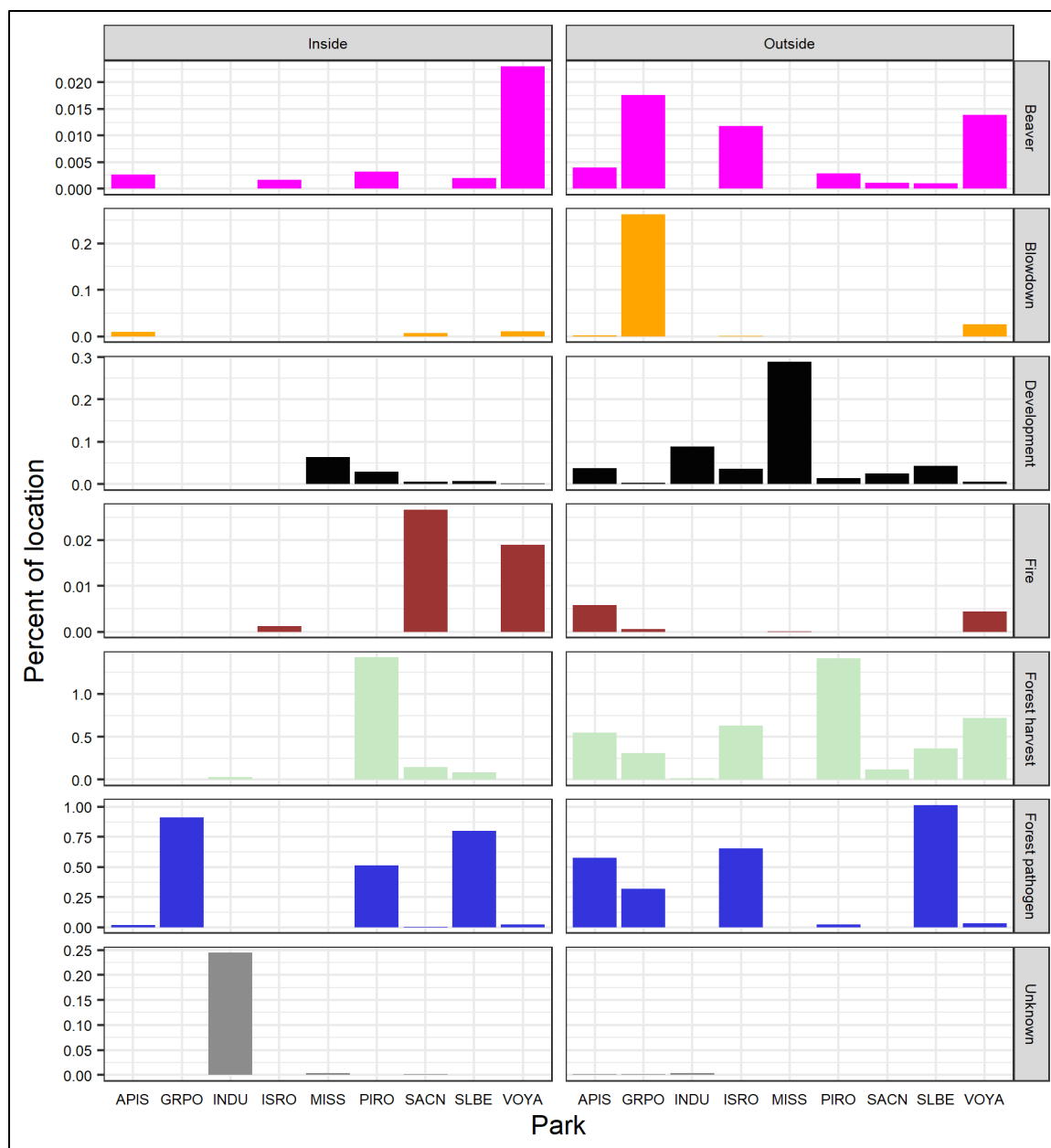


Figure 12. Yearly average percent of land disturbed inside and outside eight Great Lakes Network national parks, by disturbance agent, 1990–2019. Note: Y axis scale varies by disturbance agent. APIS=Apostle Islands, INDU=Indiana Dunes, ISRO=Isle Royale, MISS=Mississippi National River and Recreation Area, PIRO=Pictured Rocks, SACN=St. Croix National Scenic Riverway, SLBE=Sleeping Bear Dunes, VOYA=Voyageurs.

Conclusion

This data summary analysis confirmed the following points:

- 1) During the 30-year time period of this analysis, MISS park lands have experienced very low levels of landscape disturbances. This is similar to other parks in the Great Lakes Network (Kirschbaum and Gafvert 2013b, 2014a, 2014b; Gafvert and Kirschbaum 2015; Kirschbaum and Gafvert 2017; Kirschbaum 2021, 2022a, 2022b). However, the dominant disturbance type at MISS (development) is not transient, it is the nearly permanent conversion of land from a natural state to an impervious state.
- 2) Because this park is located in such an urban-dominated environment, it is important that it continues to act as a buffer from outside pressures. Development activities such as expanding roads, conversion of green space to business parks and single-family homes have been dominant for the last 30 years and, if it continues, could alter riparian 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. 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 A1. 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 A1 (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.

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