



Landsat-based Monitoring of Landscape Dynamics at Isle Royale National Park, 2003-2008

Natural Resource Technical Report NPS/GLKN/NRTR—2012/535



ON THE COVER

Spruce mortality occurring in 2003 on the shore of Lake Superior near McCormick Reef at Isle Royale National Park.
Photograph by: Paul Brown, Isle Royale National Park



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Abstract

Isle Royale National Park (ISRO) is an island in northwest Lake Superior, approximately 45 km from Thunder Bay, Ontario, and 25 km from the Minnesota mainland. The park is located at the southern range of numerous plant and animal communities of the boreal ecosystem and is home to self-sustaining wolf and moose populations. Disturbances, or distinct changes in vegetative cover, are an important part of how this ecosystem functions at the southern edge of its range. Monitoring these disturbances through time will provide information regarding historic disturbance regimes compared to present and future conditions and trends. For this analysis, disturbances in and around ISRO were delineated for six years, 2003-2008, using a combination of Landsat satellite imagery and high resolution aerial photos. We employed a set of computer algorithms, collectively known as LandTrendr, in conjunction with a dense time series of Landsat imagery to track vegetation changes in and around the park. Disturbance agents such as fire, forest harvest, development, flooding due to beaver activity, and blowdowns were attributed to each disturbance, in addition to the year of occurrence, and starting and ending vegetation classes. LandTrendr was used to identify apparent disturbances, after which high resolution imagery (e.g., airphotos, Quickbird) was used for photo interpretation to substantiate evidence of a disturbance, and hence, validate whether the disturbance occurred. Summary analyses showed that disturbances outside the park were dominated by forest harvest and development, while inside the park disturbances were most often caused by beaver, blowdowns, or forest pathogens. After relativizing the data, the areas adjacent to ISRO in Canada and Minnesota experienced 88 times more disturbance than inside the park.

Acknowledgments

We would like to acknowledge staff at Isle Royale National Park for assistance in aerial photo acquisition, providing on-the-ground knowledge of land cover changes, logistical support, and in helping to design the land cover monitoring program's scope and extent for the park.

The team at Oregon State University has been instrumental in the development of the Great Lakes Network's land use / land cover program, by providing assistance and guidance in development of the land cover monitoring protocol and in the implementation of the LandTrendr methods in land cover change detection.

We would also like to thank Bill Route, Paul Brown, and Mark Romanski for reviewing and providing useful comments on this report, which greatly improved it. Lastly, we would like to thank Ted Gostomski for final formatting and additional edits.

List of Terms and Acronyms

Electromagnetic spectrum	The range of all possible frequencies of electromagnetic radiation. The electromagnetic spectrum of an object is the characteristic distribution of electromagnetic radiation emitted or absorbed by that particular object.
Panchromatic	Incorporates all wavelengths of visible light.
B&W	Black and white: in this report it refers to the airphoto type and was more commonly used prior to the 1990s.
CIR	Color infrared: in this report it refers to the electromagnetic spectrum the airphotos capture, i.e., the ‘true color’ portion of the spectrum (red, green, blue) and the infrared portion. However, CIR film can only capture 3 bands of information at one time, which is most commonly green, red, and infrared.
RGB	Red, green, and blue: sometimes referred to as ‘true color’, it is the portion of the electromagnetic spectrum the film, or sensor, is quantifying.
Landsat	In this report it refers to the Landsat satellite family, and more specifically to either Landsat 5 (launched in 1984) or Landsat 7 (launched in 1999), both with 30 m pixels (resolution). http://landsat.gsfc.nasa.gov/about/
TM	Thematic Mapper: one of the Earth observing sensors introduced into the Landsat program, located on the Landsat 5 satellite. http://en.wikipedia.org/wiki/Thematic_mapper
ETM+	Enhanced Thematic Mapper plus: one of the Earth observing sensors introduced into the Landsat program, located on the Landsat 7 http://landsat.usgs.gov/
SLC	Scan Line Corrector: device on-board the Landsat 7 (ETM+) satellite which compensates for the forward motion of the spacecraft so that the resulting scans are aligned parallel to each other.
SLC-off	Scan Line Corrector – off: this device failed on May 31, 2003, creating data gaps in each Landsat 7 (ETM+) image acquired after May 31, 2003.
APFO	Aerial Photography Field Office: a United States Department of Agriculture (USDA) Farm Service Agency (FSA) office located in Salt Lake City, UT. This office stores a large amount of aerial photography, among many other types of data. http://www.fsa.usda.gov/FSA/apfoapp?area=apfohome&subject=landing&topic=landing
NAIP	National Agriculture Imagery Program: acquires aerial imagery during the agricultural growing seasons in the continental U.S. It commonly has 1m

	resolution. http://www.fsa.usda.gov/FSA/apfoapp?area=home&subject=prog&topic=nai
NAPP	National Aerial Photography Program: an interagency Federal effort coordinated by the USGS which uses NAPP products to revise maps. In this report it refers to a particular set of imagery circa 1987. The NAPP program replaced the National High Altitude Photography (NHAP) program which was initiated in 1980. http://eros.usgs.gov/#/Guides/napp
DEM	Digital elevation model: a digital representation of ground surface topography or terrain.
GIS	Geospatial Information System: any system that captures, stores, analyzes, manages, and presents data that are linked to location.
NVCS	National Vegetation Classification System: a scheme for classifying the vegetation of the United States, maintained by NatureServe. http://biology.usgs.gov/npsveg/nvcs.html
NLCD	National Land Cover Data: created by USGS to produce a consistent land cover map for the U.S using Landsat imagery. Currently there are two NLCD datasets, one characterizing land cover in 1990, the other for year 2001, with another (2006) to be released in the near future. http://www.mrlc.gov/
EOSD	Earth Observation for Sustainable Development of forests: Canadian agency using space technologies to create products for forest inventory. Landsat imagery was used to create this land cover dataset. http://cfs.nrcan.gc.ca/subsite/eosd

Introduction

The Great Lakes Inventory and Monitoring Network (hereafter GLKN or Network) implemented the landscape dynamics protocol (Kennedy et al. 2010) at Isle Royale National Park (ISRO) in 2010. As part of the protocol, changes in land cover/land use are summarized and categorized for six of the more recent years, in this case 2003-2008. Landscape dynamics was ranked among the top five vital signs for national parks in the Great Lakes region (Route and Elias 2007).

The landscape dynamics protocol developed for long-term implementation and monitoring identifies changes in land cover and their causal agents. The detection of disturbances occurs within the park and an area adjacent to the park to help put the park in context. The size and location of the area monitored outside park boundaries was determined during a meeting with park resource managers in the winter of 2010. Together we decided to monitor the coastline of Ontario, totaling ca. 150,000 hectares. The size of the analysis area was limited to some degree by the amount of time the Network could spend validating disturbances during the summer. We have the ability to monitor landscape dynamics outside the park because the network chose to utilize Landsat imagery as the basis for detecting changes, or disturbances.

Since 2008, the entire Landsat archive (1985 to present) has been available for download, free-of-charge. By utilizing the entire archive, we are able to view long time series of data, which allows the analysis of the normal variation and anomalies present in the data to better distinguish disturbances of interest. Such disturbances include, but are not limited to, harvest, windthrow, flooding due to beaver, fire, development, conversion of agriculture to buildings, and mortality due to insects or disease outbreaks. With free access to a consistent source of base imagery (Landsat), the Network can monitor multiple types of disturbances both within and outside the park boundaries, allowing us to place the park in context. Although ISRO is truly an island, it can still be affected by its surrounding environs. Thus, being aware of what is happening on the coastline directly to the north and west of the island will better inform resource managers on the island.

Previous landscape dynamics studies in the Upper Great Lakes region

Previous landscape change studies have focused on large-scale changes in land cover / land use using moderate resolution imagery such as Landsat with 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 Data (NLCD) (Vogelmann et al. 1998). The study found that 2.5% of the entire watershed experienced change, with forest and agriculture 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 (Wolter et al. 2006).

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 pre-settlement (1860-1890) to the 1910-1940 period, followed by a decrease in fire frequency, which was replaced by increases in timber harvest rates. A more recent study focused on forest cover type transitions and landscape structural changes in the same area using Landsat imagery from 1990-1995, which found that of the mature forested area, 4.2% was harvested, flooded, or burned

5 years later (Wolter and White 2002). Not surprisingly, forest harvests were highest on private lands (ca. 1.7% per year) and lowest on tribal land (ca. 0.55% per year), with the greatest rates of disturbance on publicly-managed land occurring on managed state forests (ca. 1.1% per year).

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

While the previously mentioned studies have provided useful information regarding land cover and land use, their geographic scope has been large and they excluded Ontario, Canada. In addition, many studies have focused on individual agents of vegetation change such as moose (McLaren and Peterson 1994), beaver (Smith and Peterson 1988, Host and Meysembourg 2010), fire (Scheller et al. 2005), and blowdowns (Moser et al. 2007, Rich et al. 2007, Woodall and Nagel 2007, Rich et al. 2010), but no study has incorporated multiple disturbance agents focused on ISRO and the adjacent areas. Moreover, we are unaware of any studies performed on the island that have spatially delineated changes with disturbance agents in a systematic way.

There is a long history of mammalian research on the island (Peterson and Page 1988, Vucetich et al. 1997, Peterson et al. 1998, Jordan et al. 2000, Post et al. 2002, Vucetich et al. 2004, Jost et al. 2005, Romanski 2010), with some of these studies focusing on how the large mammals have affected the vegetative structure (Sell 2007, De Jager and Pastor 2009, De Jager et al. 2009). The U.S. Forest Service has implemented the Forest Health Monitoring program to monitor change in vegetation across the United States (Steinman 2004). Because of its nationwide scope, few plots are located on ISRO. To fill the need for site-specific data on vegetation change on ISRO, the Great Lakes Network has established long-term vegetation plots on the island that will allow us to detect subtle shifts in vegetation composition on the ground (Sanders and Grochowski 2011). The study reported here provides spatial context and is complementary to the work of Sanders and Grochowski (2011). Together, the two monitoring programs provide ISRO managers with both fine-scale and large-scale monitoring of forest change.

Methods

Study area

This study was conducted using two Landsat scenes (path 25, rows 26 and 27) at Isle Royale National Park (ISRO) and the adjacent coast of Ontario, near Thunder Bay (Figure 1). The park itself is often referred to as an island but is actually a 544 km² archipelago, dominated by one large island, 71 km long and at 13 km its widest. The landscape is rugged, composed of northeast-trending valleys with steep, north-facing slopes and gentle, south-facing slopes (Huber 1973). The Precambrian volcanic lava flows of the Portage Lake Formation form the bedrock geology of the valleys (Huber 1973).

During the winter of 2010, we met with ISRO staff to decide on the long-term analysis area for ISRO and surrounding area. The study area was divided into two for summary and analysis purposes: the park (ISRO) and the remainder of the study area simply referred to as Canada with ca. 54,000 and 160,000 ha of land, respectively (Table 1 and Figure 1).

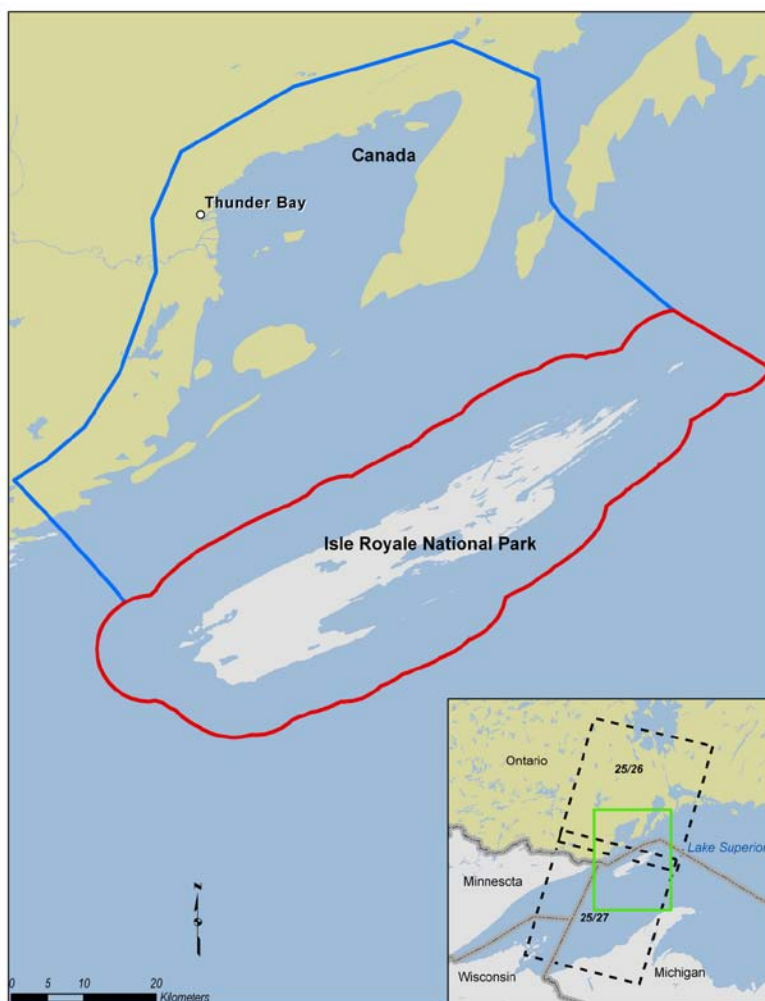


Figure 1. Study area for long-term monitoring of landscape-scale disturbances in and around Isle Royale National Park. The inset shows the extent (dotted black lines) of the two Landsat scenes (25/26 and 25/27) processed and analyzed for this project. The larger map shows the extent of the analysis area with the ISRO and Canada portions of the area outlined in solid red and blue lines, respectively.

Vegetation on the west side of the island is generally comprised of white cedar and maple/birch forest, transitioning to mainly aspen in the central part of the island, and finally to a more mixed landscape on the east end containing open shrubland, aspen, and balsam fir (Sanders and Grochowski 2011) (Figure 2).

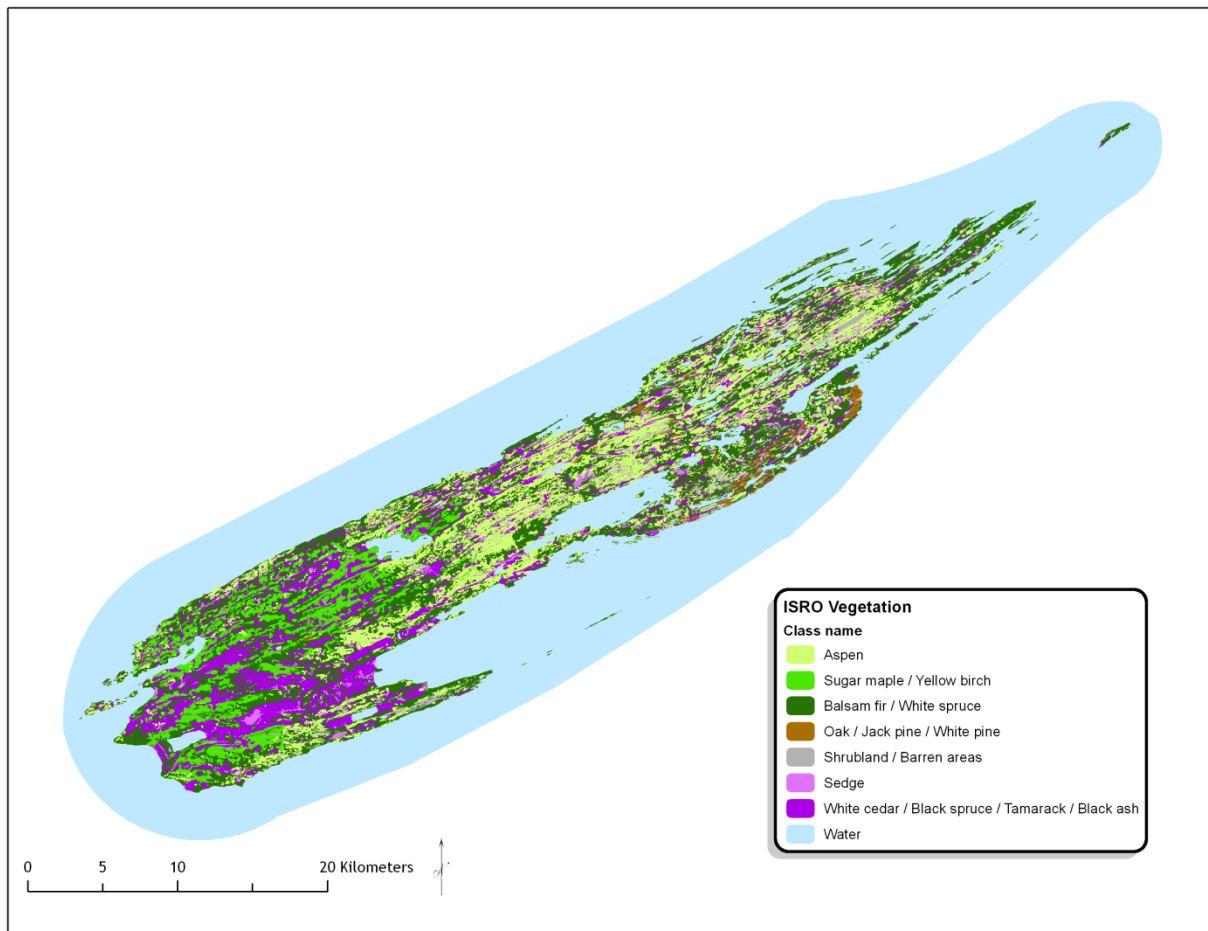


Figure 2. Map of vegetation as delineated in 1996 (The Nature Conservancy 1999).

Table 1. Land area of each analysis region in addition to the percent contribution of each analysis region to the overall analysis area.

Analysis area	Hectares	Percent of analysis area
ISRO	54,591	33.8
Canada	106,452	66.2
Total	161,043	100

Image data and processing

Landsat satellite imagery was downloaded from the Landsat data archive via the U.S. Geological Survey's (USGS) GLOVIS website (<http://glovis.usgs.gov/>). To minimize the effect of phenology, imagery was selected in a three month window (1 June – 31 August) during the peak growing season (Figure 3). For each year since 1984, the goal was to acquire enough imagery in the optimal

phenological window such that one cloud-free composite of the entire study area could be used in the analysis. To aid in the production of the cloud-free composite, we also acquired a number of scan line corrector-off (SLC-off) images. These images include strips where there are no data due to a Landsat hardware malfunction, but nonetheless can be used to fill in critical gaps in our time series (http://landsat.usgs.gov/products_slc_offbackground.php). In total, 68 images were downloaded and processed for analysis. For a single reference year, the cosine-theta (COST) correction was used to convert from Digital Counts to apparent surface reflectance. The COST correction included a standard Dark Object Subtraction (DOS) correction to account for additive noise caused by aerosols, and also included a multiplicative correction using a first approximation of atmospheric transmission based on the cosine of the sun's zenith angle at the time of image acquisition (Chavez 1996).

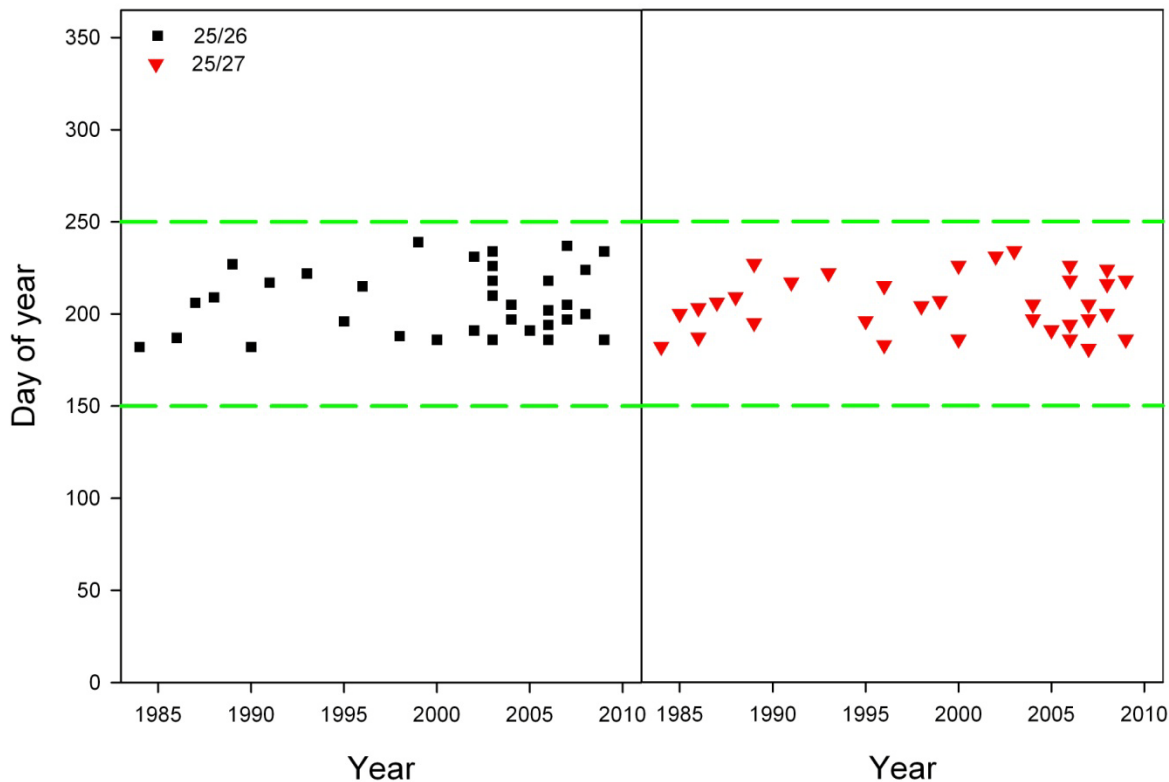


Figure 3. Day and year of Landsat images used for analysis for the two path/rows (25/26 and 25/27) with green dotted lines denoting the ideal phenological window between 1 June and 31 August.

The COST-corrected reference image was then used as the base for relative radiometric normalization of the remainder of the images in the stack. We used the MADCAL automated approach for detection of stable targets, as evaluated by Schroeder et al. (2006), but applied to the special case of normalizing many images in a stack (Kennedy et al. 2007). Additional information regarding this technique can be found in Kennedy et al. (2010).

To remove clouds and their shadows we used an automated cloud masking algorithm that incorporates the thermal band, a digital elevation model (DEM), a forest mask, and sun illumination geometry to

automatically detect and remove clouds and associated shadows (Huang et al. 2010). This is a new technique, which was not available for our previous work at VOYA (Kirschbaum and Gafvert 2010b).

Following image preprocessing, a number of computer algorithms, collectively known as “LandTrendr” were applied at the pixel (30 m x 30 m) level to identify disturbances. These disturbances were then grouped into similar patches and identified as individual polygons. Additional information regarding the LandTrendr process can be found in Kennedy et al. (2007), Cohen et al. (2010), and Kennedy et al. (2010).

Validation of disturbances

After disturbance polygons were created, the next step was to validate whether a change actually occurred in the polygon. In addition to validating whether changes occurred, additional information such as the change agent (Table 2) and starting/ending classes were added during the validation process. Using high resolution imagery (Table 3), we were able to determine whether changes had indeed occurred, and by using contextual information we were able to determine the disturbance agent. In addition to using high resolution imagery, we also employed the use of an application called TimeSync (Cohen et al. 2010). This program allows the user to view composite image chips of the entire stack of Landsat imagery for pre-determined locations as well as the associated spectral trajectory of the pixel through time.

By viewing the high resolution aerial photos, temporally high resolution image chips, and spectral trajectories, we could make a well-informed decision regarding the validity of the disturbance. To limit the potential for bias, two interpreters validated all disturbances. If a disturbance was validated within a polygon, additional attributes (fields) were populated within the feature class (Kirschbaum and Gafvert 2010a). To determine the starting class, or the most likely vegetation type that was disturbed, we used two land cover datasets, one for Canada, the other for ISRO. The best available land cover map for Canada was a 2000 land cover map for forested areas of Canada (Wulder et al. 2003), while the park had a detailed vegetation map produced from high resolution aerial photos flown in 1996 (Table 4; The Nature Conservancy 1999).

No field visits were necessary during this analysis period due to the availability of high resolution aerial photos and the relative lack of change polygons identified by LandTrendr processing.

Table 2. Disturbance agents and our definitions for each of them.

Disturbance agent	Definition
Beaver	Disturbances caused by beavers fall into two categories. When beavers flood a previously wooded wetland, it usually kills trees, which then show up as a disturbance. Also, when beaver vacate a previously flooded area, the dam usually degrades and allows the water to escape, exposing bare ground which eventually fills in with grasses, shrubs and trees.
Blowdown	Strong wind events, sometimes termed ‘straight-line winds,’ can create varying patch sizes of downed trees. These blown down trees are evident in high resolution airphotos and are usually oriented in the direction of the wind event. If this event occurs on private lands and a salvage harvest occurs before it is seen, it is classified as a harvest.

Table 2. Disturbance agents and our definitions for each of them (continued).

Disturbance agent	Definition
Development	Permanent conversion of vegetated surface to non-vegetated surface such as mines, paved roads, parking lots, and buildings
Fire	Detection is limited to instances where there is mortality in the overstory. Thus, areas in which fires only burn in the understory are not delineated.
Harvest	Forest harvests, including clearcuts and thinnings, new logging roads, and post-harvest prescriptions such as herbicide application or scarification.
Forest pathogen	Disturbances (mortality) in the overstory due to insects (e.g., forest tent caterpillar, spruce budworm) or diseases (e.g., oak wilt, root rot).

Table 3. Aerial photos and high resolution satellite imagery used for validation. For explanation of acronyms used in this table, see list of acronyms on page xiii.

Date	Resolution (meters)	Image spectrum	Funding source	Source	Analysis area coverage
5/19/1992	1	B & W	APFO-NAPP	Airphoto	ISRO-complete
5/1/1998	1	CIR	APFO-NAPP	Airphoto	ISRO-complete
Multiple dates in 2005	0.6	RGB & CIR	GLKN	Quickbird	Canada-partial
7/1/2005	1	RGB	APFO-NAIP	Airphoto	ISRO-complete
Multiple dates in 2006	0.6	RGB & CIR	GLKN	Quickbird	Canada-partial
Multiple dates in 2007	0.6	RGB & CIR	GLKN	Quickbird	Canada-partial
6/7/2008	0.6	RGB & CIR	GLKN	Quickbird	Canada-partial
5/17/2009	0.2	RGB & CIR	GLKN	Airphoto	ISRO-complete
8/31/2009	1	RGB	APFO-NAIP	Airphoto	ISRO-complete
Multiple dates in 2009	0.6	RGB & CIR	GLKN	Quickbird	Canada-partial

Table 4. Land cover datasets used for labeling the original land cover class for disturbed areas.

Analysis area	Dataset	Time period represented
Ontario, Canada	Earth Observation for Sustainable Development of Forests (EOSD)	2000
ISRO	National Vegetation Classification System (NVCS)	1998

Land and water mask

To compare the amount of land disturbed in each analysis area, we needed to summarize the total amount of land within them. To do this, we chose one cloud-free image from each Landsat scene (Figure 1 inset) and developing a water index by dividing band 5 (shortwave infrared) by band 2 (green), which has been used to distinguish water from land (Alesheikh et al. 2007, Ji et al. 2009). The resulting image was overlain on an airphoto from the same time period as the Landsat image used to develop the index, and a threshold was chosen that eliminated persistent bodies of water, yet preserved low-lying areas subject to periodic flooding during times of high water levels. Thus, wetlands and seasonal bodies of water in this simple classification are considered to be ‘land.’

Results

ISRO

During the six year period, a total of 0.03% of the land was disturbed at the park. The only year with a significant amount of disturbance was in 2003. There were small amounts of disturbance in years 2005-2008, although they only total 0.01% of land area in the park (Figure 4).

Canada

Collectively, 2.66% of the land in the Canada analysis area was disturbed during the six-year period. The largest amount of land disturbed occurred in years 2003 and 2004 (0.61%), with the lowest amounts occurring in years 2007 and 2008 (0.28 and 0.15% disturbed, respectively) (Figure 4).

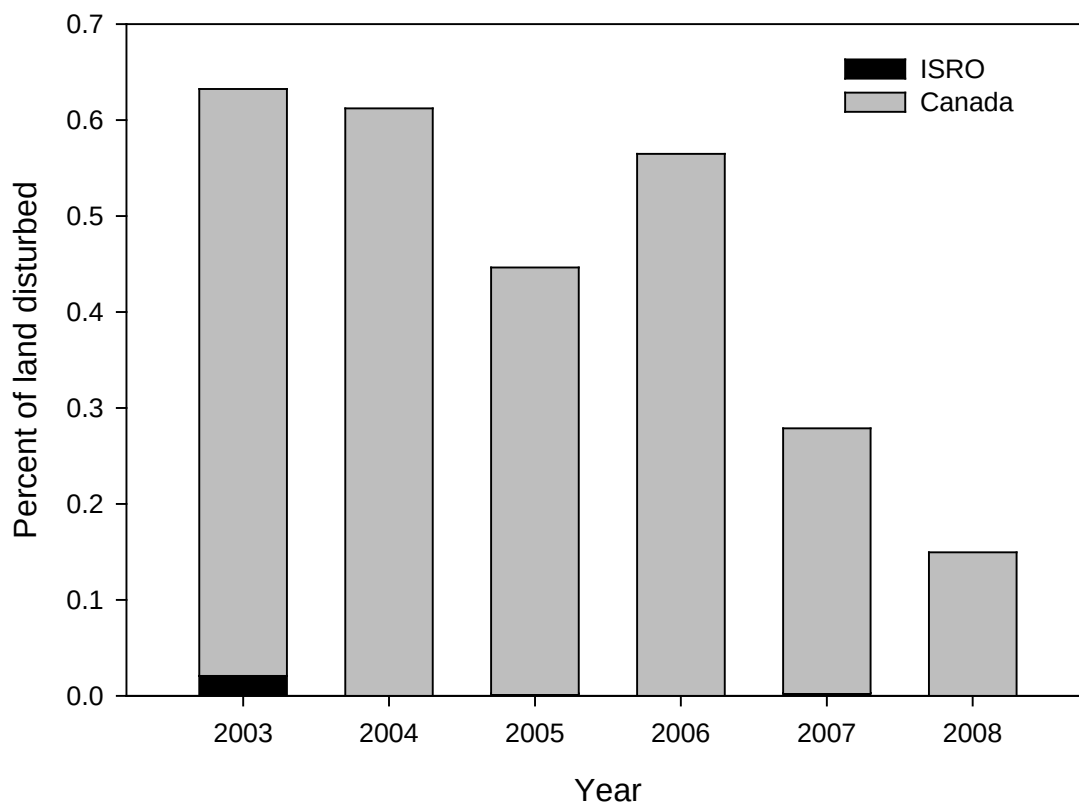


Figure 4. Percent of land disturbed in the analysis area, 2003-2008.

Disturbance agents

During the validation process, disturbance agents such as logging, beaver, development, and windthrow were noted. We viewed disturbances by agent through time and across analysis areas. In this section we will summarize disturbances by their causal agents. Descriptions of these casual agents can be found in Table 2.

ISRO

On the island, we detected change from only three disturbance agents during the six-year analysis period. These three agents were beaver, forest pathogens, and blowdown (Figure 5). The largest amount of land was disturbed in 2003 by beaver and forest pathogens. The areas disturbed by beaver tended to be small in size and scattered throughout the park, while the area disturbed by the forest pathogen was larger but only occurred in one area of the park (Appendix Figure A1). We found beaver to be the most consistent agent of change, and we detected their activities in four out of the six years. The only other cause of change we detected was blowdown, which affected 0.8 ha in 2007 (Figure 5). The blowdown event occurred in the Washington Harbor area (Appendix A).

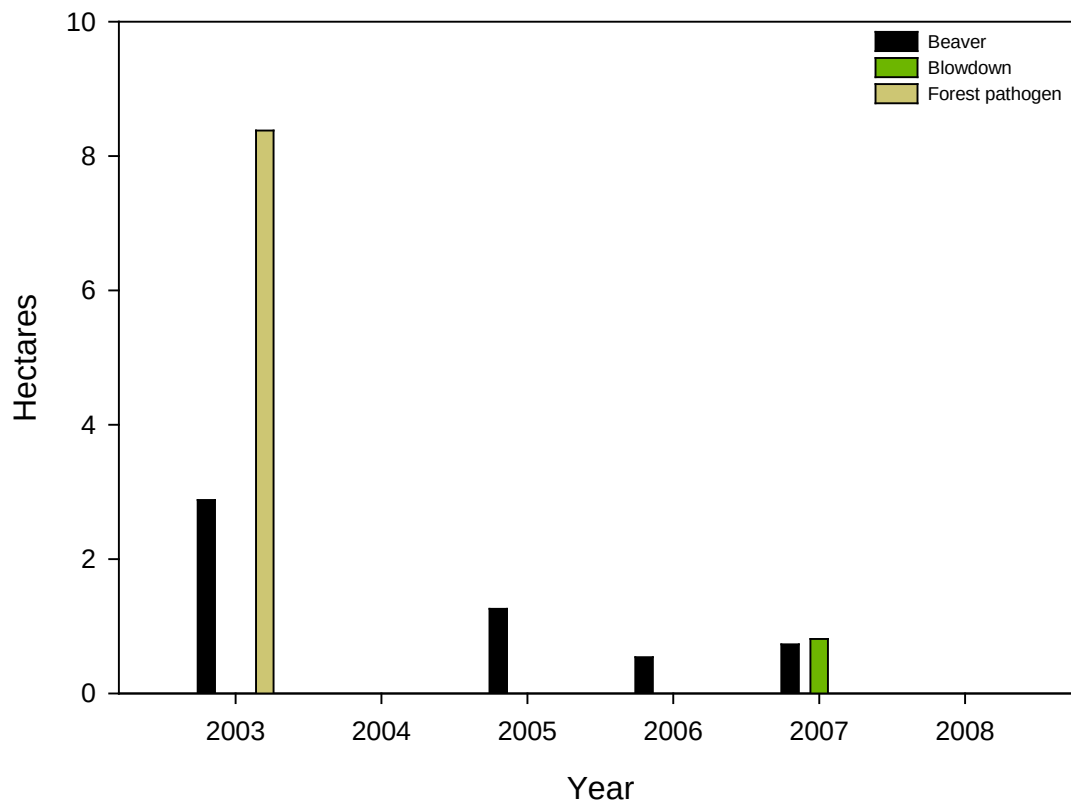


Figure 5. Hectares of land disturbed by disturbance agent at ISRO, 2003-2008. For a complete tabular view of all data and disturbance agents monitored at ISRO, see table D2.

Canada

We found forest harvest to be the largest and most consistent disturbance agent outside the park, with disturbances occurring each year and totaling 2,568 ha over the six-year period. The only other agent present in each year was development, although the total amount of land disturbed by this agent was much lower than that of forest harvests (Figure 6). In addition to forest harvest and development, the only other cause of disturbances was beaver, which was also detected in each analysis year. Disturbances resulting from fire, forest pathogens, and blowdown were not evident during the analysis period (Figure 6).

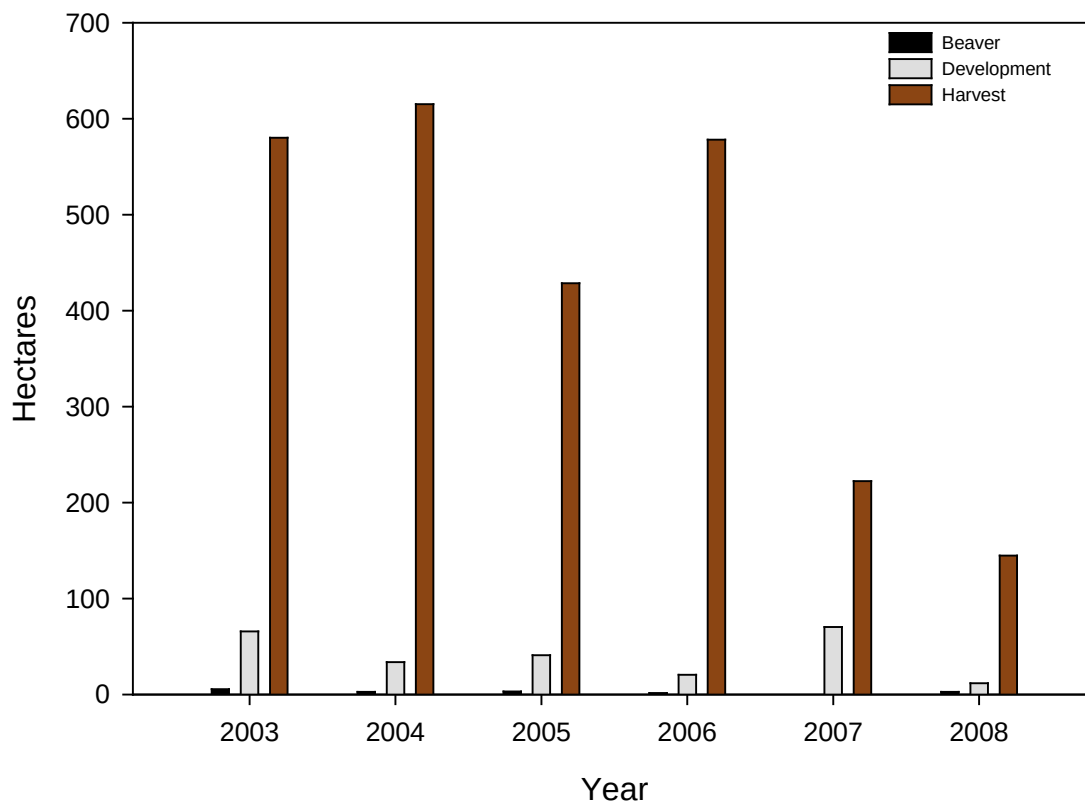


Figure 6. Hectares of land disturbed by disturbance agent in Canada portion of study area, 2003-2008. For a complete tabular view of all data and disturbance agents monitored in Canada, see table D2.

Disturbance patches

In some cases a disturbance simply creates a single patch, as is normally the case with beaver disturbances. However, some other disturbances, such as fires, blowdowns, or forest pathogens, can create multiple patches. In these instances the overstory vegetation typically dies in sporadic patches and not in a contiguous fashion, creating a more diverse landscape.

ISRO

Inside the park, beaver were the most consistent creator of disturbance patches (four of six years; Figure 7). Forest pathogens created the greatest number of patches (8 in 2003), but have not created any others since that time. One patch was created in 2007 by blowdown in the Washington harbor area. No patches were identified in 2004 or 2008 (Figure 7).

The mean patch size inside the park was less than one hectare (Figure 9). The range of patch sizes was quite narrow, with a maximum patch size of two hectares and minimum patch size of only a quarter of a hectare (Table 7). In total, 15 patches were created during the analysis period.

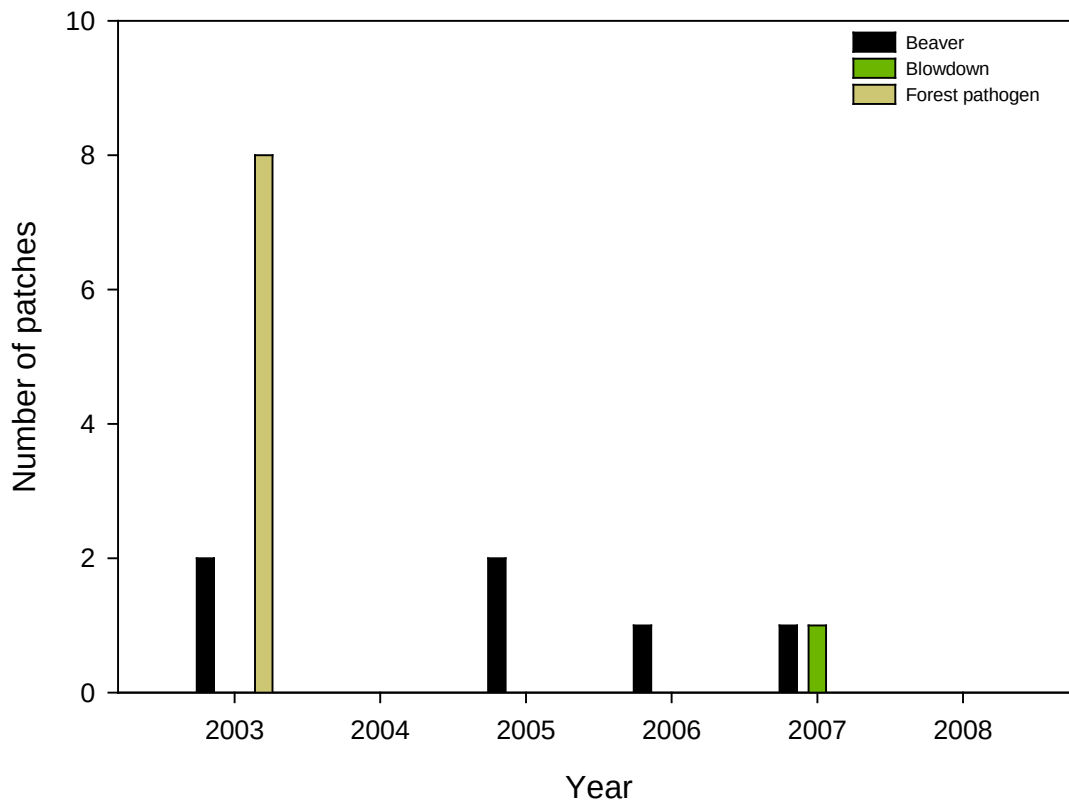


Figure 7. Number of patches created by disturbance agent at ISRO, 2003-2008. For a complete tabular view of all data and disturbance agents monitored at ISRO, see table D3.

Canada

Forest harvests accounted for the largest proportion (74%) of disturbance patches in Canada and occurred in each analysis year (Figure 8). Development and beaver created multiple patches in each analysis year. A total of 86 patches were created during the analysis period, with the greatest number occurring in 2007. We did not find any patches caused by blowdown, fire, or forest pathogens in Canada during the analysis period.

The mean patch size in Canada was 7.39 ha, with a median and maximum size of 2.43 and 113.22 ha, respectively (Table 5). Also, 75% of the patches were equal to or less than the mean patch size (Figure 9).

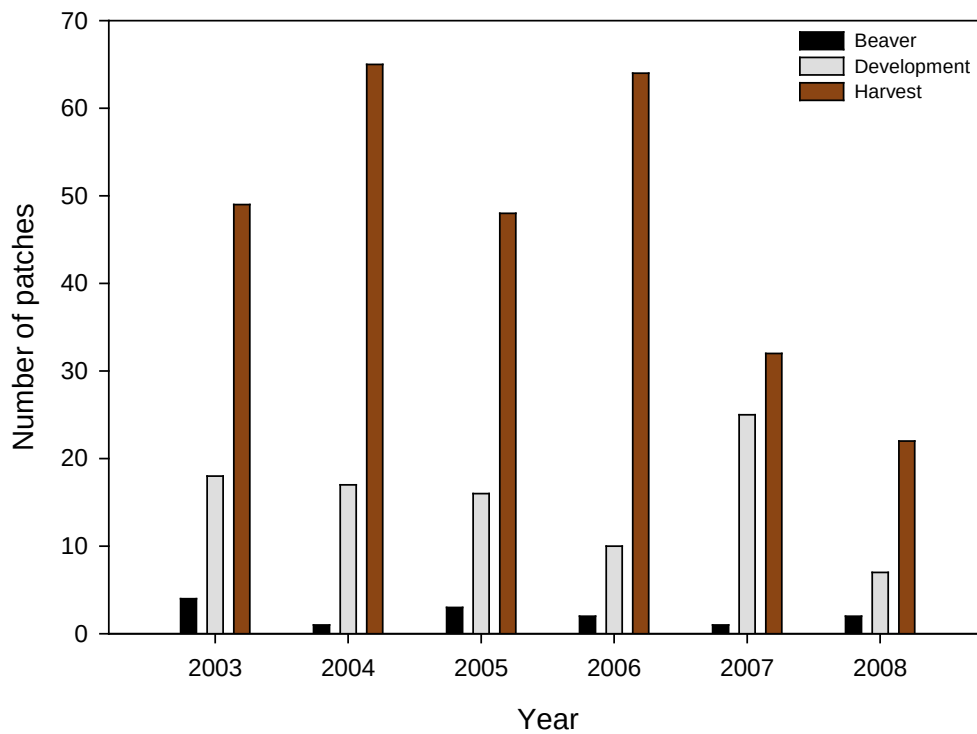


Figure 8. Number of patches created by disturbance agent in Canada portion of the study area, 2003-2008. For a complete tabular view of all data and disturbance agents monitored in Canada, see table D3.

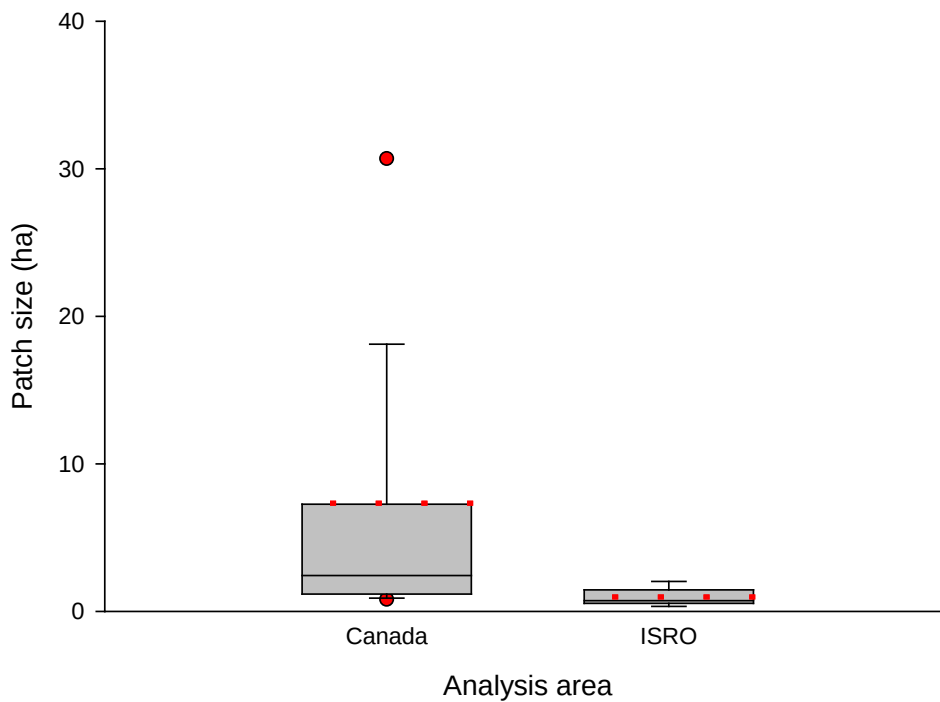


Figure 9. Mean (dotted red line) and median (solid black line) patch size in Canada and on ISRO, 2003-2008. Also indicated are the 5th and 95th percentiles (red dots), 10th and 90th percentiles (upper and lower error bars), and 25th and 75th percentiles (shaded grey box).

Table 5. Summary statistics of disturbance patches by analysis area.

Location	Count	Mean (ha)	Minimum (ha)	Maximum (ha)	Median (ha)
ISRO	15	0.97	0.27	2.03	0.73
Canada	386	7.33	0.24	113.22	2.43

Land cover dynamics

As part of the validation process we assigned starting and ending vegetation classes to each disturbance polygon. It is possible to identify up to three distinct starting and ending classes for polygons that encompass multiple cover types. For more details regarding how starting and ending classes are defined and chosen, see Kirschbaum and Gafvert (2010a). For purposes of displaying graphs, we have combined the relevant starting and ending classes into more generalized groupings (Table 6).

Table 6. Generalized starting and ending cover classes used to describe disturbance polygons, with the composition of each generalized class.

Generalized class	Groups in this general class
Upland forest	Upland evergreen forest, upland deciduous forest, upland mixed forest
Upland woodland	Upland evergreen woodland, upland deciduous woodland, upland mixed woodland
Upland shrub/herb	Upland shrub, upland herbaceous
Lowland forest	Lowland evergreen forest, lowland deciduous forest, lowland mixed forest
Lowland shrub/herb	Lowland shrub, lowland herbaceous
Building	Building
Agriculture	Agriculture
Road	Impervious road, pervious road, road
Water	Water
Bare ground	Beaches, rock, rocky outcrop, gravel, bare ground, impervious surface, pervious surface

ISRO

The majority of land disturbed in 2003 was upland forest that, after forest pathogens killed the trees, converted to upland shrub/herb (Figures 10a and b). The only other disturbance agent this year was beavers, which created lowland shrub/herb land by affecting almost 3 ha of lowland forest. Only lowland forest was converted in 2005, creating lowland shrub/herbaceous habitat. Then in 2006, the disturbed cover types were evenly split between lowland forest and lowland shrub/herb, each with just over a quarter of a hectare disturbed. Lowland shrub replaced the lowland forest, and lowland shrub transitioned to lowland herbaceous. In 2007, just under one hectare of water was lost due to a former beaver impoundment drying up, resulting in lowland herbaceous. Nearly one hectare of upland forest was converted to upland shrub after a blowdown.

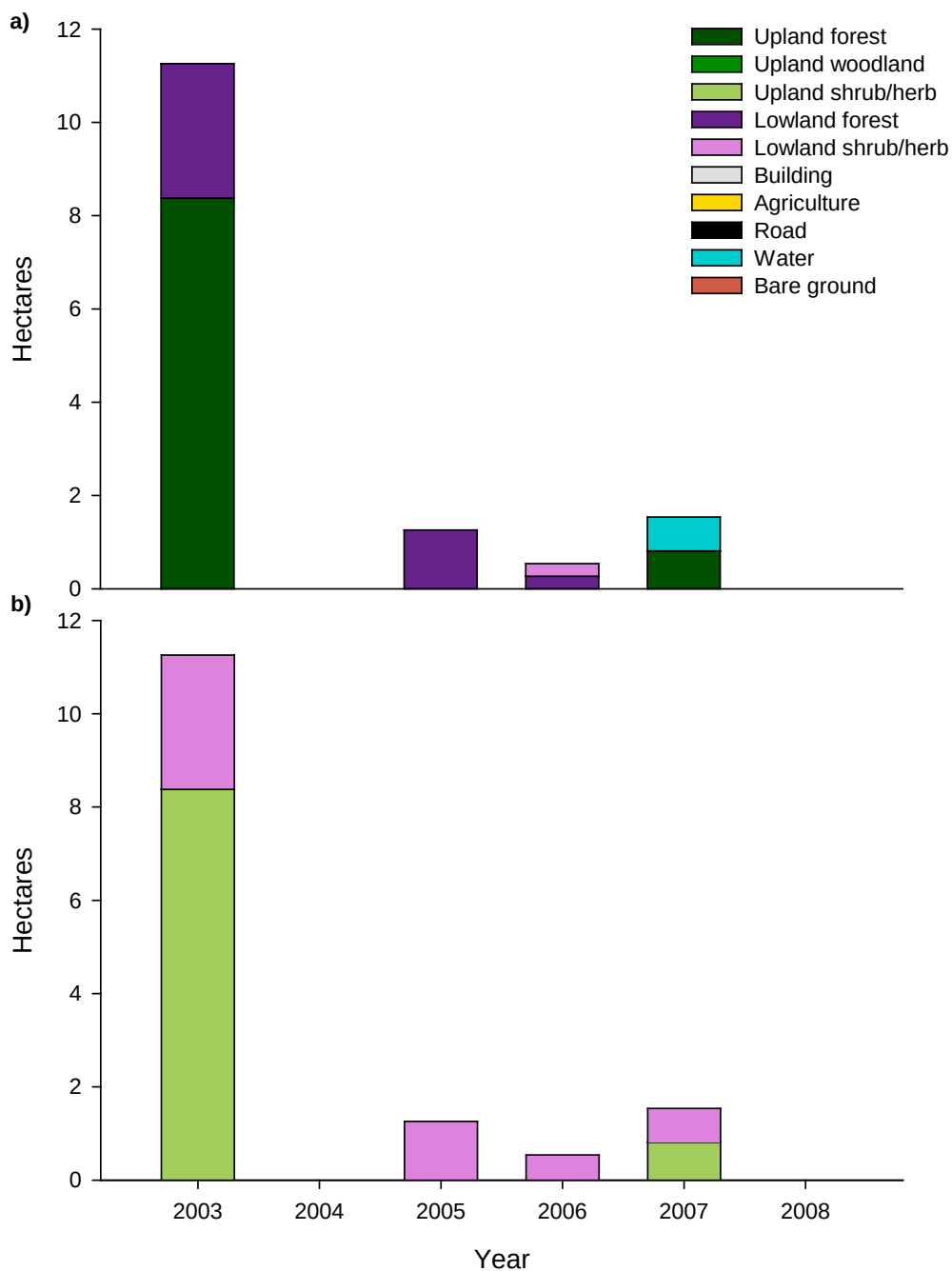


Figure 10. Area of cover types lost (a) and gained (b) in the ISRO analysis area, 2003-2008.

Canada

Due to the large amount of forest harvests occurring in Canada, the majority of the cover converted during this analysis period was upland forest, which accounted for the greatest proportion of land cover changed in each year (Figure 11a). Most of the upland forest was converted to upland shrub/herb (Figure 11b), which is a normal progression after clearcutting. There was also some upland shrub/herb converted to bare ground in each of the years, most likely the result of development. In 2005 our generalized classification show several cases of 'bare ground' to 'bare ground', which were attributable to

transitions from bare earth to impervious surface. Lastly, in each of the years, some of the disturbances transitioned to the road class, which includes both pervious (dirt/gravel) roads and impervious (asphalt/cement) roads (see Table 9).

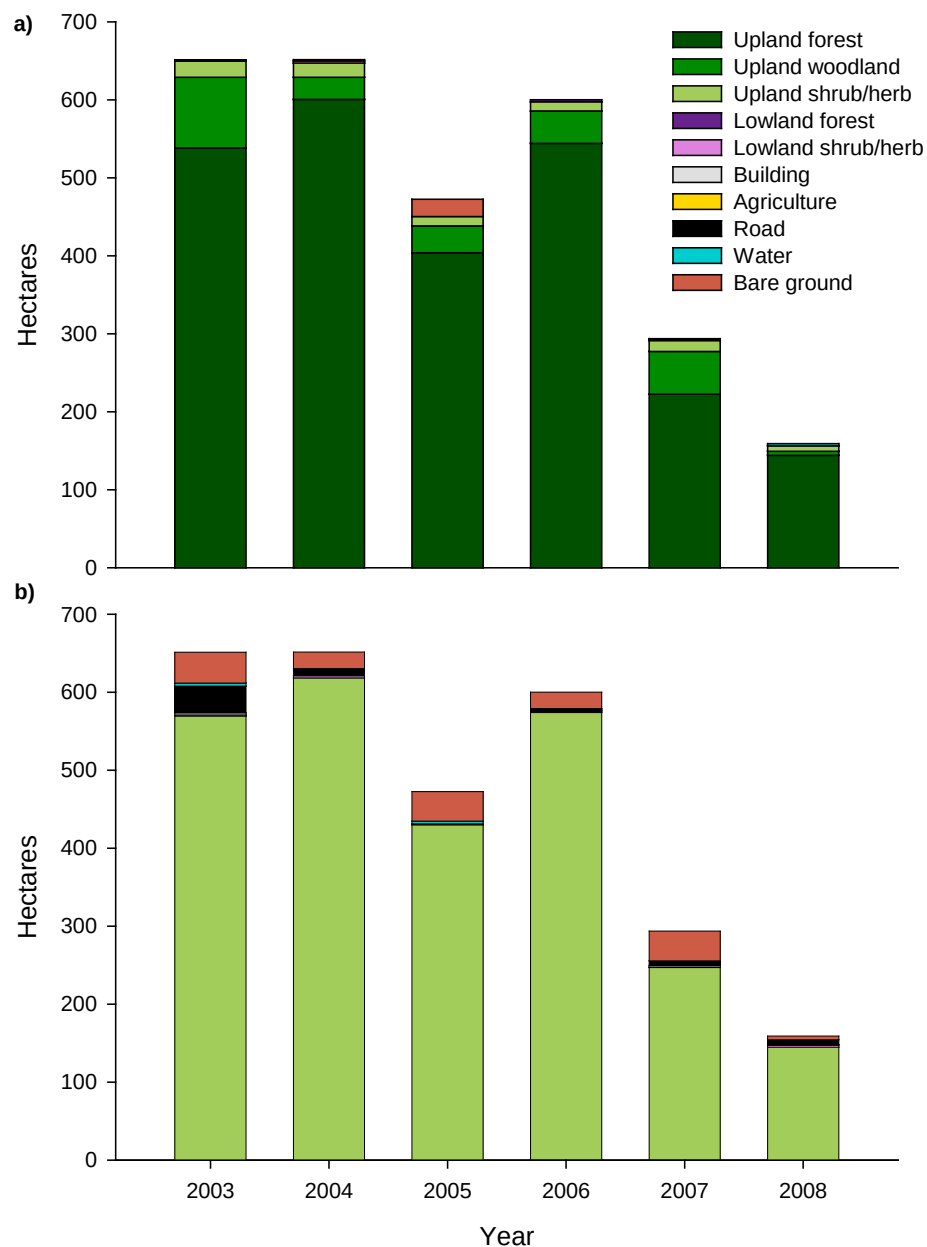


Figure 11. Area of cover types lost (a) and gained (b) in the Canada analysis area, 2003-2008.

Discussion

Percent land disturbed

Not surprisingly, Canada had much more disturbance activity than ISRO. This difference was expected due to the very different management strategies between analysis areas. The management goals for the National Park Service were defined in the Organic Act as “...to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations” (16 U.S. Code, Subch. 1). As such, management inside national parks varies greatly from the strategy of private landowners and other agencies such as the U.S. Forest Service. While the absence of human-caused disturbance on ISRO between 2003 and 2008 was expected, a healthy ecosystem must have enough natural disturbance to maintain a diversity of habitats for native plants and wildlife. The amount and type of disturbance considered “natural” for an area the size of ISRO is a question that needs further consideration. Our monitoring program will return to ISRO in 2016, at which time we should have sufficient data to compare with the longer historical record of major disturbances such as fire. This should help evaluate the extent to which fire suppression has altered the successional path for the forests of ISRO.

The method of using Landsat imagery to look at a relatively large area outside the park allows us to compare human-induced disturbances with natural disturbances, which over time will provide managers and the scientific community the ability to quantify how they alter the trajectory of forest change.

Historically, at least one large scale disturbance has been documented that affected a large part of the island. The Greenstone fire of 1936 burned 10,500 hectares in the central part of the island, nearly single-handedly saving the island’s moose population from near-extinction (Jordan et al. 2000, Scarpino 2011). Another major disturbance on the island is the moose themselves, though they may not have occupied the island historically. When the moose did arrive in the early 1900s, they severely altered the vegetation, feeding on the abundant browse available to them. Through the boom and bust years of the moose population, vegetation has responded with increased growth (McInnes et al. 1992, De Jager and Pastor 2009, De Jager et al. 2009). Although these vegetative responses are substantial, they are not likely to be detected using remote sensing techniques. A more appropriate method for quantifying vegetation responses to browsing would be fine scale measurements of vegetation, such as that being carried out by the Network’s vegetation program (Sanders and Grochowski 2011).

In Canada, there has been a decreasing trend in the percent of land disturbed, especially in the last two analysis years, 2007 and 2008 (see Figure 6). Potentially, this could be due to the drop in housing construction, thus affecting the demand for timber. We will continue to monitor this in future years.

Comparing Isle Royale and Voyageurs National Park

We conducted the same type of disturbance analysis at Voyageurs National Park (VOYA) in 2009, and similar to ISRO, we included areas surrounding the park (Figure 12). Both parks are located on the southern edge of the boreal ecosystem and as such, are comparable in ecosystem function, while also sharing a border with Canada.

For the five years of overlapping data for the two parks (2003-2007), we found a much greater proportion of the landscape being disturbed in VOYA than in ISRO (Figure 13a). We will compare these trends in future analysis years to see if they continue.

The same trend is seen, although to a lesser degree, in the Canadian portion of both the ISRO and VOYA analysis areas. In recent years (2006-2007), the Canadian portion of the analysis area at ISRO has been more similar to the VOYA Canadian portion. However, in earlier years (2003-2005) the area north of VOYA had a much larger proportion of disturbed landscape (Figure 13b).

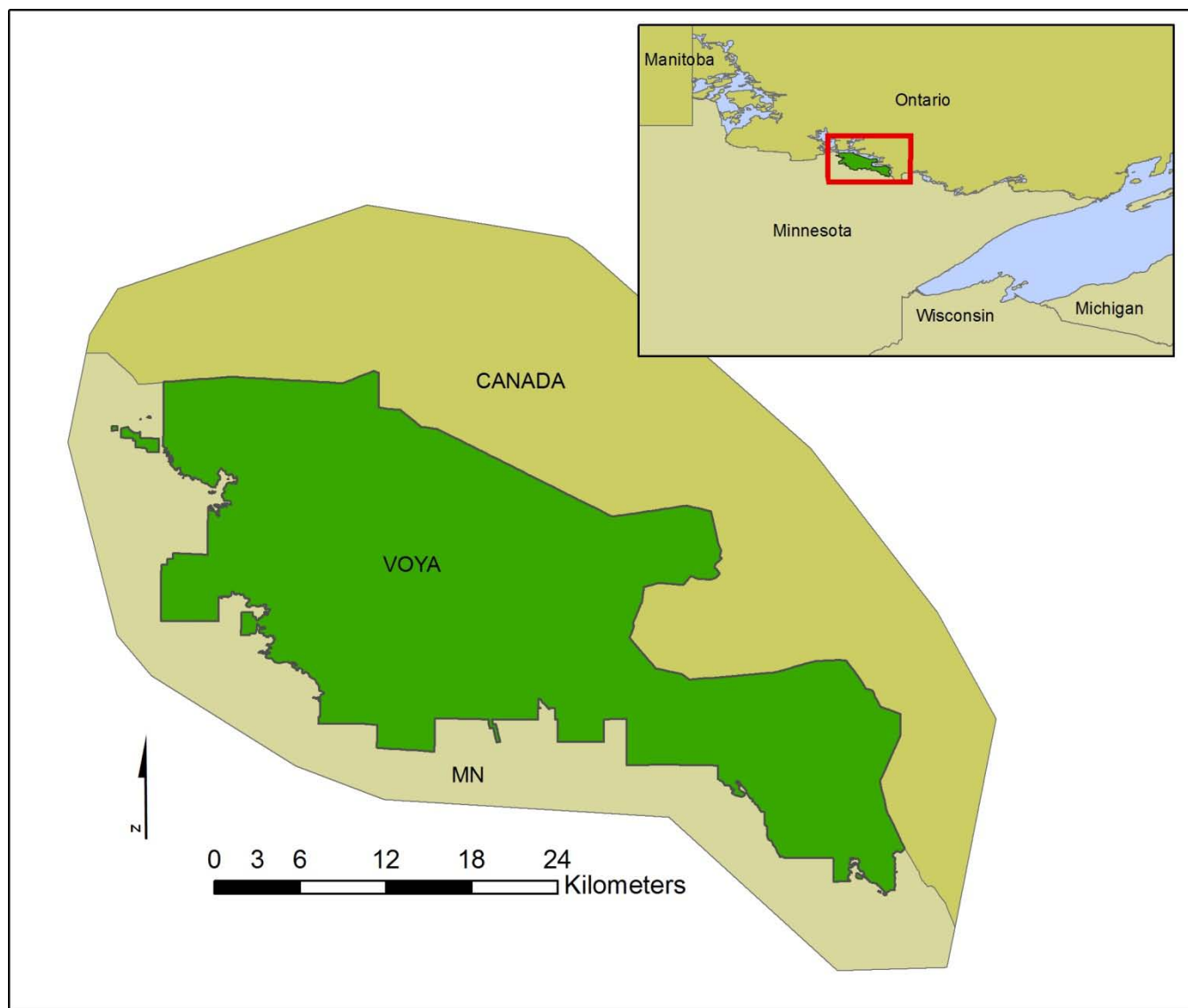


Figure 12. Map of VOYA analysis area, which shows the park (green) and the areas outside the park in Canada and Minnesota.

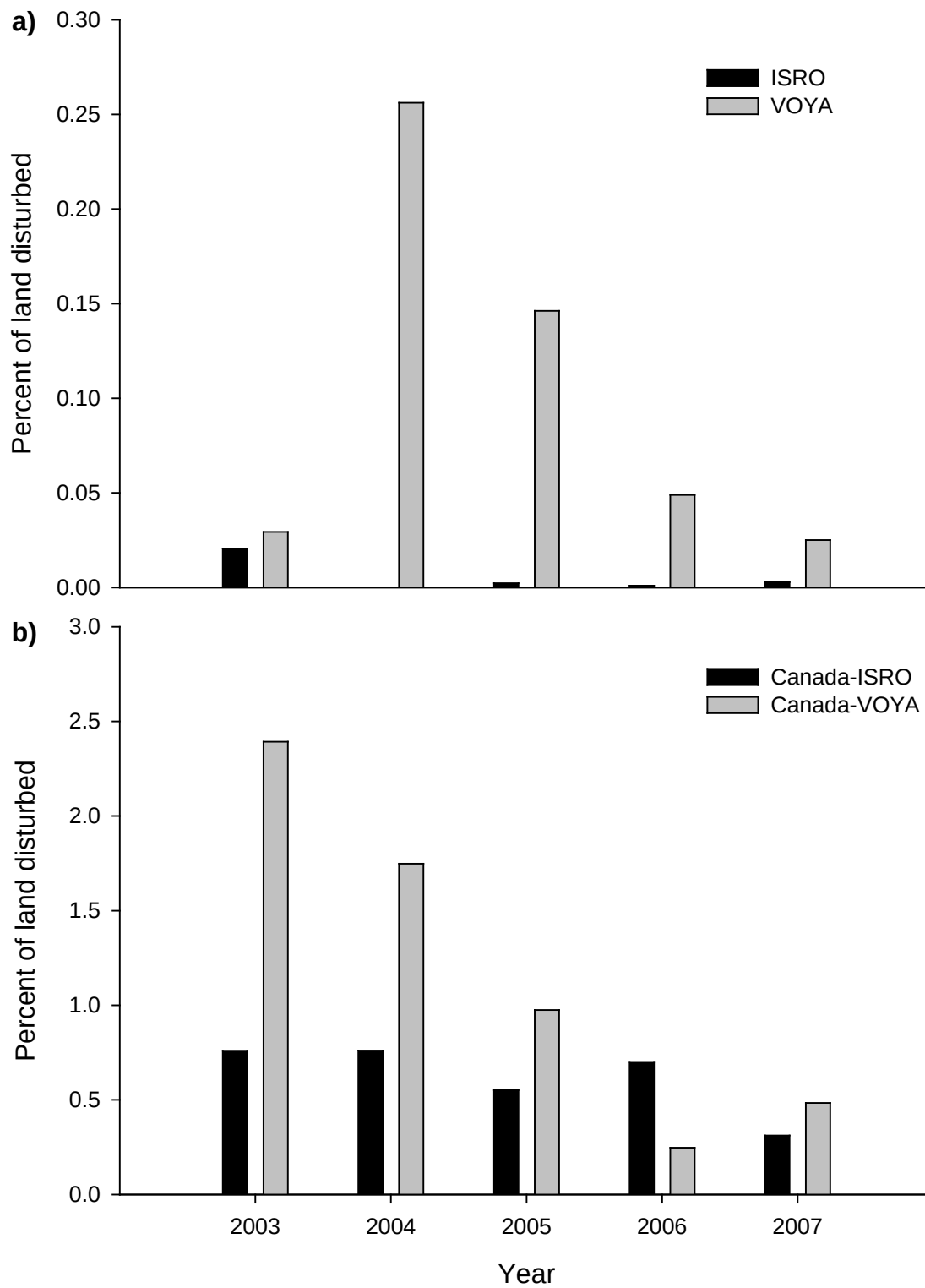


Figure 13. Percent land disturbed at ISRO and VOYA (a) and in the Canadian analysis area outside each park (b), 2003-2007.

Disturbance agents

Disturbance agents acting within ISRO were limited largely to beaver and a forest pathogen, with a small blowdown occurring in 2007 (see Figure 5). Beaver was the most consistent change agent through time, occurring in four of the six analysis years. Outside the park, the two dominant disturbance agents were forest harvest and development (see Figure 6).

Comparing ISRO with VOYA

We can look at the disturbance agents to help us better understand the different disturbance regimes between the parks (Figure 14a). We can see that the Shoepack Lake fire that occurred at VOYA in 2004 accounts for a large portion of the difference between the two parks. Blowdown and beaver were also large contributors to the VOYA disturbances, and were more consistent agents of change.

Outside the parks, forest harvest was the major agent of change (Figure 14b). The percent of disturbed land adjacent to VOYA was approximately double that of ISRO, but with no disturbance caused as a result of development around VOYA. This is due to the fact that Thunder Bay, Ontario (population 122,639), is nearly in the center of the ISRO-Canada analysis area, whereas the VOYA-Canada analysis area only has the two communities of International Falls (population 5,839) and Fort Frances, Ontario (population 8,983) which, in total, represent 12% of the population of Thunder Bay alone.

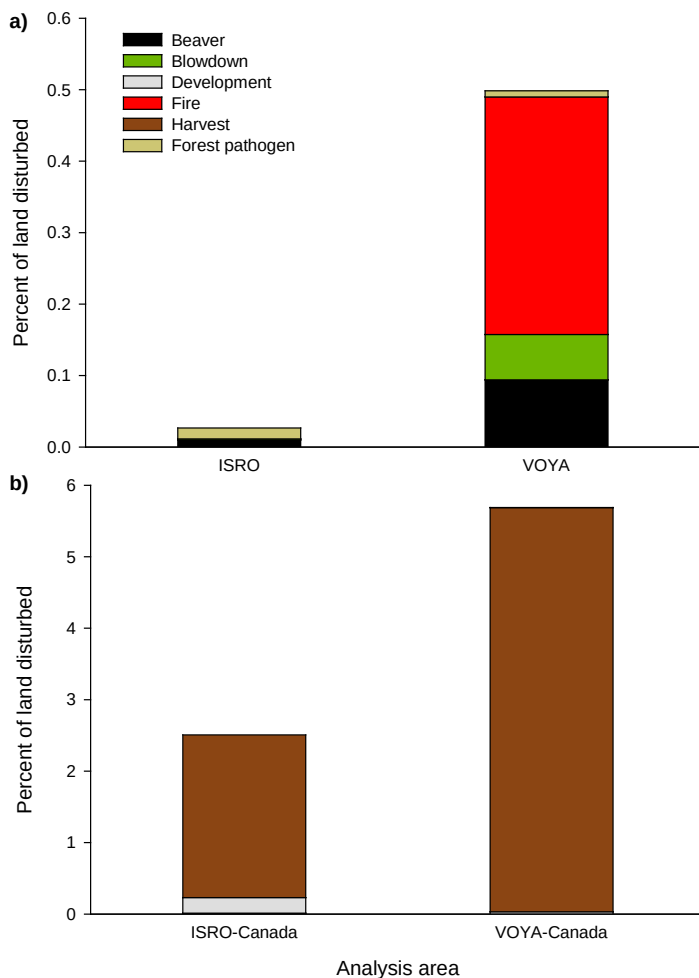


Figure 14. Percent of land disturbed, by disturbance agent, inside ISRO and VOYA (a) and in the adjacent Canadian portions (b) of the analysis area, 2003-2007.

Conclusion

We document here six years of disturbance activity, which is too short of a time period to draw any sweeping conclusions or provide trend analyses of the disturbance regimes at work in the park and the neighboring area in Canada. Instead, this report represents a foundation on which we will continue to monitor the same types of activities and develop a long-term record of disturbance.

Tracking the amount, location, and occurrence of roads, houses, and clearcuts in the adjacent area will offer insight into the processes that may affect two of the island's most prominent species: wolves, moose and beaver. The loss of roadless areas and increased fragmentation along shoreline areas in Canada may greatly affect the abundance and movement patterns of wolves and moose, which could provide the island with new recruits (Mladenoff et al. 1995, Lovallo and Anderson 1996, Mladenoff and Sickley 1998, Mladenoff et al. 1999). If development continues to occur at the current rates, the likelihood of a new influx of either wolves or moose will greatly decrease.

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Appendix A. Spatial distribution of disturbances at ISRO.

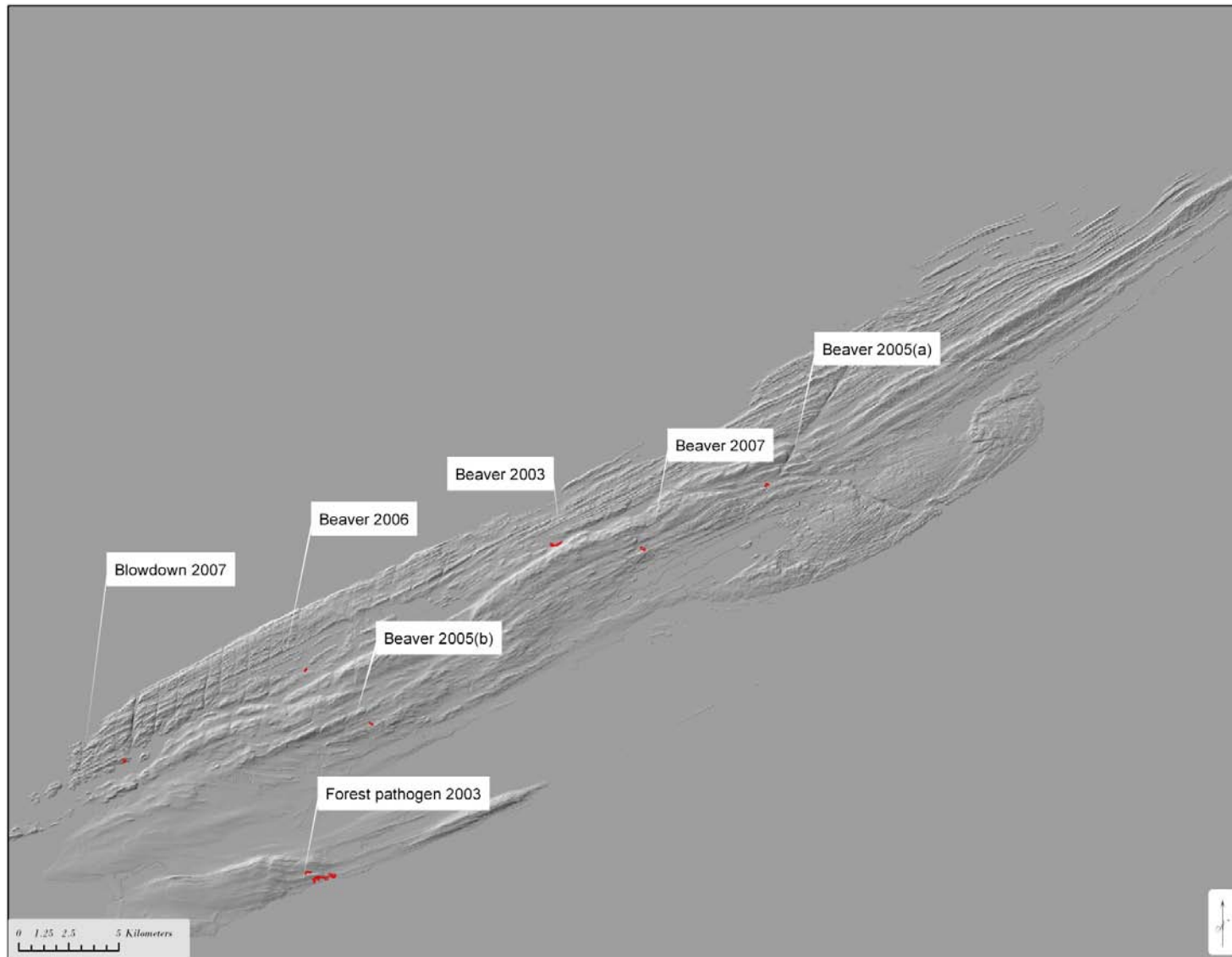


Figure A1. Geographic overview of the disturbances detected at ISRO, 2003-2008. Airphotos showing examples of some disturbances are shown in Appendix B.

Appendix B. Pre- and post-disturbance aerial photos of selected disturbances at ISRO during analysis period (2003-2008).

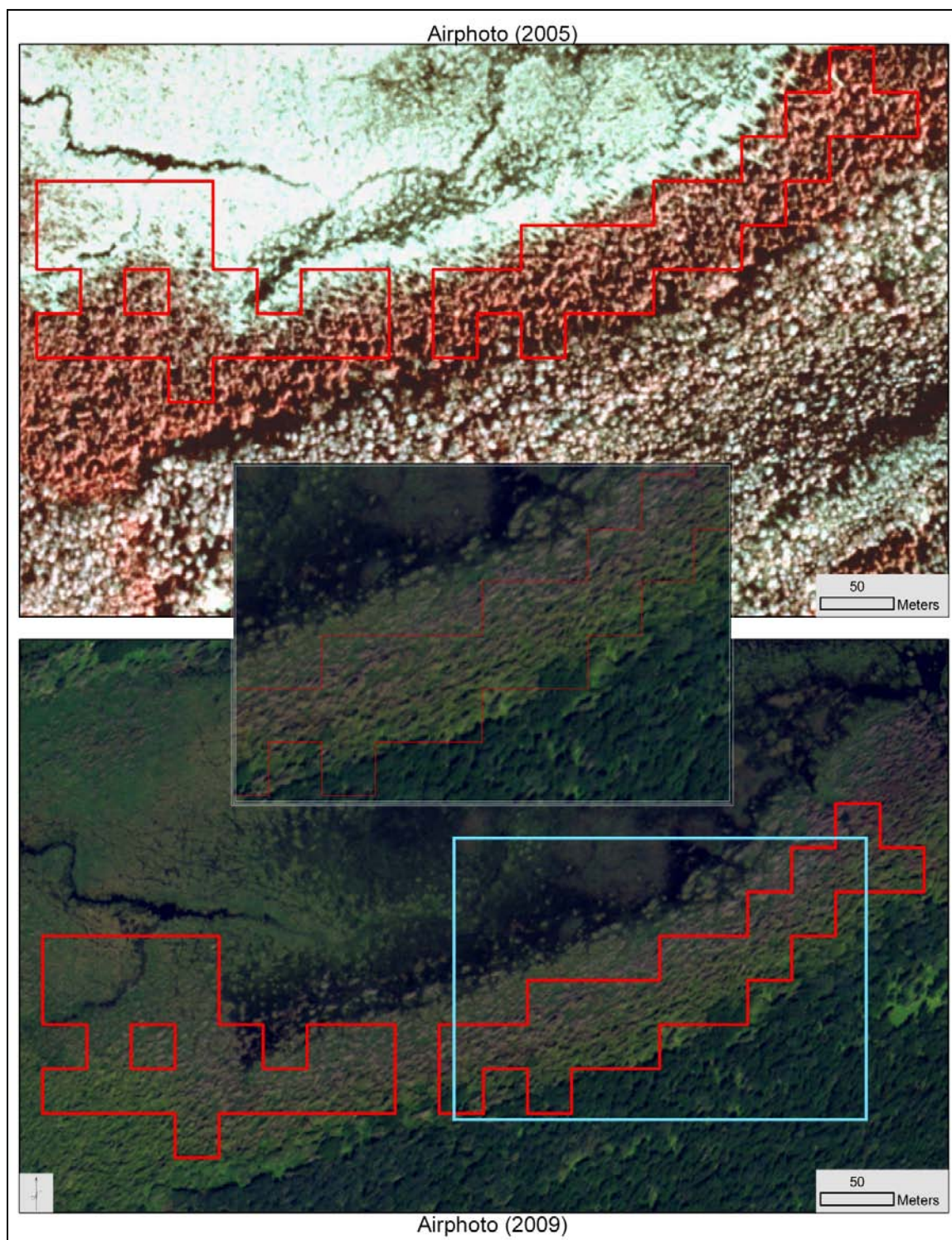


Figure B1. Beaver disturbance occurred in 2003, resulting in dead trees on edge of lowland forest.

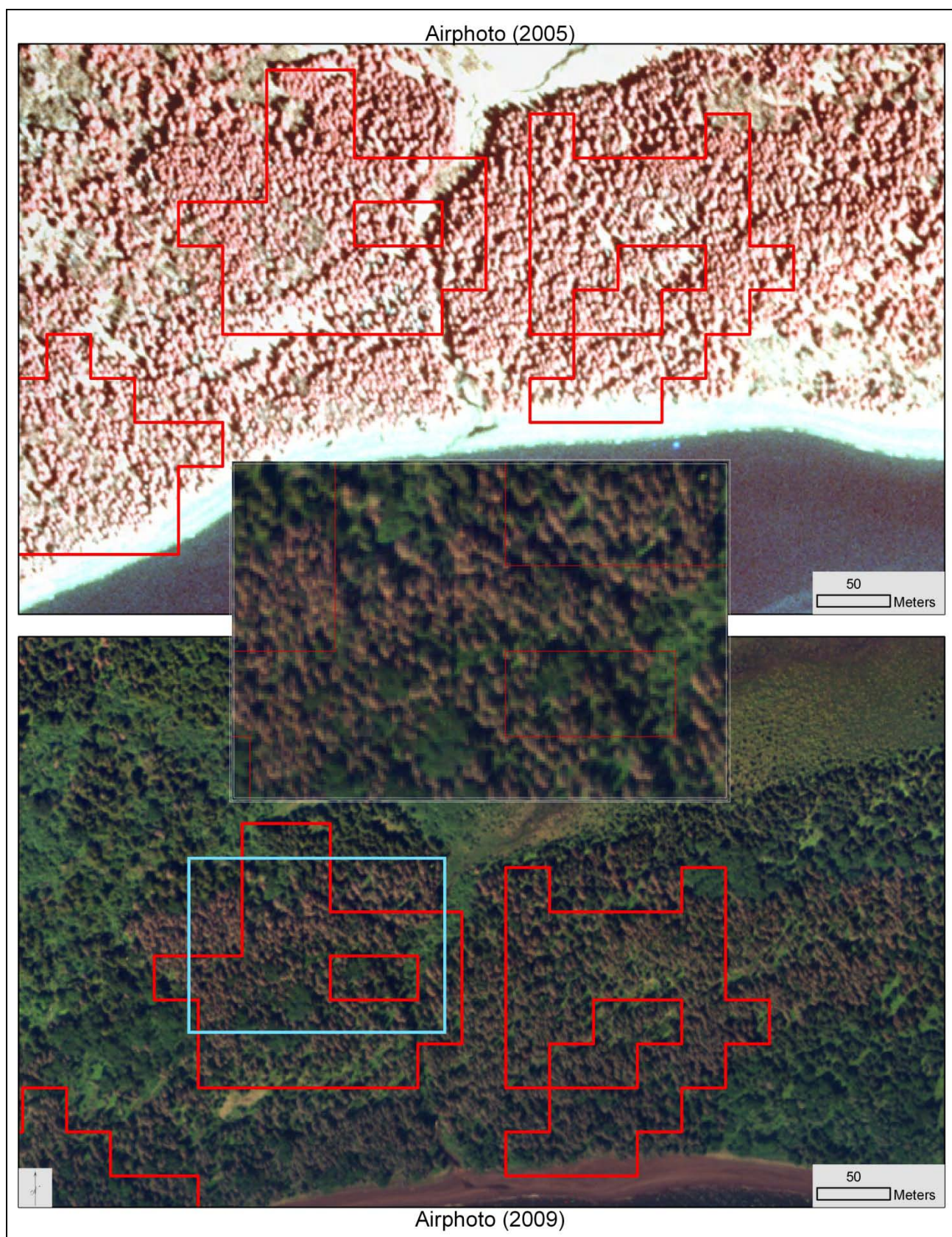


Figure B2. A forest pathogen killed trees in patches near the Houghton Ridge area, 2003.

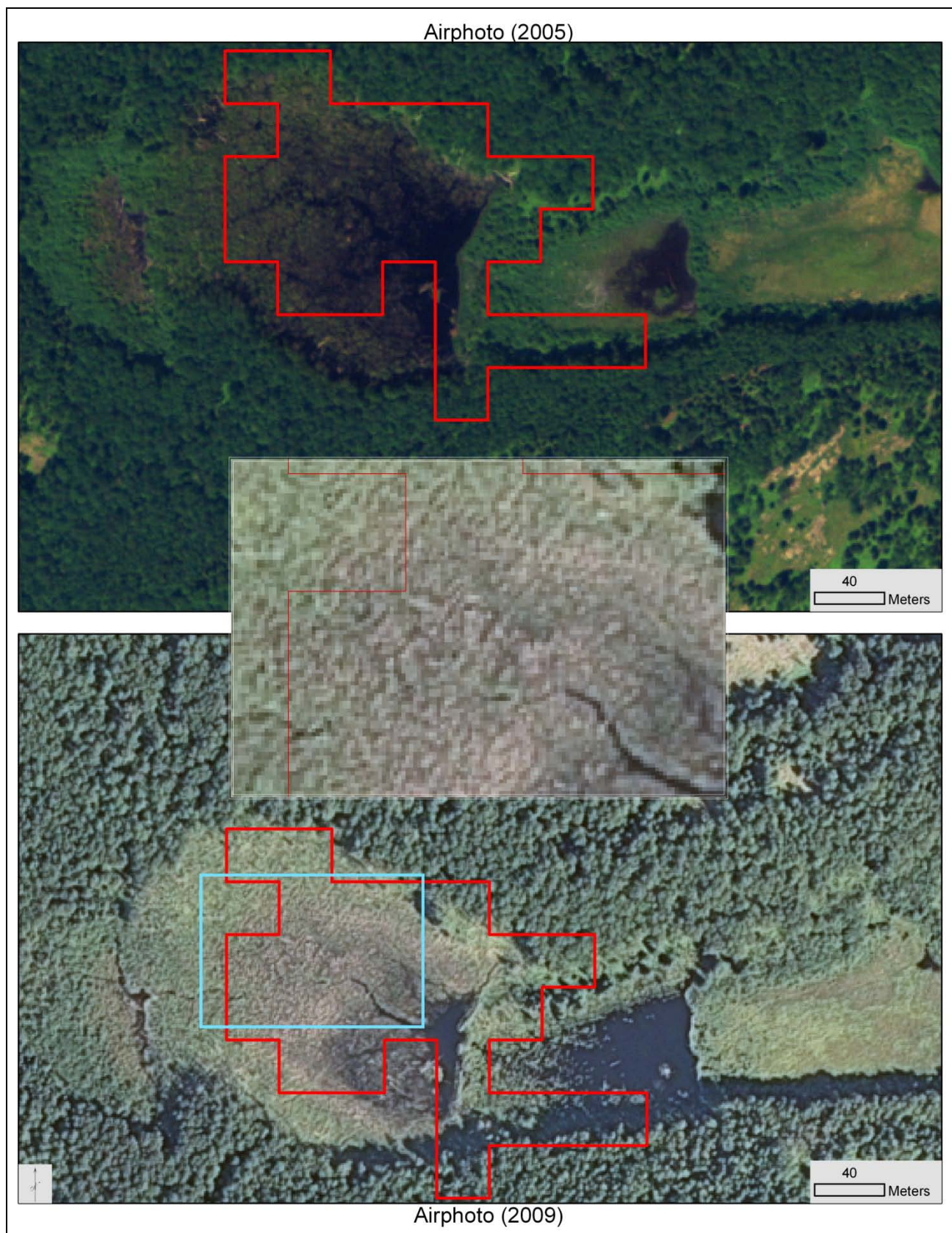


Figure B3. Beaver disturbance in 2007 resulted in water draining out of a wetland.

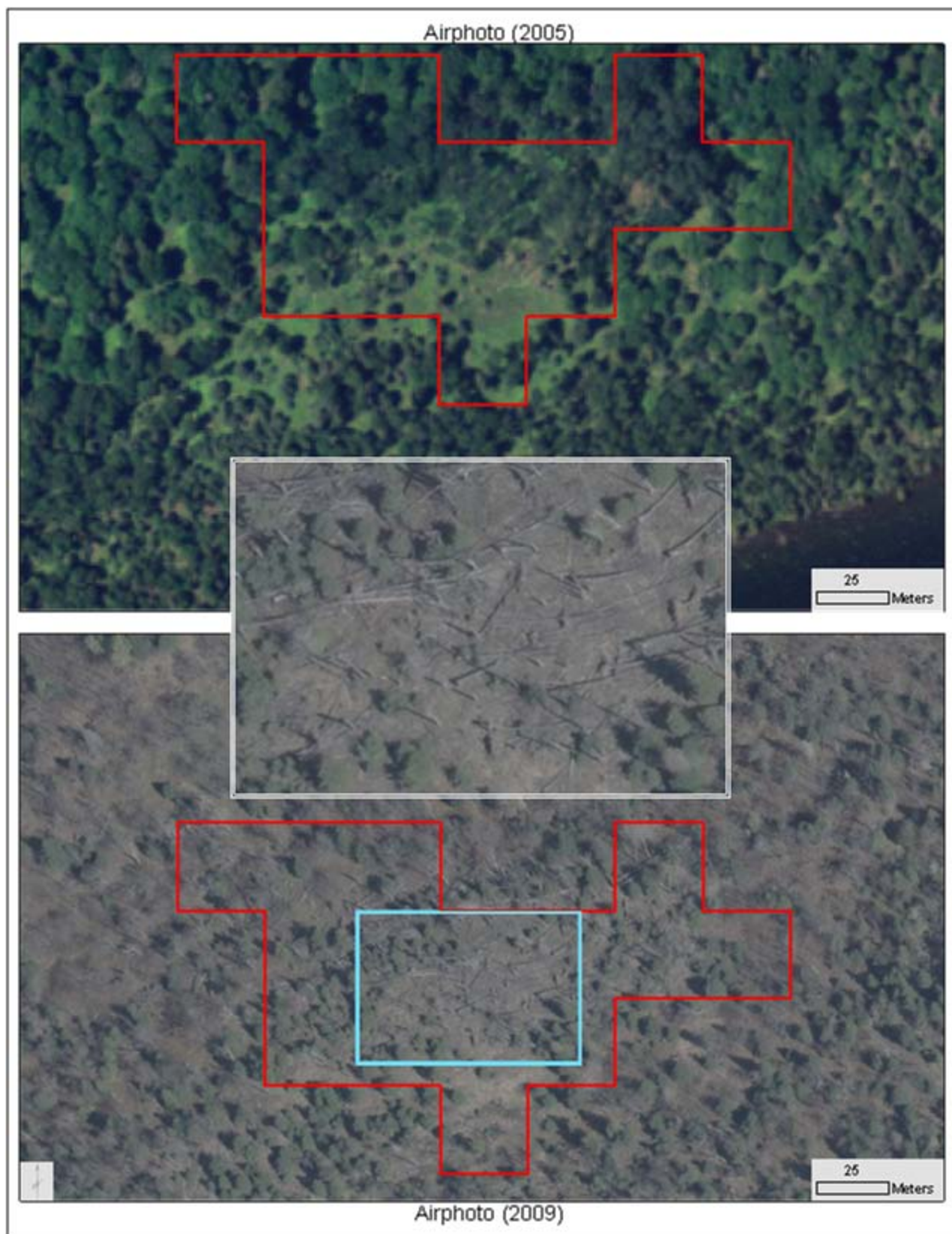


Figure B4. A blowdown event in 2007 affected only a few trees in the Washington Harbor area.

Appendix C. Spatial distribution of disturbances in analysis area.

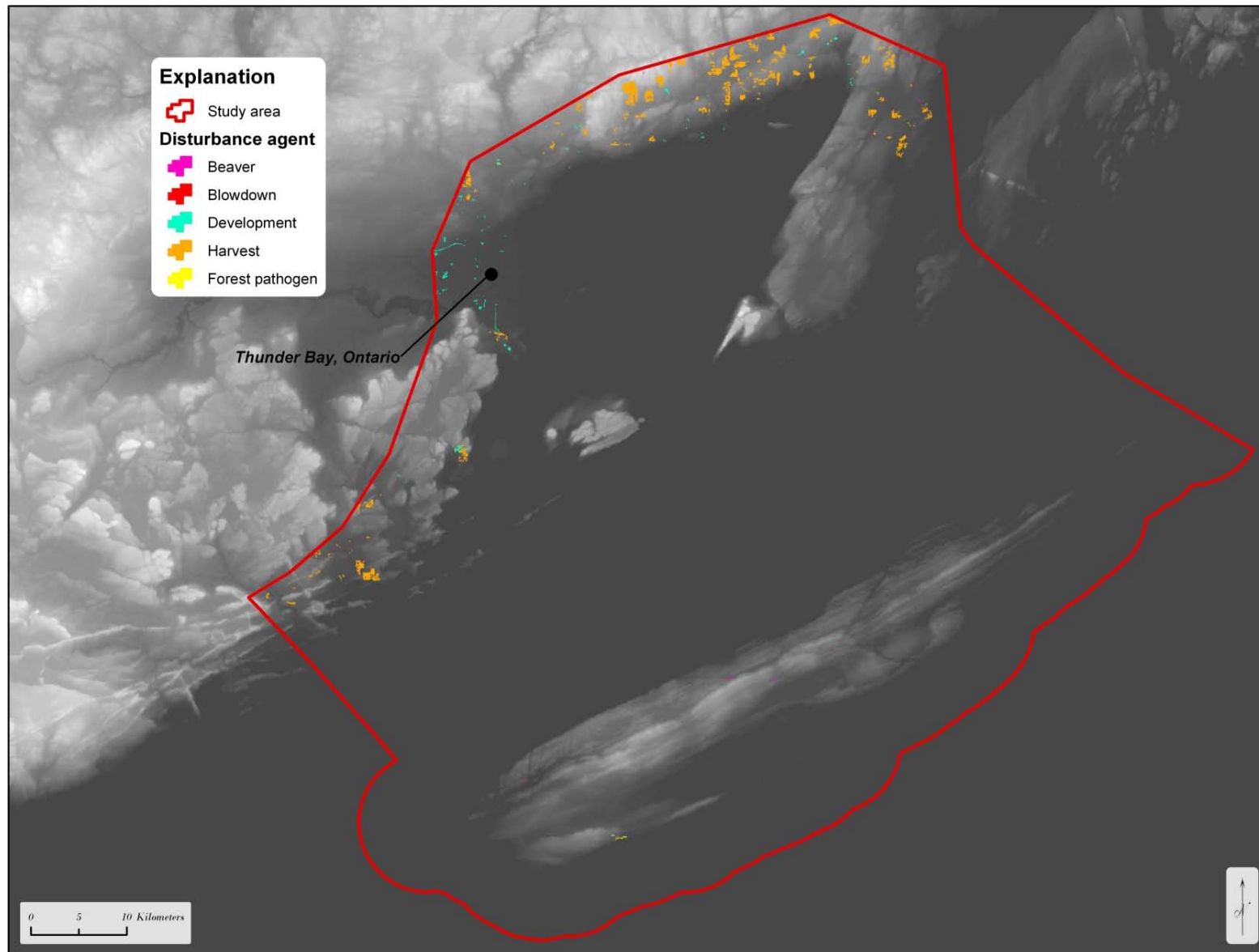


Figure C1. Overview map of analysis area identifying disturbances by causal agent overlaid on a digital elevation model.

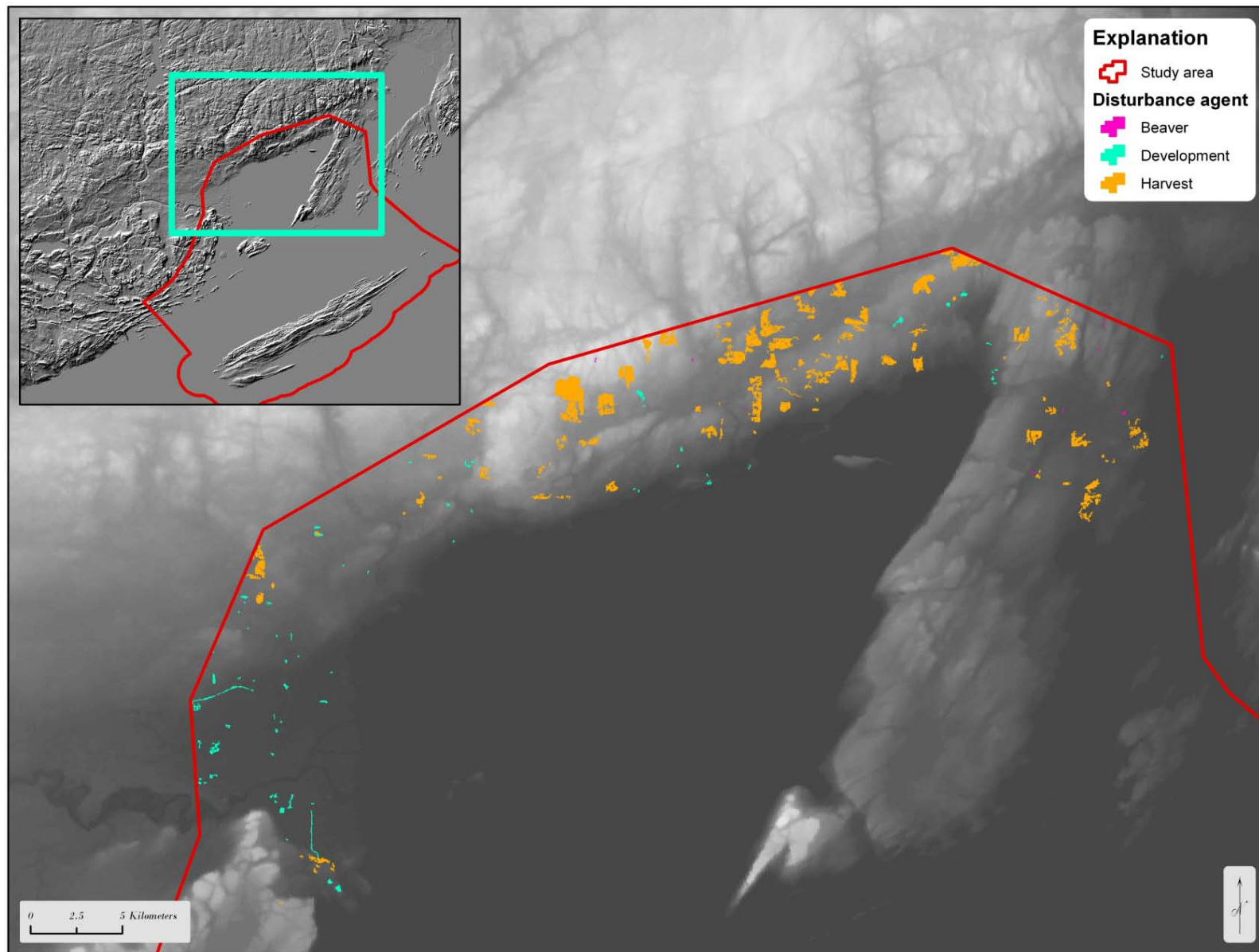


Figure C2. Map of disturbances north of Thunder Bay, Ontario. Inset map shows current extent in light blue box.

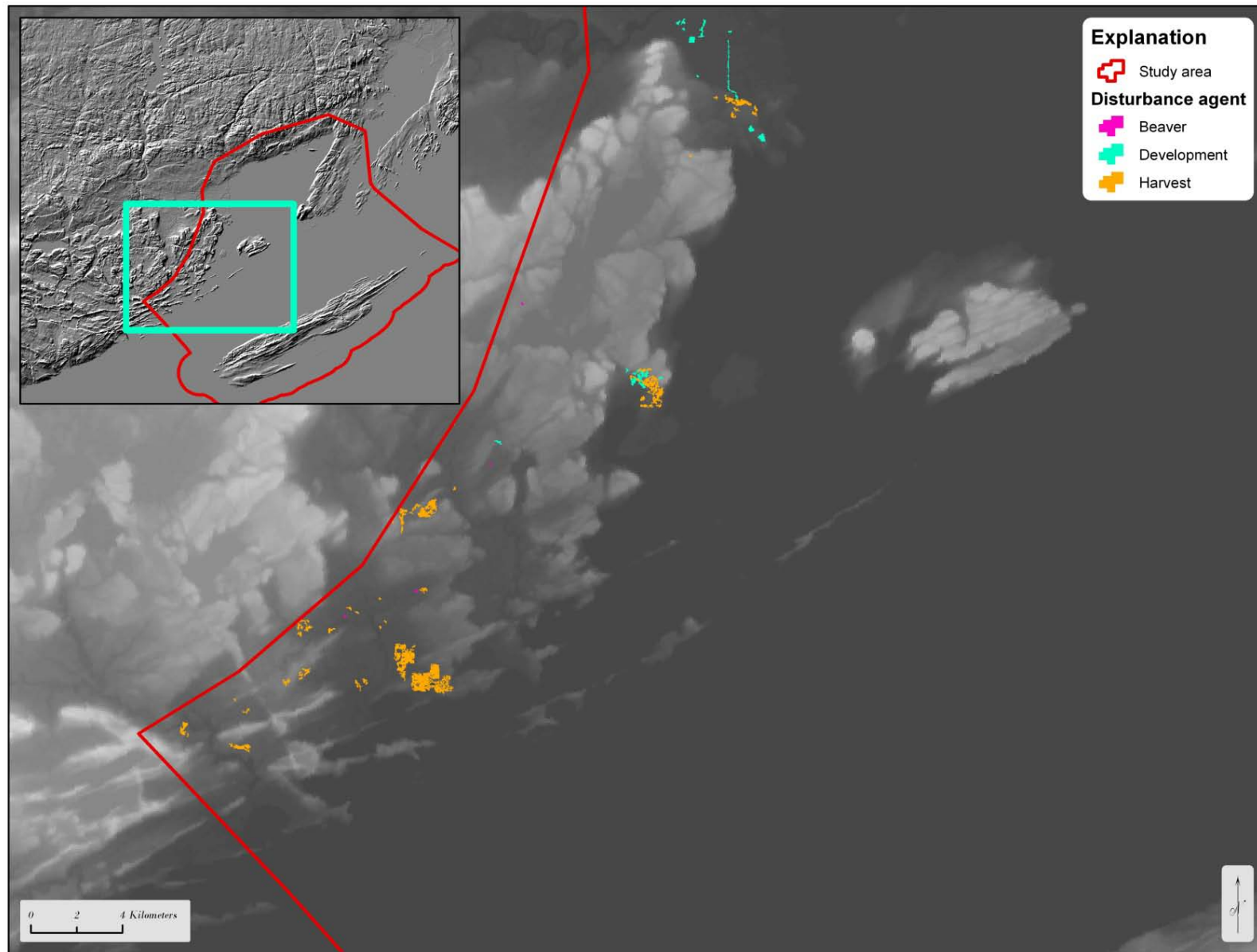


Figure C3. Map of disturbances south of Thunder Bay, Ontario. Inset map shows current extent in light blue box.

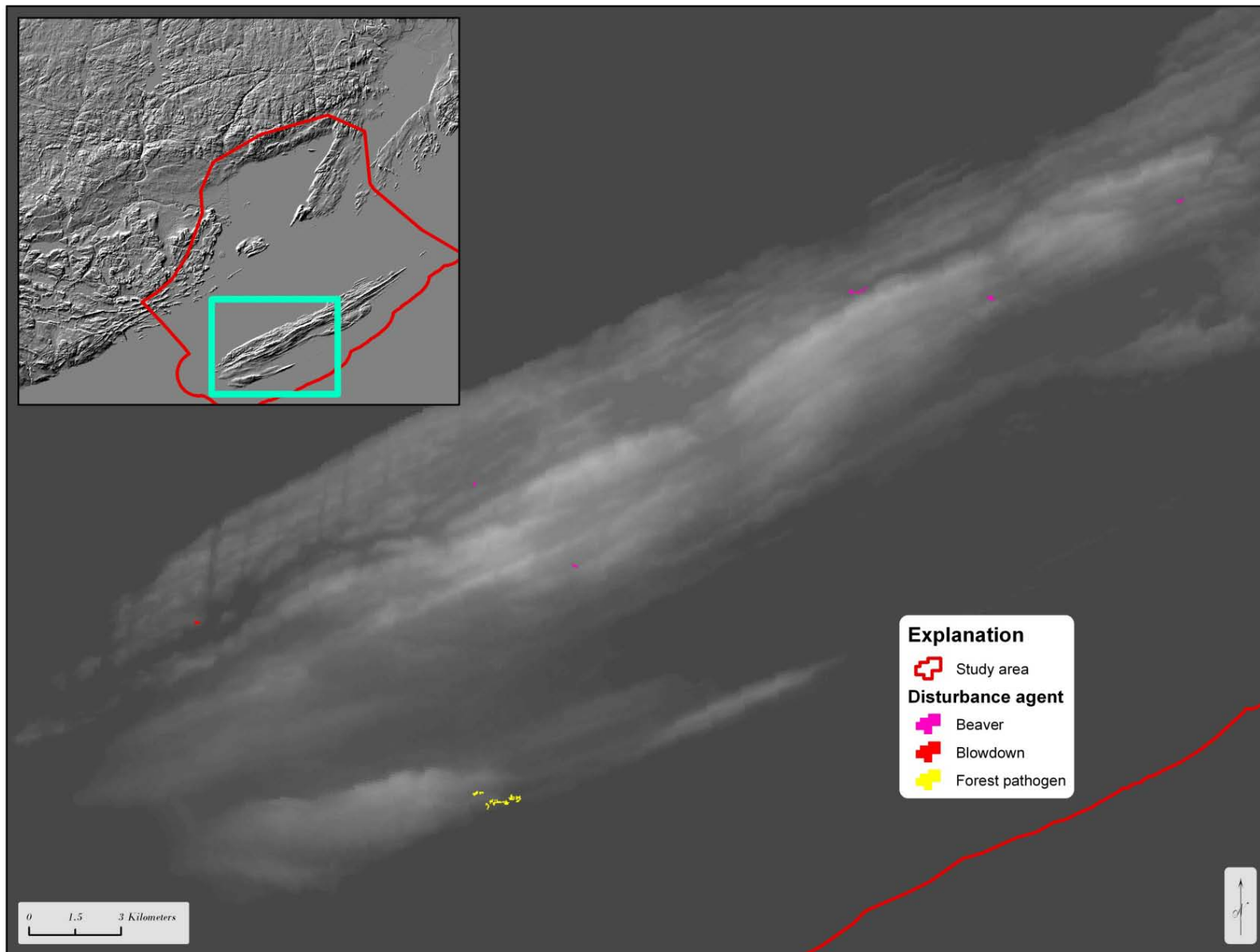


Figure C4. Map of disturbances present on ISRO. There were no disturbances in the northeast portion of the island. Inset map shows current extent in light blue box.

Appendix D. Supplemental tables.

Table D1. Percent of land disturbed by year and analysis area for the 6 year analysis period.

Year	Analysis area	
	ISRO	Canada
2003	0.02	0.61
2004	0	0.61
2005	<0.01	0.44
2006	<0.01	0.56
2007	<0.01	0.28
2008	0	0.15
Total	0.03	2.66

Table D2. Hectares disturbed by agent and year for each analysis area.

Analysis area	Year	Hectares of disturbances						Total
		Beaver	Blowdown	Development	Fire	Harvest	Forest pathogen	
ISRO	2003	2.9	0	0	0	0	8.4	11.3
	2004	0	0	0	0	0	0	0
	2005	1.3	0	0	0	0	0	1.3
	2006	0.5	0	0	0	0	0	0.5
	2007	0.7	0.8	0	0	0	0	1.5
	2008	0	0	0	0	0	0	0
	Total	5.4	0.8	0	0	0	8.4	14.6
Canada	2003	5.5	0	65.7	0	580.0	0	651.2
	2004	2.8	0	33.6	0	615.1	0	651.5
	2005	3.1	0	40.9	0	428.6	0	472.5
	2006	1.5	0	20.5	0	578.1	0	600.1
	2007	0.9	0	70.3	0	222.4	0	293.6
	2008	2.8	0	11.8	0	144.6	0	159.1
	Total	16.5	0	216.6	0	2568.8	0	2828.2

Table D3. Number of disturbance patches by year and disturbance agent for each analysis area.

Analysis area	Year	Beaver	Blowdown	Development	Fire	Harvest	Forest pathogen	Total
ISRO	2003	2	0	0	0	0	8	10
	2004	0	0	0	0	0	0	0
	2005	2	0	0	0	0	0	2
	2006	1	0	0	0	0	0	1
	2007	1	1	0	0	0	0	2
	2008	0	0	0	0	0	0	0
	Total	6	1	0	0	0	8	15
Canada	2003	4	0	18	0	49	0	71
	2004	1	0	17	0	65	0	83
	2005	3	0	16	0	48	0	67
	2006	2	0	10	0	64	0	76
	2007	1	0	25	0	32	0	58
	2008	2	0	7	0	22	0	31
	Total	13	0	93	0	280	0	386

Table D4. Hectares of land area that were lost in each of the cover types. The following classes were not included in the table because no area was disturbed: building, agriculture, road, and bare ground.

Analysis area	Year	Upland forest	Upland woodland	Upland shrub / herbaceous	Lowland forest	Lowland shrub / herbaceous	Water
ISRO	2003	8.4	0	0	2.9	0	0
	2004	0	0	0	0	2.3	0
	2005	0	0	0	1.3	2.9	0
	2006	0	0	0	0.3	1.3	0
	2007	0.8	0	0	0	0	0.7
	2008	0	0	0	0	0	0
	Total	9.2	0	0	4.5	6.5	0.7
Canada	2003	538.3	90.6	20.7	1.6	0	0
	2004	600.4	28.6	18.0	0	2.8	0
	2005	403.8	34.4	12.1	0	0	0
	2006	544.2	41.4	12.0	2.5	0	0
	2007	222.5	54.8	13.9	1.5	0	0.9
	2008	144.2	5.1	7.1	0	0	2.8
	Total	2453.4	254.9	83.8	5.6	2.8	3.7

Table D5. Hectares of land area that were gained in each of the cover types. The following classes were not included in the table because no area was disturbed: building, agriculture, road, and bare ground.

Analysis area	Year	Upland shrub / herbaceous	Lowland shrub / herbaceous	Building	Road	Water	Bare ground
ISRO	2003	8.4	2.9	0	0	0	0
	2004	0	0	0	0	0	0
	2005	0	1.3	0	0	0	0
	2006	0	0.5	0	0	0	0
	2007	0.8	0.7	0	0	0	0
	2008	0	0	0	0	0	0
	Total	9.2	5.4	0	0	0	0
Canada	2003	569.4	1.6	2.6	34.3	3.9	39.5
	2004	618.3	2.8	0	9.3	0	21.1
	2005	429.8	0	0	1.4	3.5	37.7
	2006	573.9	1.7	0.9	1.9	0.8	20.9
	2007	246.9	0.9	1.9	5.9	0	38.0
	2008	144.6	2.8	0.8	6.1	0	4.9
	Total	2582.9	9.8	6.2	58.9	8.2	162.1

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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