# An analysis of large-scale forest cover disturbance in Canada (1998-2004) based on multi-temporal coarse resolution data

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***Abstract*- A procedure was developed to map large-scale forest disturbances at annual, continental scales using 1-km resolution data from a combination of satellite sensors and ancillary spatial data. The method, dubbed Change Screening Analysis Technique (Change-SAT), creates a probability of change map using multiple logistic regression and multi-temporal change metrics. The probability map is converted to binary change map and a decision tree model applied to attribute the most likely cause of change among burning, harvesting, flooding, or defoliation. This paper presents the results of applying Change-SAT over Canada for the period 1998-2004. A variety of interesting change examples is demonstrated, including insect defoliation, flooding related to a hydroelectric project, and widespread damage and die-off resulting from drought and a snow/wind storm. Although the method is generally not well suited to providing quantitative estimates of change, it identifies large disturbances that can be investigated in greater detail based on field visits or higher resolution imagery.**

***Keywords*:** change detection; disturbance; forest; NOAA AVHRR; SPOT VEGETATION

## I. Introduction

Satellite remote sensing is an especially valuable tool for monitoring vegetation changes over large extents where comprehensive aerial and ground surveying is cost-prohibitive. In Canada, for example, large-area information on land cover / land use change (LCLUC) and natural disturbance is needed for sustainable management of natural resources, monitoring the impacts of climate change, and reporting to international conventions, such as the United Nations Framework Convention on Climate Change and Kyoto. This information must be spatially comprehensive, timely, and gathered in a cost-effective, consistent, and repeatable manner.

Natural Resources Canada is developing several satellite-based systems designed to monitor LCLUC and disturbance across Canada using fine resolution imagery, such as that collected by Landsat's TM and ETM+ sensors. These programs include (a) the Earth Observation for Sustainable Development (EOSD) Program of the Canadian Forest Service to map forest cover and monitor changes [1]; (b) the Canadian Wildland Fire Information System (CWFIS) to collect information on and map burned areas; and (c) an initiative within the Earth Sciences Sector to map land cover and LCLUC above the tree-line in Northern Canada.

Improved computing and disk storage capabilities have made it possible to perform comprehensive land cover mapping and change analysis using Landsat-type data over a country as large as Canada. However, the frequency of change detection will likely remain limited to multi-year intervals (e.g. 5 years) in the foreseeable future considering the high data volume and cost, and limited sensor availability and revisit periods. For example, it can take up to several years to acquire a suitably cloud-free Landsat scene in some areas of Canada, especially those with persistent cloud cover and short growing seasons [1].

By contrast, wide-swath sensors providing coarse (250-1,000m) resolution imagery and daily revisit (e.g. AVHRR, VEGETATION, MODIS, MERIS) can be used to monitor large areas in a cost-effective and continuous manner. Their major drawback for monitoring and reporting is the ability to detect only large-scale changes to vegetation. For example, Fraser et al. [2] found that boreal burned area mapping using SPOT VEGETATION is most effective for burns larger than about 5-10 $km^2$.

An effective strategy, therefore, for continental-scale monitoring of LCLUC may be one that considers a hierarchy of spatial and temporal scales [3-4]. For example, annual coarse resolution monitoring could be used as a first-pass filter to flag areas of large-scale change for finer-scale analysis and field investigation. It can also provide information about the timing and trajectory of changes identified at finer resolutions. Fine resolution change detection could be applied to quantify the area and type of change at longer intervals (e.g. five years). This information can also be very useful for calibrating and validation coarse resolution products [5] [Fig 1].

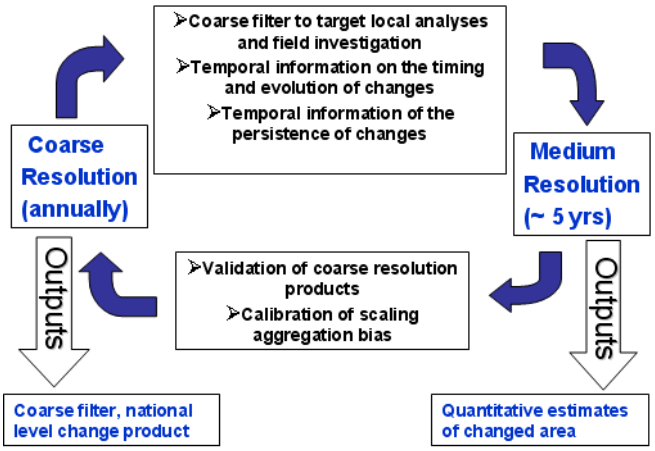


Fig. 1. A multi-scale approach for monitoring LCLUC at continental scales.

## II. Change Detection Method (Change-SAT)

This paper presents 1998-2004 results produced by a method dubbed Change Screening Analysis Technique (Change-SAT), which was designed to apply coarse resolution data for annual mapping of large forest disturbances across Canada. The method is described in detail in [6] and summarized in Fig. 2. A change / no-change logistic regression model is first applied using a variety of multi-temporal change metrics. These include inter-annual changes in reflectance, vegetation indices (VI), texture, and VI temporal variability computed using 10-day SPOT VEGETATION composites (S10 data), and inter-annual changes in temperature based on 10-day NOAA AVHRR products. The logistic regression probability of change is then converted to a binary change map by deriving an optimal probability threshold based on the expected areas of change from Canadian forestry statistics.

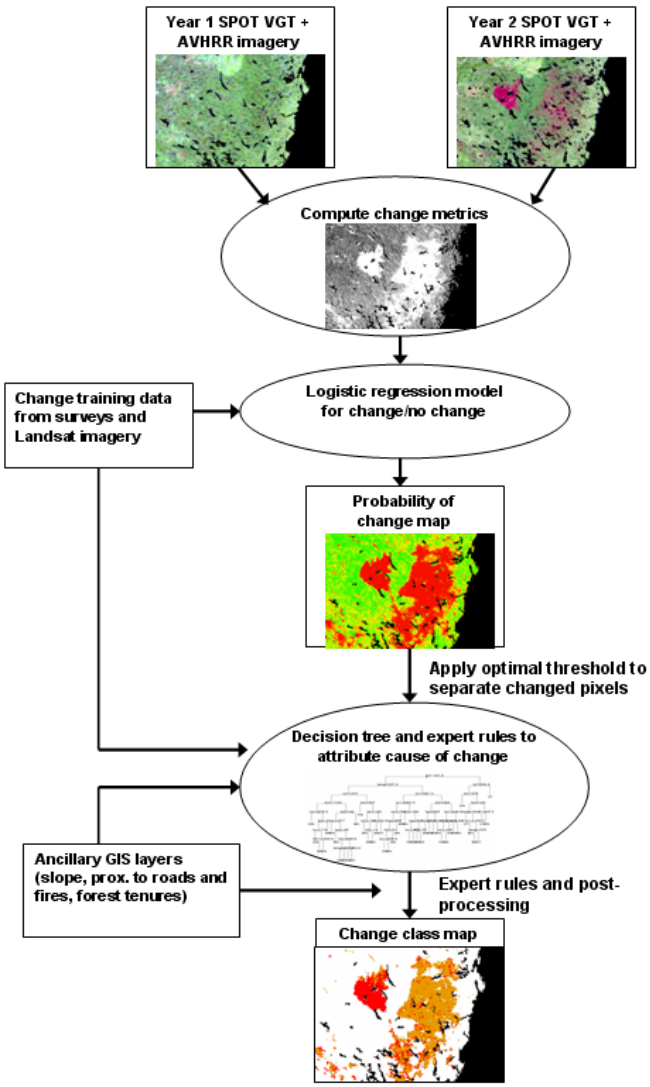


Fig. 2. Flowchart showing steps required for change detection procedure.

The binary change map is further refined to attribute the probable cause of change among burning, harvesting, flooding, or defoliation. This is accomplished using a classification decision tree that uses as input the multitemporal change metrics in addition to other, ancillary spatial layers. These layers include slope, proximity to the nearest road, local density of satellite-detected fire locations, and a map showing the tenured forest areas in Canada where commercial forestry companies may operate.

## III. Canada-wide Results (1998-2004)

Change-SAT was applied to produce annual change products over Canada for 1998-2004, the time period for which VEGETATION data are available. Table 1 summarizes the extent of changes for the four change classes over the six-year period. As a result of optimizing the logistic regression change threshold, resulting areas for burning and harvesting were similar to those from national forestry statistics. However, the cumulative Change-SAT defoliated area was significantly smaller by comparison to official statistics. Note that these statistics are believed to overestimate actual defoliated area due to double counting of different insect defoliators and the insect surveys being generalized as to including non-forested areas. Nevertheless, it appears that the Change-SAT product is capable only of mapping the most severe cases of defoliation that lead to significant tree mortality. National statistics are not available for the area of flooded forest (e.g. for hydroelectric projects). Change-SAT was clearly able to identify the location of one new hydroelectric reservoir (see example B below), yet also prone to producing false detections near the edge of water bodies.

Table 1. National-level Area ($km^2$) of the change classes mapped using Change-SAT and compiled in the Compendium of Canadian Forestry Statistics

| Change Class | Change-SAT 1998-2004 | Forestry Statistics (est.)[a] |
|---|---|---|
| Burn (BN) | 127,819 | 112,849 |
| Flooding (FD) | 5,070 | Unknown |
| Defoliation (DN) | 58,481 | 962,002[b,c] |
| Harvesting (HT) | 41,823 | 54,069[c] |
| Total Change | 233,193 (5.6%) | Unknown |

[a]Estimated by summing 1999-2003 statistics and 50% of 1998 and 2004 statistics
[a]30% or more foliaged removed; statistics are prone to overestimating affected area
[c]assumes that 2003-2004 statistics (not yet available) are same as 2002

## IV. Regional Examples of Forest Disturbance

Fig. 3 contains regional views of the change products from 1998-2004 showing a range of disturbances that could be corroborated with independent field surveys conducted by government forest health agencies.

(A) A large outbreak of Hemlock Looper that severely impacted more than 1,000 $km^2$ of balsam fir forest was mapped in 1999. The majority of trees in this area were completely

defoliated and killed in the first year of the insect outbreak.

(B) Shows a large area flooded for a reservoir in 1999 as a part of a hydroelectric project. The Sainte-Marguerite 3 reservoir has a surface area of 253 $km^2$, which was mapped as 140 $km^2$ in the 1-km resolution change product. Also visible are several patches of forest harvesting.

(C) An area in Ontario impacted by an early snow/wind storm in 2001 was mapped as defoliated. The region was surveyed by the Canadian Forest Service in 2002 and found to contain >10,000 $km^2$ of moderately to severely damaged forest. Ground photographs indicate damage mainly restricted to conifers, in the form of snapped and bent crowns.

(D) Shows a large band of defoliation in the Aspen Parkland zone, which lies north of the agricultural prairie region and south of the boreal forest. This region was impacted by the most severe drought on record during 2001-2003, which led to widespread dieback of Aspen that has been surveyed by the Canadian Forest Service. In the Boreal Plains to the north are several large burns >1,000 $km^2$. The Landsat image shows the House River burn in Alberta, which affected 2,500 $km^2$ and cost $49 million for suppression.

(E) An expansion of a mining operation in the Oil Sands Region appears as a mixture of harvested and defoliated forest. In the vicinity are several burns from 1999.

(F) Forests in the province of British Columbia have been affected by a widespread infestation of mountain pine beetle, which has grown exponentially since the late 1990's. A large defoliated patch from the Change-SAT product is shown, in addition to a pair of Landsat 7 scenes, where impacted forest appears red in the RGB=5-4-3 false colour composite.

## V. Summary

A method has been developed to map large (~ >5km2) forest disturbances at annual, national scales using a combination of 1-km imagery from coarse resolution sensors and ancillary spatial data layers. Application of the method to 1998-2004 demonstrates that it is capable of mapping a wide range of disturbance types, including severe insect caused defoliation, tree damage and die-back caused by storm events and drought, wildfires, patches of clear-cut harvesting, areas flooded for producing hydroelectricity, and mining related development. These coarse resolution change products can complement fine-scale change analysis (e.g. based on Landsat) by providing a timely coarse filter to identify areas affected by large disturbance and information on the timing and persistence of forest changes.

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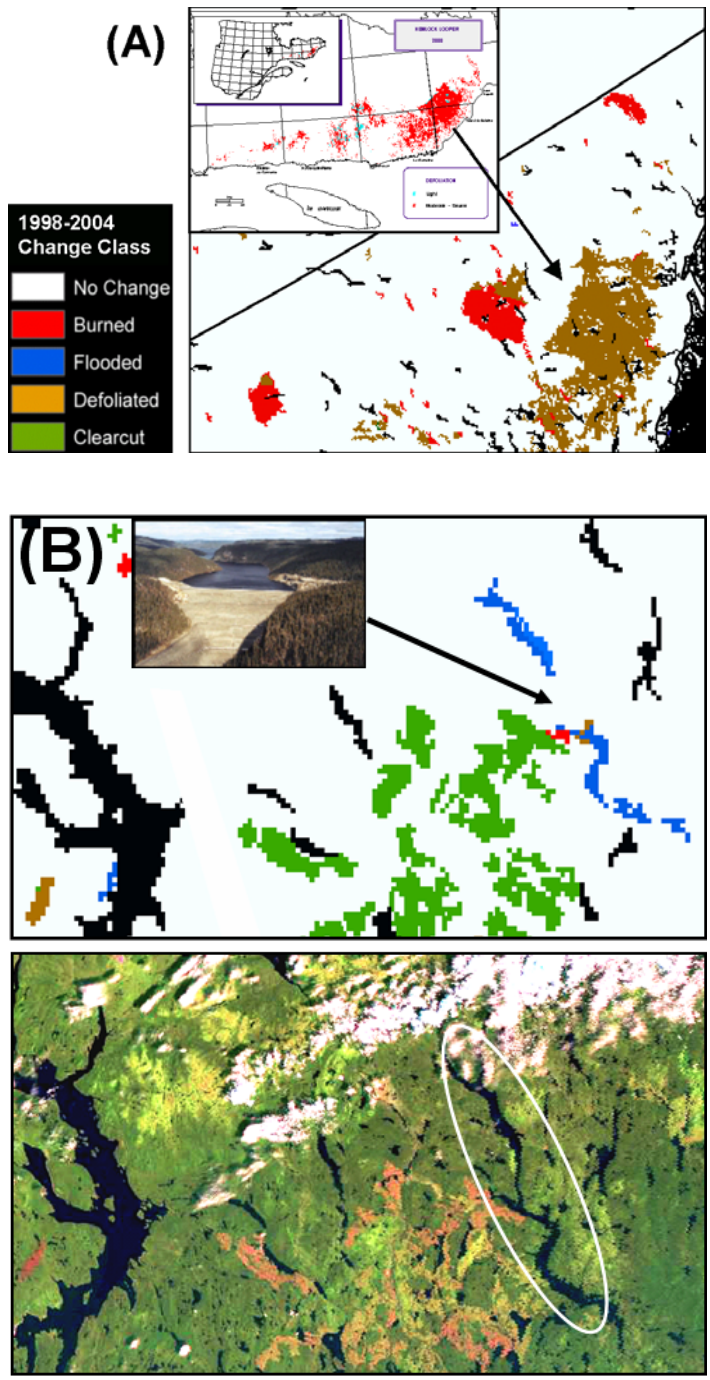
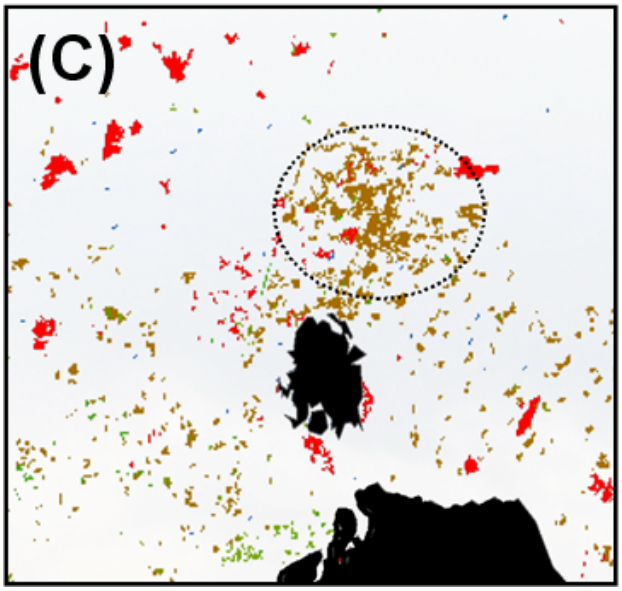
Fig. 3. Regional examples of forest disturbance mapped between 1998-2004

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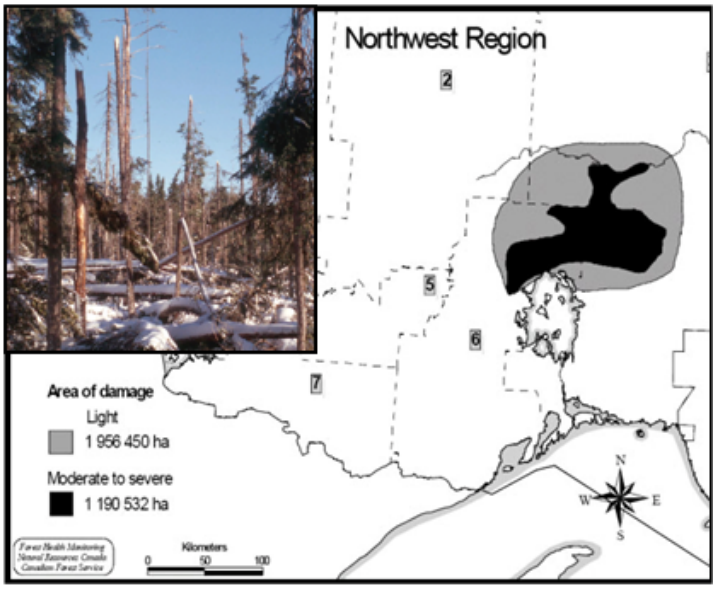
Northwest Region
2
5
6
7
Area of damage
Light
1 956 450 ha
Moderate to severe
1 190 532 ha
Kilometers
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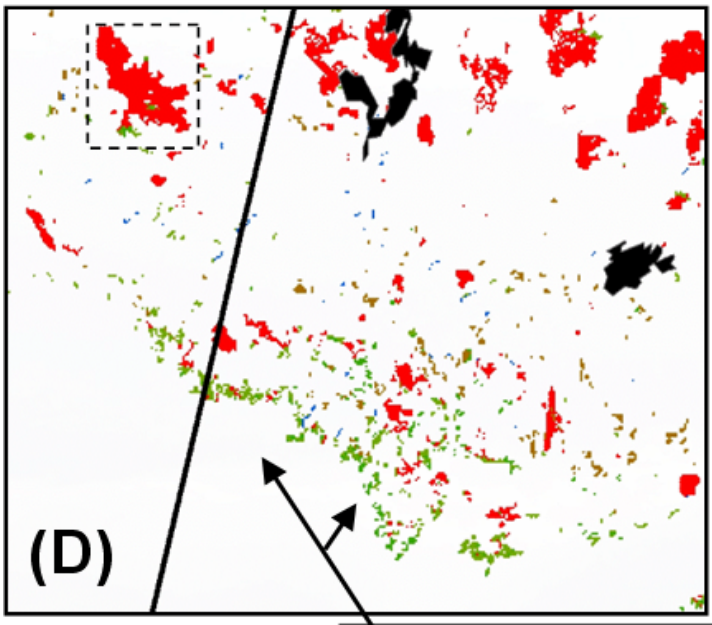
50
100
N
W
E
S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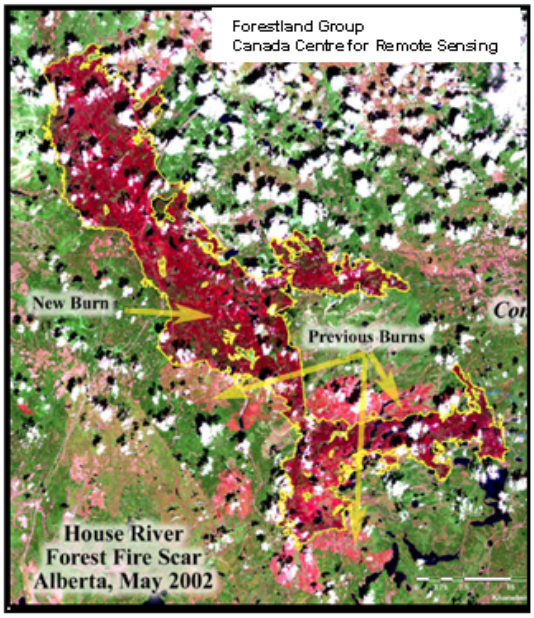
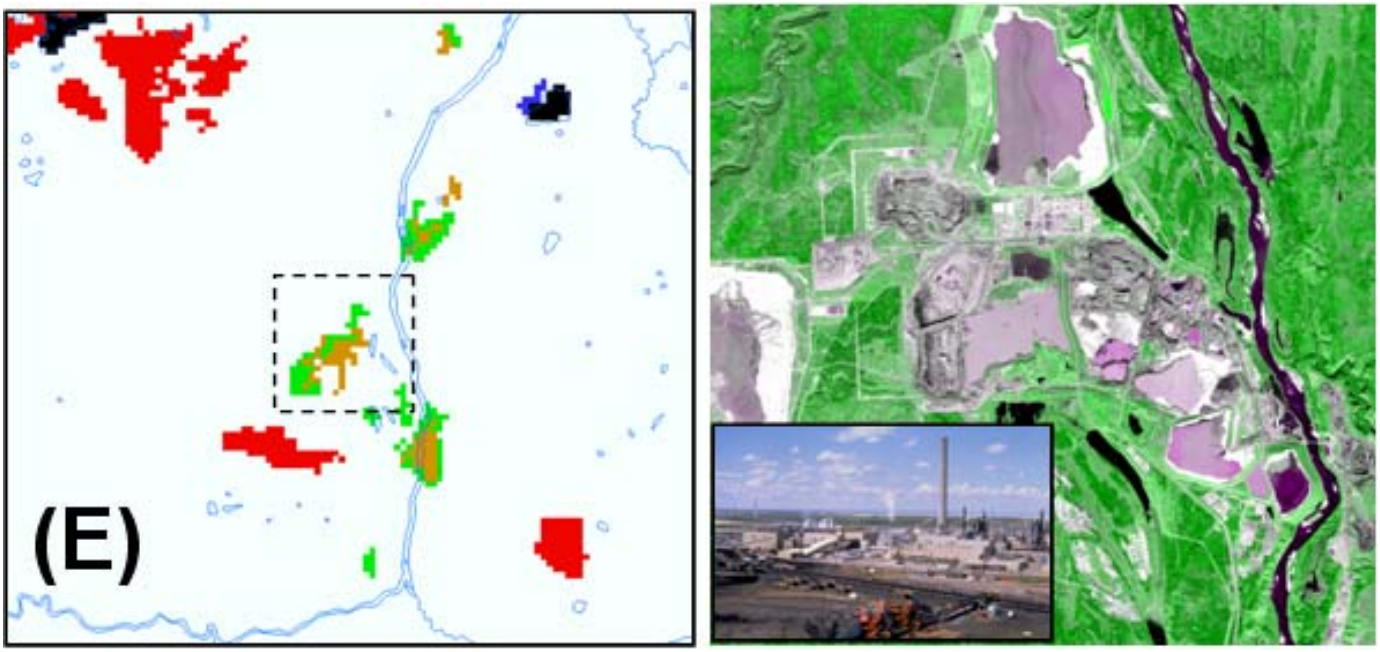

Forestland Group
Canada Centre for Remote Sensing
New Burn
Previous Burns
House River
Forest Fire Scar
Alberta, May 2002

Photo by M. Michaelian,
Canadian Forest Service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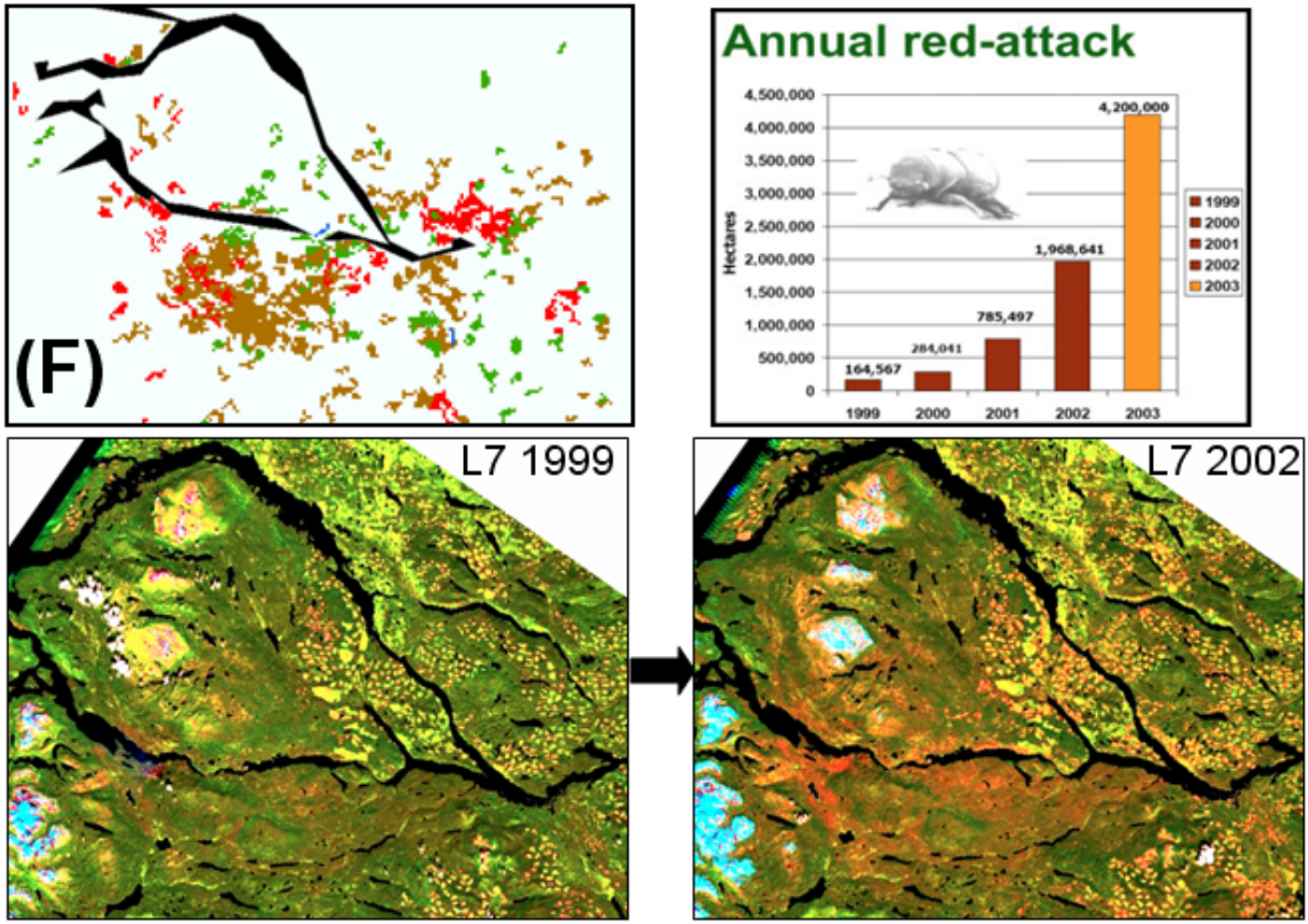
(F)
Annual red-attack
Hectares
4,500,000
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
164,567
284,041
785,497
1,968,641
4,200,000
1999
2000
2001
2002
2003
L7 1999
L7 2002