Identification of Hurricane Juan Blow-Down Using Aerial Photography

Renewable Resources Branch
Forestry Division
Forest Inventory Section

FOR 2004-7 July 2004

EXECUTIVE SUMMARY

Photo interpretation of approximately 680 000 hectares in central Nova Scotia identified at least 15 860 ha and at least 2 056 000 cubic metres of merchantable wood volume blown down in forest stands, as a result of hurricane Juan on September 29, 2003. These figures are based on areas that are greater than 1 hectare in size. Blow-down occurring in areas less than 1 hectare in size were often not detectable in the aerial photography due to the scale of 1:24 000, nor in the digital scans of same. A helicopter survey carried out soon after the hurricane indicated that a significant quantity of blow-down, in addition to the 15,860 ha, had occurred over areas less than 1 hectare in size.

Efficiencies of interpretation were enhanced by digitally scanning photography and subsequently viewing the imagery with graphics computer screens. Digital images of the original photography, flown at a scale of 1:24 000, were enlarged to an equivalent scale of 1:2000 on computer screens.

Photographs were scanned at 1350 DPI resulting in an equivalent resolution of 0.5 metre pixels on the ground. In comparison conventional satellite imagery provides minimum ground resolutions of four metre pixels for colour bands (Multi-spectral).

Cost estimates of satellite imagery ranged from $0.03 to $29.70 per square kilometre and the Department will further investigate the use of such imagery for future disturbance detection over wide areas. Comparable photography costs range from $13.00 to $21.00 per square kilometre plus additional costs for scanning and preparation of digital imagery files.

Introduction

Hurricane Juan struck Nova Scotia on September 29, 2003 with winds reaching 154-177 km/hr. Hurricanes of such strength have not hit this part of Nova Scotia in recent memory. The last severe summer hurricane to hit Nova Scotia was Edna, which occurred in 1954. Juan was the first hurricane since 1893 to directly hit the city of Halifax. The storm hit land close to Halifax and proceeded in a northerly direction through the centre of the province before moving across the Northumberland Strait into Prince Edward Island.

The severe damage to buildings, infrastructure, and primarily trees caused by the hurricane, and the wide-spread nature of the damage in the central part of the province, created the thought that extensive blow-down in the forest could have a significant impact on forest resource management. For this reason the Forestry Division of the Department decided that an inventory of the extent and severity of blow-down was necessary.

The Preliminary Blow-down Estimate (The Helicopter Assessment)

On the second day following Juan's landing on shore, the Department's Forestry Division carried out a preliminary helicopter survey over the four central counties of Nova Scotia. This survey was designed to obtain a preliminary estimate of the extent of blow-down in forest stands and to determine if a significant quantity of forest tree volume had been affected. The information obtained from the helicopter assessment indicated that a more detailed inventory would be needed to further quantify blow-down damage. The total area of assessment totalled 680,400 ha of forest and non-forested land in Halifax, Hants, Pictou and Colchester counties.

The Forestry Division geographic information system (GIS) and the forest resources data base was used to mask out the non-forested land from the hurricane zone. Using this method in the GIS data base, it was determined that 481,200 ha of the 680 400 was classed as forest land. A series of sample points were randomly selected over forest land in the area to be surveyed by helicopter (Figure 1). The GIS system generated GPS coordinates for the points and Forestry Division staff hovered over each point in a helicopter and conducted the preliminary survey.

The assessors viewed the ground through templates which approximated an area of one hectare in size on the ground (Figure 2). The quantity of blow-down was categorized into four classes as shown in Table 1.

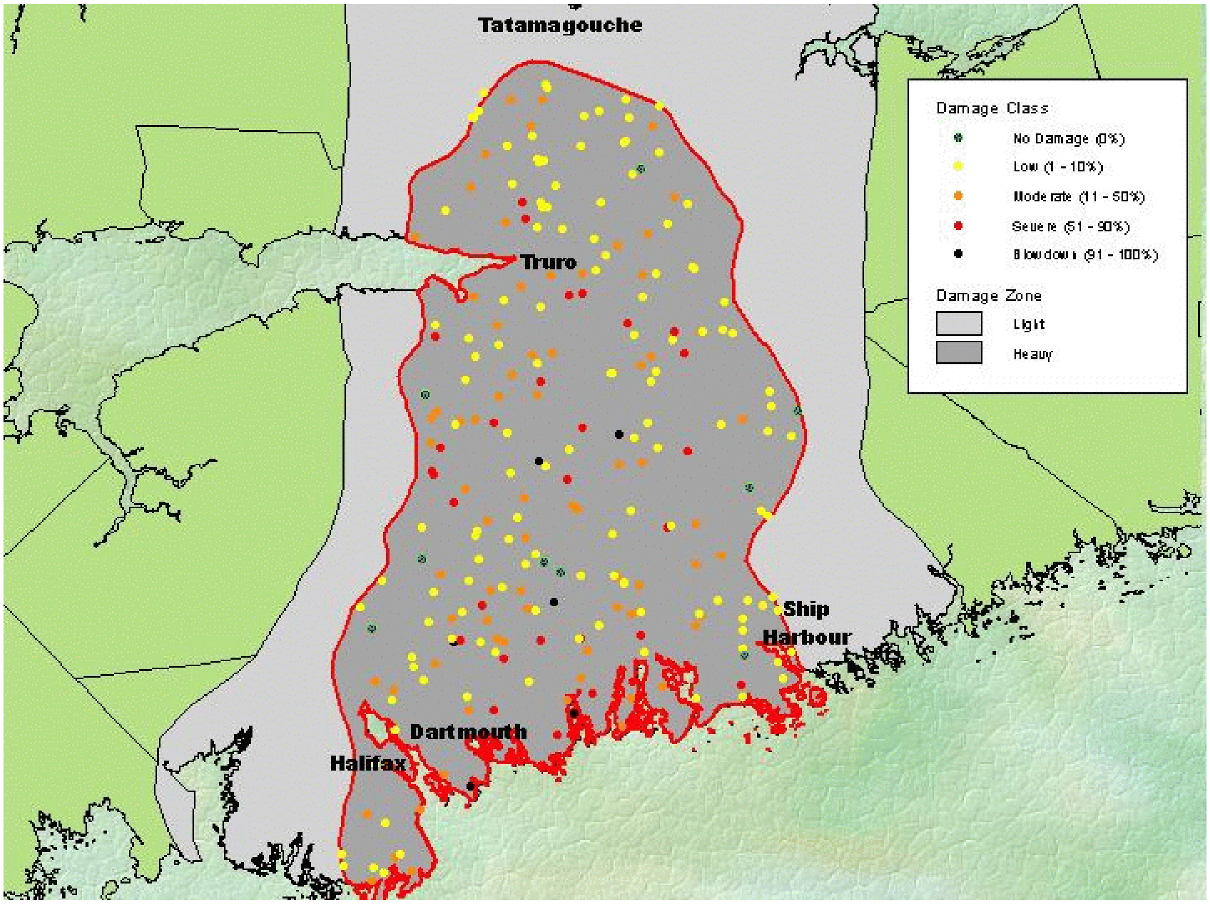


Figure 1. Randomized point locations surveyed by Helicopter.

Figure 2: A view of the assessment square used by helicopter crews.

Table 1. Blow-down Classes used in the Helicopter Survey

Blow-down Class	**Percent of Ha Blown Down**
None	1-10
Light	11- 50
Moderate	51-90
Severe	91 +

Two Hundred and fifty survey points were assessed over a two week period. Field crews on the ground visited 13 of the GIS/GPS sample points to provide ground assessment data. This preliminary assessment determined that blow-down in the three counties assessed was significant and should be investigated further.

Detailed Inventory of Blow-Down

A detailed inventory of blow-down was conducted over the area encompassing the 481 200 ha in Halifax, Hants and Colchester counties. The assessment area included all forest land from the city of Halifax and stretched north to Central New Annan in Colchester County and would cover a swath approximately 70 km wide, mostly east of the hurricane path.

Because of the immediacy of the need to have details of the blow-down for the assessment area, remote sensing and image interpretation were chosen as the methods to inventory blow-down. Image analysis and GIS software would facilitate the input, mapping, analysis and presentation of the inventory information resulting from interpretation. Interpretation would provide the location of the blow-down areas and the GIS data base would be used to estimate the tree volume affected.

Data sources

Satellite Imagery

Satellite imagery was investigated for its utility to provide the data source for blow-down assessment. Based on a review of imagery on hand, it was determined that Landsat satellite imagery, with 30 metre resolution in multi-spectral bands, may not have the resolution required to carry out the assessment. Nor would the ten metre panchromatic (black and white) band have the resolution nor the information in the visual wave lengths that would facilitate image classification.

Higher resolution satellites such as IKONOS and QUICKBIRD (both with 4 metre resolution in the multi-spectral bands) were also assessed but the cost of acquisition prohibited their use. These two satellites provide imagery over targeted areas for specific planned projects and thus their archived (images already in existence - usually ordered by other agencies) imagery would not show the blow-down, resulting in the need for a special directed satellite mission. Costs of such a mission would exceed $200 000 just for data acquisition alone. In addition optical satellite imagery acquisition is highly weather dependant with no guarantee that the sky would be cloud free on the day the satellite would be passing over the target area.

The assessment of blow-down for potential salvage harvest planning as well as other disaster recovery planning needed to take place as soon as possible. Obtaining satellite imagery could be delayed by 30 days or more due to weather. Based on past experience in obtaining satellite imagery, particularly for the Central Region of Nova Scotia, it was decided that the risk of delay for image acquisition, due to weather would be too great.

Aerial Photography

An alternate source of data investigated for its utility was aerial photography. Normally the Department acquires true colour aerial photography at a scale of 1:10 000 for regular inventory use. This scale would have been ideal for identifying hurricane blow-down. The 1:10 000 scale photography has proven to be an excellent source for identifying the details of Nova Scotia's relatively dissected forests, including species and height of forest stands. Nova Scotia's forest stands have a high degree of species richness per stand, requiring a larger scale of photography to enable the identification of inventory parameters. The cost however, of acquiring 1:10 000 true colour photography and digital scans for the area was estimated to be at least $200 000.

An alternative scale of 1:24 000 true colour aerial photography was investigated. Experience in the private sector had demonstrated that aerial photography at this smaller scale ratio is useful for forestry operations planning and inventory. A review of samples of 1:24 000 scale photography indicated that blow-down identification was possible. A contract was tendered and awarded to James W. Sewall Company of Maine.

James W. Sewall Company was selected because they tendered the lowest price and had the experience which would facilitate a successful completion of the project, within the relatively short time frame required. Flying began the last week in October and was completed by the middle of November. The contract called for the delivery of products no later than 30 days after the completion of the flying.

Sun angle and cloud cover play a major role in the quality of photography acquired for forest interpretation. A sun angle of 30-45 degrees above the horizon is considered the best acceptable for acquiring aerial photography for detailed forestry interpretation. In Nova Scotia the sun angle in late October reaches the 30 degree position above the horizon for only a few short hours each day and by November 10, 2003 it did not attain that altitude for any appreciable time, ie less than one-half hour. A portion of the photographs thus obtained, while still useful for the project purposes, were found to contain a greater amount of shadow than would normally be considered acceptable.

The contract deliverables included hard copy photographs, digital scanned files of the photos and a set of digital orthophoto maps at a scale of 1:10 000 rectified and mosaiced to the Provincial standard topographic base maps. The digital products facilitated the on- screen heads up identification of blow-down and the use of GIS technology to directly capture blow-down polygons. The polygons could then be directly overlayed on the existing forest resources GIS layer.

Photography was flown using true colour positive film. The diapositive rolls were then scanned at 1350 DPI, which provided an equivalent ground resolution on the imagery of 0.5 metre pixels.

Photo Interpretation

A base layer containing a 2 km grid was created in Arcview, the Division's desktop GIS. The digital orthophotos were then brought into the base layer, one map sheet (approximately 4300 ha) at a time. Using large graphic computer screens, interpreters could expand images until blow-down could be identified. The most effective on-screen scale was 1:2 000. Once identified the blow-down was classed into one of two categories and an on- screen polygon was traced by the interpreter. Because of time, and partly because of the resolution, photo interpreters were instructed to attempt to identify blow-down only in areas greater than one hectare in size for the majority of the assessment zone. This is compatible with the smallest forest polygon delineated through normal interpretation processes in DNR.

Table 2. Photo Interpretation Blow-down classes identified on screen

Blow-Down Classes	**Percent of Area Blown Down**
Moderate	31- 69
Severe	70+

The Department dedicated 3 full-time interpretation staff and two large land owners dedicated one part-time interpreter each. All digital files were assessed by the Forestry Division remote sensing specialist for consistency and quality of interpretation. The digital blow-down layer thus created greatly increased the rate at which blow-down volume could be determined.

Interpretation in the Brown Spruce Longhorn Beetle Quarantine Zone

The Canadian Food Inspection Agency requested that in the quarantine zone for the Brown Spruce Long Horn Beetle, all visible blow-down be identified and marked, because of the concerns for beetle population control and a potential enhanced fire hazard. The Forestry Division complied with the request and all blow-down visible in the photography for the quarantine zone were identified regardless of size. The quarantine zone (46 000 ha) represented approximately one-seventh of the total area (680 000) assessed for blow-down.

Results

Helicopter Survey

The survey found visible damage in 244 of the 250 points assessed for blow-down. Thirty-seven of the helicopter points were classified as having severe blow-down and 50% of all of the points had some blow-down. This indicated that blow-down was extensive in the assessment area and a more detailed inventory would be justified.

Aerial Photography

Photographic acquisition was successful, however due to the low sun angle in November, photographs in the northern area of Colchester County have reduced utility due to large amount of shadow and due to partial snow cover.

The smaller scale chosen for the project provided efficiencies in the lower number of prints acquired, facilitating a quicker production of orthophoto images from the scanning processes. The cost of photo acquisition was held within estimates.

The scanning process was simplified by using a positive film in the aerial camera which eliminated the creation of photo negatives. The rolls of positive film could be fed directly into a scanner. The disadvantage of using the positive film however, was the inability to reproduce hard copy prints at the Nova Scotia Geomatics Centre as is done with the annual provincial 1:10 000 colour photography.

Photo Interpretation

The interpretation process using the on-screen imagery, expanded to a large scale, proved to be a very useful source of data for identifying blow-down. Interpreters could view and identify areas of less than one hectare if the blow-down was complete i.e. the trees were not leaning at angles greater than 30 degrees above the horizontal.

The hard copy photography at the initial scale of 1:24 000, viewed stereoscopically could not provide the detail required to identify the smaller areas of blow-down. Forest stands where trees were leaning at a significant angle above the horizontal could not be identified.

The blow-down layer, overlayed as shown in Figure 3, will provide enormous value in resource planning, including protection planning, and will be critical for accurate future analysis of sustainable resource management in the central part of the province.

Table 3 shows hectares with identified blow-down as well as estimates of volume affected. The quantity of blow-down shown should be considered minimum values for both area and volume because of the pattern of blow-down. For example, forest land contained large patches of blow-down areas interspersed with smaller areas of blow-down which may not have been detected particularly where patches of blow-down were less than one hectare in size. As mentioned above the only area for which an attempt was made to identify blow-down sites of less than one hectare was in the Ministerial containment zone for the brown spruce long horn beetle, which was around the city of Halifax. Future analysis may be able to determine the cause and effect relationship between blow-down and features such as topography, soil drainage patterns and the stage and structure of affected forest stands.

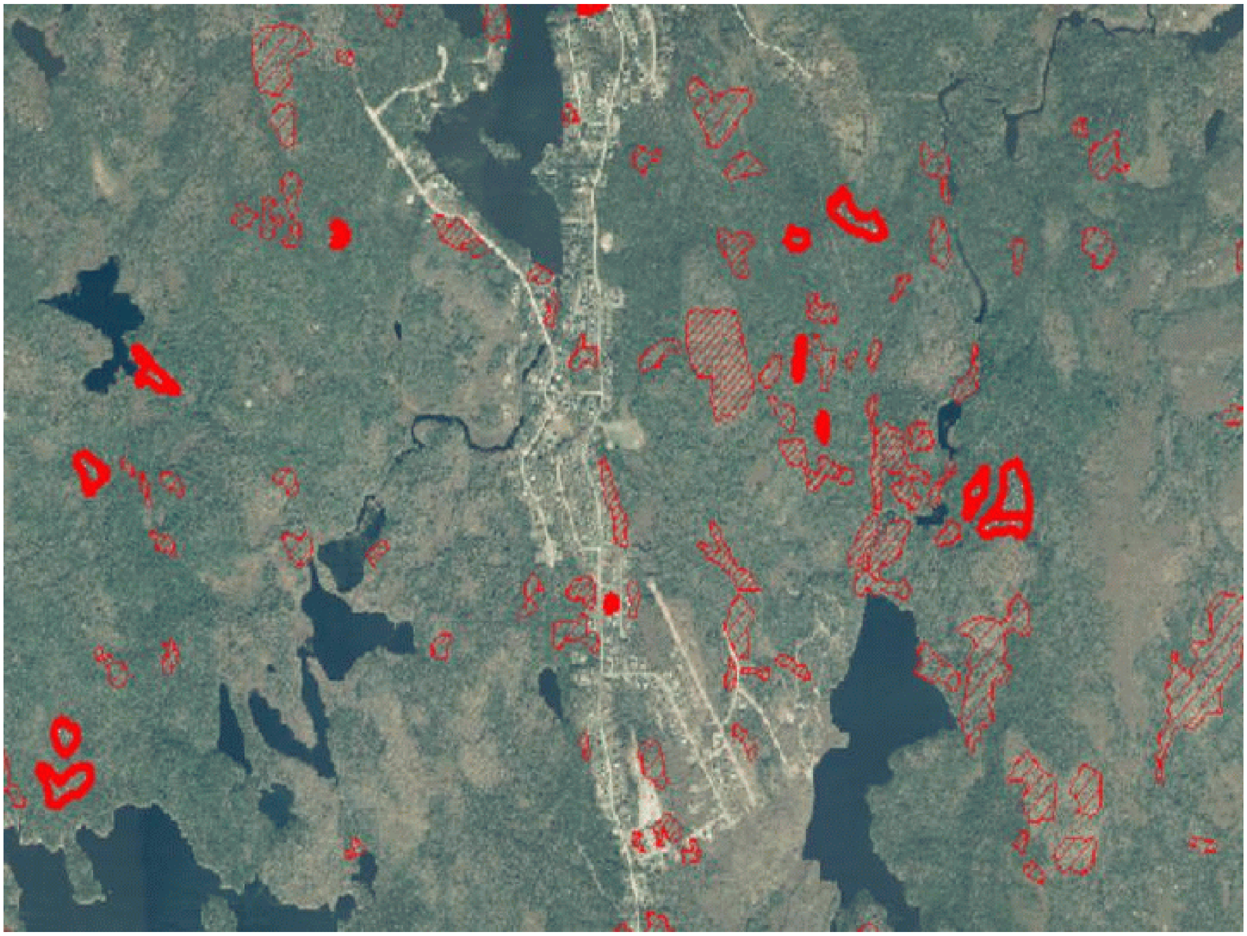


Figure 3. Blow-down overlay as shown on a graphics screen. Blow-down polygons are overlayed on the original digital orthophoto imagery. Scale shown is approximately 1:10 000.

The interpretation of the on-screen digital imagery provided a match to the helicopter survey points for only 73 of the 244 points. The relatively low agreement between the helicopter survey and image interpretation is attributed to seasonal canopy conditions, image resolution, image distortion and shadow due to low sun angle effects. This conclusion was reached after studying each survey point in relation to its corresponding ortho-imagery. Blow-down in highly productive stands with large trees of high volume was easily identified. The distinctive pattern of divergently brushed vegetation in open canopy stands or the cris-crossed pattern of fallen tree boles in closed canopy stands was also recognizable. Low site stands, young stands or stands where the damage takes the form of leaning rather than downed trees could not be reliably identified. These sites were difficult to consistently and reliably separate from image distortion and seasonal factors. Stands at the edge of the imagery or on steep slopes appeared to be leaning, or in some cases fallen, due to off nadir distortions. Field verification confirmed that additional blow-down in small areas was difficult to identify on the 1:24 000 scale photography.

Blow-down identified in the quarantine zone totalled 4 200 hectares of which 1 100 hectares were visible in areas less than one hectare in size. The small areas represented approximately 26% of the total.

Table 3. Forested hectares and merchantable volume(cubic metres) identified in blow-down areas

OWNERSHIP	AREA	SOFTWOOD	HARDWOOD	TOTAL	%
PRIVATE	12 960	1 332 400	346 600	1 679 000	81
CROWN	2 180	236 500	51 000	287 500	14
CROWN PROTECTED	490	55 000	10 200	65 200	3
OTHER	230	16 800	7 700	24 500	2
TOTAL	15 860	1 640 700	415 500	2 056 200	100

Table 4. Severity class distribution of all interpreted blow-down.

BLOW-DOWN CLASS	HECTARES	PERCENT OF AREA
Moderate(30-69%)	9 800	62
Severe(70-100%)	6 050	38

Interpretation and Arcview Program Development Efforts

Photo interpretation using the onscreen process consumed the majority of the hours in the blow-down identification process. Approximately 1700 hours (based on an average of 7 hours per map sheet of 4340 ha, portions of several maps contained water etc.) were required to review the imagery, interpret and digitize the polygons of blow-down on screen, for the 481 200 ha. An additional 280 hours were required to develop the necessary computer programs and carry out the QA assessment of the interpretation, including field checking a sample of sites on the ground and by helicopter as part of the interpretation process.

Project Deliverables

The GIS layer of blow-down, created in Arcview, provided data for planning salvage operations and forest stand remediation. The overlay with the forest resources data base showed blow-down in the assessment area had encompassed at least 15 860 ha. This figure includes all visible blow-down in the quarantine zone. Only polygons 1 ha in size or greater were delineated in the assessment area outside the quarantine zone. It was decided to limit the delineation outside the quarantine zone in order to save time.

The Department's Cartographic Services section created hard copy orthophoto maps at the 1:10 000 scale. These maps were provided to the Regional Services Division and the Forestry Division for use in future management planning.

In addition the Department placed a version of the digital orthophoto maps on a publicly accessible web site. The general public can view the imagery as well as the blow-down polygons derived by the photo interpretation process.

In cooperation with Service Nova Scotia, the Department was able to process a land ownership layer for use in the salvage harvest assistance program. The ownership layer contained the graphic polygon boundaries with associated Parcel Identifier (PIDs) numbers and names and addresses of owners. When landowners applied for assistance they were required to provide PID numbers for their property. A quick cross reference could be made through the PID, to identify owners and estimate potential volumes blown down, using the forest resources data base.

The GIS layers and overlays, including the Forest stand layer, the original digital orthophoto layer, the property ownership layer and the interpreted blow-down polygon layer were provided to the Association of Sustainable Forestry(ASF). The ASF had been contracted by the Department to implement the salvage assistance program on private land.

Implications of Juan Blow-down on Nova Scotia Forests

The volume of trees blown down in the hurricane zone was significant. The project identified at least 2 056 000 cubic metres of wood volume blown down which represents approximately 95%

of the annual harvest in the central Region of the province and 33% of the total provincial harvest for 2003.

There may be an increase in fire hazards in certain areas as fuel loading would be expected to be higher than normal. Concern has been expressed in the Halifax Regional Municipality for potential fire hazards in areas close to human communities.

In addition, the weakened and dead trees may also support insects above normal population levels, leading to severe pest outbreaks.

Fig 4. Blow-down in a hardwood stand in the Truro Watershed.

Blown down volume, normally slated for harvest over a longer period of time, should be harvested while the material still has economic value. In this regard harvest activity in designated areas within the hurricane zone is being conducted as quickly as logging contractors can be engaged by the industry. The dead wood maintains sufficient moisture for processing in wood products conversion plants, such as sawmills and pulp and paper mills for a relatively short period of time, measured in months, rather than years. In the Christmas Mountain blow-down in Northern New Brunswick wood remained useful for product generation for approximately two years after the event.

The Department of Natural Resources has engaged contractors to salvage harvest in provincial Parks focussing on areas where the blow-down has been significant. Areas particularly hard hit include Porter's Lake, and McNab's Island.

The Nova Scotia Registry of Buyers for primary wood products has reported that more than 50% of the sustainable wood supply has traditionally originated in the central Region of the province, which includes Halifax, Hants, Colchester, Cumberland and Pictou counties. The Department's analysis of sustainable wood supply over the next 5 years will need to consider the increased area of harvest, due to salvage operations, in the central region.

Figure 5. Juan Salvage Operations

Regenerating Juan harvested areas may pose challenges given that the large quantity of tree root mass left standing in a vertical mode as shown in Figure 6, will probably remain for a long period of time unless they are physically/mechanically returned to a horizontal mode. The holes left by uprooted stumps exposes bare mineral soil and may alter drainage patterns at micro sites around the tree stump.

Figure 6. Uprooted tree stump in Point Pleasant Park, Halifax.

Conclusions

The sources of information for wide area disturbance detection and mapping are best provided by remote sensing imagery. If the imagery can be obtained when required, digital data provides the opportunity for the quickest and most efficient method to detect and Input, Map, Analyse and Present, referred to as IMAP, elements of a major disturbance.

In Nova Scotia, digital aerial photography at the 1:10 000 scale would be the preferred source of imagery. The photography would be scanned, ortho rectified, and mosaicked and would provide an efficient tool for IMAP. Constraints using aerial photography at the 1:10 000 scale are cost and time required (number of flight lines and prints) to obtain data after a disturbance.

The utility of satellite imagery for event detection was not proven in this project but it may have potential for future use. High resolution satellite data, at 4 metre pixels or smaller, certainly would be able to detect major disturbances. A disadvantage of this satellite imagery is the cost of acquisition and the ability to acquire the data when required. Also cloud free optical satellite data is often hard to obtain for Nova Scotia. In addition, high resolution satellites don't usually capture a lot of archive data as they are usually mission driven, which adds to the cost of acquisition.

The IKONOS data also has potential for use but the cost is prohibitive at this time, particularly if disturbances require that a mission specific data set be acquired.

Landsat satellite imagery, while one of the less expensive data sources, has a resolution of 30 metre per pixel, and may be suitable for detecting disturbances such as hurricane blow-down if imagery could be obtained within a reasonable time frame of the event. Landsat imagery has the potential to detect large disturbances such as fire or insect and disease disturbances. Presently Landsat data is used by the Division to detect and map clear and partial harvesting.

It is recommended that the Division acquire a sample data set of high resolution satellite imagery over the hurricane Juan assessment area. The imagery would to be used to investigate its utility for large scale disturbance detection and monitoring of Nova Scotia's forests.

Alternate digital imagery could have potentially been acquired through airborne digital sensors such a the CASI sensor but past experience in other jurisdictions have shown that costs would be prohibitive and image registration over such a large area would take an unacceptable length of time.

Comparable costs of digital data for large scale detection and mapping are shown in Table 4.

Table 4. Comparable Digital Imagery costs.

Imagery Type	**Resolution**	**Image acquisition costs: $/Km^2**
IKONOS Satellite[1]	4 Metre	$23.00
Landsat Satellite	30 Metre	$0.03
QuickBird Satellite	1 Metre	$29.70
Aerial Photography[2]	1:10 000[5]	$22.00[3]
Aerial Photography[2]	1:24 000	$12.90[4]

1. Imagery from a directed mission.
2. Costs shown for both scales of aerial photography do not include scanning nor mosaicing to provide digital ortho photo files.
3. Based on 4500 line km at $30 per line km covering 6140 square km
4. Based on 2265 line km at $37 per line km covering 6500 square km
5. To further clarify the cost comparisons aerial photography scanned at 1300 Dots Per Inch(DPI) at the 1:10 000 scale provides a pixel resolution of .2 Metre on the ground, and 1:24 000 scale gives .5 Metre resolution.

Recommendations

Satellite imagery may be useful for large area disturbance detection and mapping if imagery can be acquired as needed. New sample imagery of the hurricane zone will be acquired for determining its utility for disturbance mapping.

The utility of aerial photography for disturbance mapping will be further investigated by acquiring samples at the 1:12 500, 1:15 000 and 1:20 000 scales over a forested area in Central Nova Scotia. Photography would be scanned and digital files created for on screen interpretation.

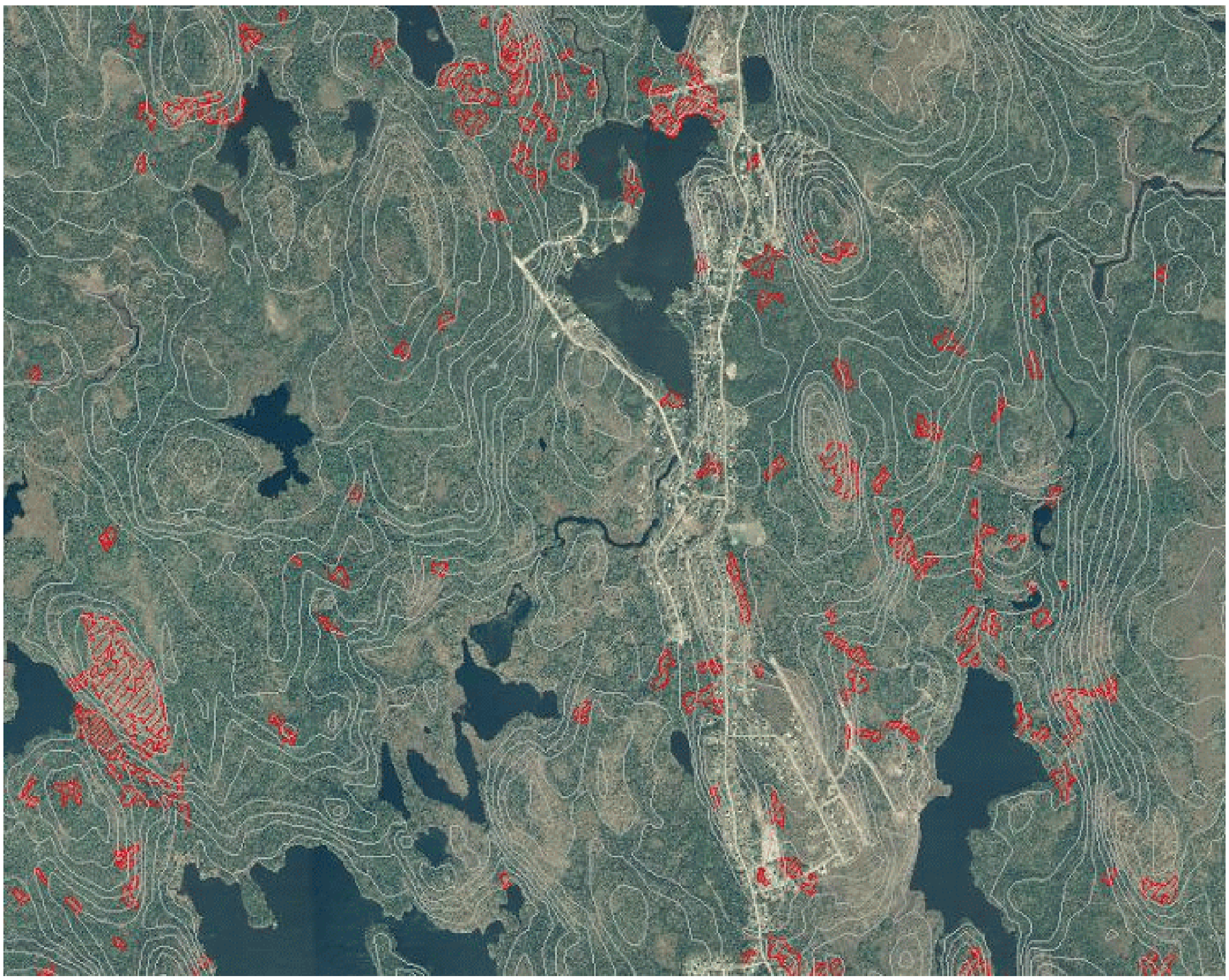
The 1:24 000 scale photography did not have sufficient resolution for the detection of blow-down in patches less than 1 hectare in size. Subsequent field operations have shown that significant blow-down has occurred in patches of that size. For this reason it is recommended that the 1:24,000 scale photography not be used for disturbance detection and inventory.

On screen or heads up photo interpretation should be done within one agency. This would help to insure that interpretation, which is a subjective process no matter how or where it is done, would be consistent and quality assurance processes could be more efficiently implemented, particularly when time frames are critical.

The Division should investigate land topography, soil drainage, forest stand height and density in terms of developing predictors for future blow-down in Nova Scotia Forests. As shown in Figure 7, GIS analysis capabilities can be used to attempt to determine relationships between topography, soil drainage, forest stand development and blow-down.

This project has shown the utility of digital ortho-photo maps for resource management and planning. It is recommended that DNR support efforts by Service Nova Scotia, Geomatics Centre, to produce a series of ortho-photo maps for the Province, over a ten year period.

Figure 7. Hurricane blow-down and contours



Acknowledgements:

The Juan interpretation project was carried out by the Forestry Division of the Department of Natural Resources with interpretation assistance provided J. D. Irving Ltd. and Kimberly-Clark Inc.

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