Harvest of Riparian Forests in Minnesota: A Report to the Legislature

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This report summarizes the results of DNR efforts to estimate the extent of timber harvesting in riparian areas in Minnesota and describes the techniques used to generate these estimates. This report is in response to the charge from the Legislature to the Department of Natural Resources in the Sustainable Forest Resources Act (SFRA). The SFRA states:

> 89A. 05, Subd. 4. ***Monitoring riparian forests***. *The commissioner, with program advice from the council, shall accelerate monitoring the extent and condition of riparian forest, the extent to which harvesting occurs within riparian management zones and seasonal ponds, and the use and effectiveness of timber harvesting and forest management guidelines applied in riparian management zones and seasonal ponds.*

Introduction

Riparian areas are those areas where the transition from aquatic to terrestrial ecosystems occurs. Along streams, lakes, and wetlands, soils often are wetter than in adjacent uplands and usually support rich assemblages of plants and animals unlike those of adjacent upland and aquatic systems. Riparian areas strongly influence water quality and aquatic habitat because they help regulate the flow of materials (e.g., water, soil, leaves, woody debris, anthropogenic chemicals) from terrestrial to aquatic ecosystems. The width of riparian zones (i.e., the distance from the edge of a water body to the point where the vegetation no longer reflects the influence of enhanced soil water) varies widely from place to place in response to many factors including topography and geologic history, hydrologic regime, climate and precipitation, and management activities.

Although we often use the terms 'riparian areas' and riparian management zones' interchangeably, they seldom are equivalent. Riparian management zones (RMZs) are arbitrarily defined areas adjacent to rivers, streams, lakes and wetlands, the width of which we determine to suit management objectives, such as enforcement of shoreline regulations and protection of water quality. In RMZs we often modify typical management actions to accommodate and protect the unique features and functions of riparian areas. The Minnesota Forest Resource Council's site level forest management guidelines define RMZs as 'that portion of the riparian area where site conditions and landowner objectives are used to determine management activities that address riparian resource needs' (MFRC 1999). In the guidelines, recommended widths for RMZs vary primarily with water body type and size and the adjacent forest management method (even-aged vs. uneven-aged). For the purpose of estimating timber harvest in this study, riparian management zones were defined as the area within 200 feet of the shoreline of lakes, wetlands, and large rivers and within 200 feet of the centerline of small streams. Forested riparian management zones were defined as those RMZs in the areas where forest cover was the dominant cover type as determined by the Minnesota Gap Analysis Program.[1]

Surface water is abundant in Minnesota and riparian areas occur throughout the state (Table 1). The characteristics of riparian areas generally reflect the state's broad geographic patterns of land cover and

[1] Minnesota GAP protocols for satellite image processing and vegetation classification are available at http://www.umesc.usgs.gov/umgaphome.html. Minnesota GAP vegetation maps and metadata are available to DNR users at http://maps.dnr.state.mn.us:8080/gis/dp_list.jsp?tier=1.

use. Nearly 50 percent of the state's riparian areas occur in agricultural areas of the western and south-western parts of the state while about 35 percent occur in forested portions of the northeast and southeast. Whether a riparian area is forested, however, depends in large part on past land use decisions and current land use, as well as location.

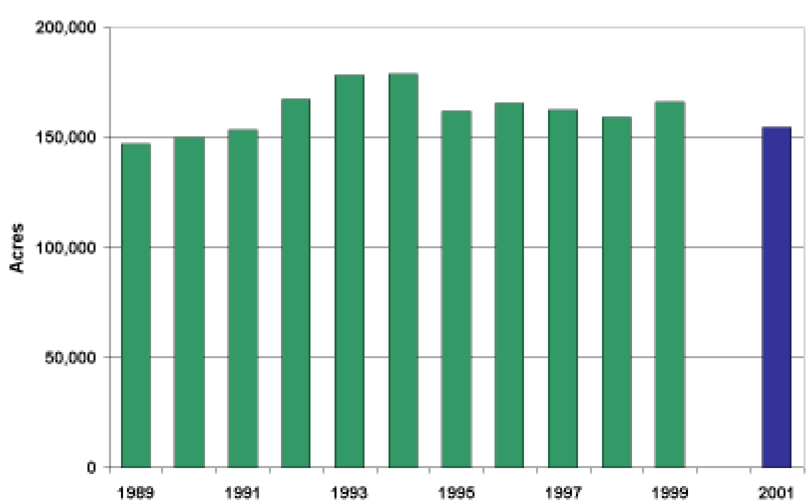
Table 1. Riparian management zones in Minnesota and the general land covers and uses in which they occur (DNR Resource Assessment 2000).

General Land Cover	**Riparian Lands**	
	Acres	% of total
Agriculture	3,823,300	49.5
Forest	2,668,200	34.6
Deciduous Forest	1,401,500	18.2
Lowland Forest	860,100	11.1
Mixed Forest	225,400	2.9
Evergreen Forest	181,200	2.3
Marsh	854,400	11.1
Water	168,300	2.2
Developed	148,700	1.0
Shrub-Grassland	28,500	0.4
Barren	27,800	0.4
TOTAL	7,719,200	

Annual harvest estimates

Based on information for the period beginning in August 1999 and ending in July 2001, our estimate of statewide annual forest harvest in RMZs is 10,145 acres. This is approximately six percent of the 157,212 acres harvested during that period and approximately 0.4 percent of the forested RMZs in the state. Because we based these estimates on a sample of harvest sites rather than a complete census of harvest sites, using additional information (i.e., by increasing the sample size or obtaining data from other sources) could change them substantially. Our estimate of annual statewide harvest agrees closely with annual estimates for recent years derived from other sources (Figure 1).

Figure 1. Estimated annual forest harvest in Minnesota since 1988. Data for 1988-1999 are based on annual estimates of cords harvested compiled by the USDA Forest Service North Central Experiment Station and the Minnesota Department of Natural Resources (DNR Division of Forestry 1999). For comparison with the acre-age estimated in this project, cords harvested were converted to acres harvested by multiplying by 1 acre/23 cords. The 2001 estimate was based on remote sensing data for the period August 1999 – July 2001.



Methods

The following discussion is a brief overview of the methods we employed for estimating annual statewide forest harvest and harvest of forests in RMZs. The work proceeded in four general steps: 1) mapping forested riparian management zones; 2) selecting a representative sample of forest harvest sites; 3) quantifying the relationship between satellite-derived data and photo-interpreted data on harvest; and 4) calculating statewide harvest estimates. For a more detailed description of our methods and how they simultaneously fulfilled the data needs of Guideline Implementation Monitoring efforts see Appendix A.

Mapping forested riparian management zones – The task of creating a statewide map of RMZs and describing patterns of ownership and land use in them was completed in 2000. (See DNR Resource Assessment 2000 for details.) Briefly, we combined separate GIS data sets that characterize different types of surface water bodies to form a single integrated data set that better characterizes the physical connections between them at a well-known and widely accepted level of detail. The data sets described intermittent and perennial streams, drainage ditches, ponds, lakes, and wetlands. The metadata describing this GIS data layer are available at http://dnrnet.state.mn.us/mis/gis/gisdata.html. See Table 2 for a description of the water bodies included in the RMZ data set.

Selecting a representative sample of forest harvest sites – Satellite images capture the patterns of light reflected from vegetation and other land covers on large areas of the earth's surface. Comparing images of the same area at different times highlights many types of disturbance, including forest harvest, that have altered the amount or quality of light reflected back into space during the intervening period. We compared images obtained in 1999 or 2000 (Time 1) with images of the same areas obtained in 2001 (Time 2) to identify sites that may have been harvested during the interim. In order to obtain the relatively cloud free images that were needed we used images from several dates within each time frame. Thus Time 1 included images from August 1999 to August 2000 and Time 2 included images from July and August 2001. All harvest estimates, however, are estimates for a one-year period. The 20 images (10 for each time period) we used provided data for approximately 70 percent of the state's forested area. Scheduled purchases of additional satellite imagery will provide complete coverage of the state every 2 years.

Significant changes in the tree canopy from all causes (forest harvest and non-forest harvest activities) between Time 1 and Time 2 occurred at 5,238 sites within the area covered by satellite images. Figure 2 is an enhanced satellite image of one of these sites. Sites ranged in size from five acres to 1015 acres with an average size of about 30 acres. From these sites we drew samples for more detailed examination to verify harvest and more accurately measure the harvested area.

Table 2. Geographic information used to construct the Minnesota DNR 200-Foot Riparian Zone map and GIS coverage. This coverage was completed in December 2000 using versions of the input datasets that were available at that time. Revisions to the input datasets made after that date have not been incorporated into the riparian zone coverage.

Type of water body and DNR dataset name	**Source of data for DNR dataset**	**Minimum size mapped by source**	**Additional information**
Lakes *DNR Lakes (1:24K)*	National Wetlands Inventory (NWI)	Generally 2.5 acres	The NWI digitized lakes using 1980s-vintage aerial photographs and USGS quadrangle maps primarily from the 1970s and 1980s. Large rivers and streams in the NWI were included in *DNR Lakes (1:24K)*. The 200-Foot Riparian Zone GIS coverage does not include riparian buffers on islands.
Wetlands *National Wetlands Inventory Polygons*	National Wetlands Inventory	Generally 2.5 acres; in treeless areas wetlands as small as 0.10 acre may be mapped	The NWI included all wetlands mapped by the U.S. Fish and Wildlife Service during field surveys and via photo-interpretation. Actively farmed wetlands were not mapped. In areas of coniferous forest, wetlands smaller than 3 acres may not be mapped. Only wetlands classified as inland shallow fresh marshes, inland deep fresh marshes, and inland open fresh water in NWI were included in the 200-Foot Riparian Zone GIS coverage.
Rivers and Streams *DNR 24K Stream Types*	USGS 7.5-minute quadrangle maps	Unknown; it is likely that many small headwater streams in forested areas were not included in the USGS maps.	Rivers and steams were digitized from the most recent versions of USGS printed maps available in the late 1990s by a consortium of state agencies, universities, and private contractors. Additional information from aerial photographs and local sources was used to improve map accuracy where available. Efforts to improve the dataset are currently underway.

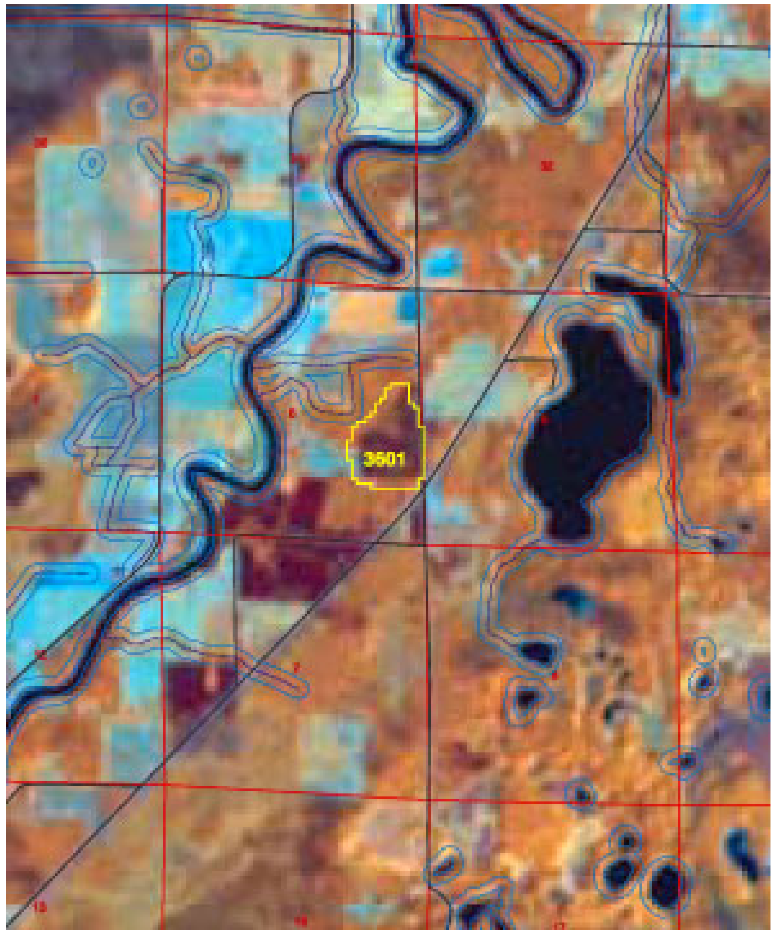


Figure 2. A satellite image showing one site identified as a potential harvest, in yellow. The image has been enhanced with section lines and numbers in red, roads and small streams in dark blue, and the RMZ in light blue.

Quantifying the relationship between harvest area estimates from satellite images and from aerial photographs – For about 200 sites randomly selected from the larger pool of satellite-identified disturbances we obtained aerial photos in October and early November 2001. (Equipment failure prevented us from photographing 3 sites.) We used low altitude flights to produce large-scale photos and improve visual detail. Sites ranged in location from Hennepin County to the Canada border. Of the 197 photographed sites, 159 included tree removals (146 due to typical forest management actions and 13 due to land uses such as housing development, gravel mining, and agriculture). On 38 sites no tree removal was evident. These sites included areas in which there was significant defoliation (likely by forest tent caterpillars or following flooding by beavers) and other changes in the forest canopy for which no cause could be determined. Using standard photointerpretation procedures we measured the total acres harvested and acres of harvest within RMZs for all harvest sites (Figure 3). Sites where tree removals or other disturbances were not the result of standard forest management activities were assigned a value of 0 acres of harvest. Paired data on harvested acres measured on aerial photographs and disturbance acres on corresponding satellite images (for 197 sites) were used to calculate a quantitative (linear) relationship. We used this equation to estimate acres of harvest in the area covered by satellite imagery. In addition, we used the proportion of total harvest that occurred in RMZs on aerial photographs as an estimate of the proportion of total harvest that occurred in RMZs in satellite images.

Figure 3. Aerial photograph of the same site depicted in Figure 2. The harvested area is outlined in yellow and the RMZ in blue. Note that the harvested area is more accurately delineated on the photograph than on the satellite image and does not overlap the RMZ.

Interpretation of aerial photos provided the information on forest disturbances that were not related to forest harvest described above. Aerial photo interpretation of these sites, however, could not provide independent verification that the satellite-based disturbance detection procedure was effective (i.e., that we successfully detected in the satellite images the harvests that occurred between Time 1 and Time 2). To do this, we needed a set of aerial photographs that were obtained without prior knowledge of the disturbances detected in the satellite imagery. If the change detection methods were adequate, these photos would show no harvests that were not also detected in the satellite imagery. Using the same cameras and procedures, we obtained aerial photographs of 80 1x6-mile blocks distributed statewide (Figure 4), with forested blocks more likely to be selected than blocks without forest. In total, the blocks comprised about 307,000 acres, of which 172,000 acres were forested. Using standard photo interpretation procedures we delineated all apparent recent harvests and verified that they had occurred since Time 1 via questionnaires to federal, state, county and private land managers in each block. A comparison of photo-delineated harvests with satellite-detected harvests in these blocks yielded the following results. Of 51 eligible harvests (i.e., harvests that occurred in areas covered by satellite imagery) in the 80 1x6-mile blocks, 44 (86%) were identified in both aerial photographs and satellite images, seven (14%) were identified in satellite images but not in the aerial photographs, and only one (2%) was identified in the aerial photographs but not in the satellite images. Given these results, we were confident that the satellite change detection procedures were adequate for identifying forest harvests.

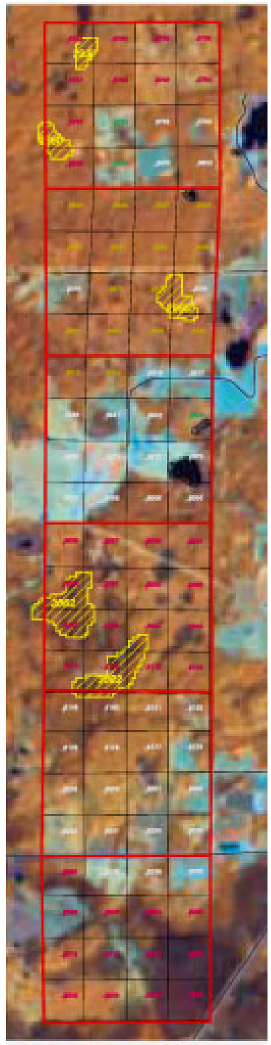


Figure 4. The satellite image for one of the 80 1x6-mile blocks used to verify the effectiveness of the change detection procedure. Black gridlines delineate 40-acre parcels, red lines delineate sections, and yellow lines delineate harvest sites.

Calculating statewide harvest estimates – We calculated our statewide estimates of harvest using the quantitative relationship obtained in the previous step and an expansion factor based on the proportion of the state's forested area covered by satellite imagery. We used the linear relationship to adjust the estimate of harvest at each disturbance site to account for differences between satellite-delineated harvest areas and photo-interpreted harvest areas and to account for disturbances not related to forest harvest. We used the expansion factor to extrapolate the total acres detected in the portion of the state covered by satellite imagery to the entire state. See Appendix A for more detail on how these adjustments were made.

Observations

As this effort demonstrated, combining satellite imagery and aerial photography is an effective means of estimating harvest in riparian forests. Additional estimates in subsequent years will be needed, however, to confirm our estimate, to document year-to-year differences and general trends, and to demonstrate the applicability of our methods under a wider range of conditions (e.g., more extensive insect defoliation, harvest practices that leave significant amounts of canopy intact). Confidence in the method and the estimates it provides will grow as we accumulate expertise in applying the techniques and interpreting the results and as the estimates are corroborated by other sources of information and personal experience.

The remote sensing data and analysis techniques we used to estimate riparian forest harvest can be used to provide information on other forest resource issues in a spatially explicit manner. We observed forest disturbances unrelated to timber harvest (e.g., tree removals for housing development) that may have significant impacts on the availability of timber and other forest resources. It is likely that techniques could be developed to capture and evaluate this information more systematically. In addition, complete coverage of the forested portions of the state would allow regional and other spatially explicit analyses of land uses and management activities that affect Minnesota forests.

References

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Appendix A

Change Analysis Applications in DNR Resource Monitoring

Change Analysis Applications in DNR Resource Monitoring

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Abstract

This paper discusses change-based methods now being implemented in Minnesota Forestry resource monitoring programs, and provides perspective on the emergence of statewide multistage (space/aerial/ground) change mapping as an alternative approach to resource assessment questions hitherto handled piecemeal and aspatially. Recent applications to logging guideline monitoring and assessment of riparian impacts are reviewed.

Introduction

Resource inventory has traditionally included spatial and aspatial components, exemplified respectively in the two forest inventory systems the Minnesota Department of Natural Resources (DNR) relies on: the map-based Cooperative Stand Assessment (CSA) for management, and the plot-based Forest Inventory and Analysis (FIA) for strategic analysis. It has also traditionally included static and dynamic elements: FIA inventories, once completed, used to remain in place for more than a decade, whereas forest insect and disease surveys have long been updated on an annual basis.

At present, technical developments and public expectations are inexorably pressing all resource inventory systems towards delivery of regularly updated data in spatially explicit form. Proliferation of Global Positioning System (GPS) and geographic information system (GIS) technology has conditioned user groups to demand visualizations rather than columns of figures and to ask "Where?" as often as "How much?" Meanwhile new scientific knowledge, growing concern over the likelihood of global change, and instant access to information from a broadening array of media have diminished negotiability of any data more than a few years old.

Rising expectations are reflected in demands for new and highly specialized resource information. The Legislature now requires continuous monitoring of forest conditions in a loosely defined "riparian" zone bordering water bodies. The Minnesota Forest Resources Council wishes to know whether loggers observe standard operating guidelines on all classes of forest property. Such requests often reveal an assumption that current and comprehensive databases exist from which any needed information can be culled and published with minimal trouble. Piecemeal attempts to respond can easily give rise to overlapping *ad hoc* inventory systems tailored to narrow objectives. DNR Forestry's Resource Assessment Unit, a frequent recipient of such requests, is attempting to build adaptable spatial data gathering systems that can shift focus from one resource-monitoring question to another without fundamental redesign.

Background

DNR Monitoring Projects

Aside from its FIA and CSA inventory work, and acquisition of conventional and supplementary aerial photography, the Resource Assessment (RA) Unit of the Forestry Division has undertaken a variety of heterogeneous monitoring assignments in response to interest from various segments of the public —

Guideline Implementation Monitoring

Since 1993 RA has been recruited to help with design and execution of a Guideline Implementation Monitoring (GIM) program, tracking logger compliance with voluntary forest practices guidelines on timber sales across Minnesota (Forest Resources Council 1999). The program sends contractor teams to inspect sample harvests on the ground, and RA was initially enlisted to help select the sample sites. The original plan was to select government timber sales from official records and find private-land sales by aerial survey, but concerns over using two different bases for selection persuaded GIM program managers to rely on aerial survey throughout. An aerial photo sampling system was designed by the University of Minnesota (Ek et al. 1999) and implemented by RA with minor alterations starting in 1999. About 40 half-townships, all at least 1/3 forested, are photographed; an RA interpreter reviews the photos to detect and delineate candidate sites harvested within the past two years; land managers confirm the detection from public records or personal knowledge; sample harvests are chosen for evaluation from this population; several site variables are measured on the photographs by RA, and the rest are measured in the field by the contractors.

Riparian Forest Monitoring

In mid-2000 RA accepted responsibility for the first stages of legislatively mandated forest monitoring along Minnesota lakeshores and streams. The Sustainable Forest Resources Act required DNR to "accelerate monitoring the extent and condition of riparian forests, the extent to which harvesting occurs within riparian management zones and seasonal ponds, and the use and effectiveness of timber harvesting and forest management guidelines applied in riparian management zones," and to make a first report by February 2001. DNR program managers interpreted this as demanding: 1) monitoring of riparian forests in general, 2) monitoring riparian harvesting in particular, and 3) monitoring effectiveness of forest practices guidelines in Riparian Management Zones (RMZs). The third task, understood as addressing appropriateness of guidelines rather than compliance, became a separate University of Minnesota research project, now under way (Streblow 2001). RA undertook the other two, creating in the first season's work a riparian GIS coverage from which statewide RMZ landcover and ownership maps were prepared (DNR Resource Assessment 2000), and completing a satellite/airphoto demonstration survey of Carlton County in which riparian harvests in the 1997-99 interval were mapped by satellite imagery using change detection techniques (DNR Resource Assessment 2001).

Technology Development

Over the past decade Resource Assessment has developed remote sensing and image analysis capabilities unique among state agencies, deriving from cooperative projects with the USDA Forest Service, the University of Minnesota, and the U.S Geological Survey.

AFIS Project

Between 1991 and 1999 RA cooperated with the Forest Service's North Central and Rocky Mountain Research Stations in devising and testing the Annual Forest Inventory System (AFIS), a plan to transform the federal FIA program in the Lake States from a periodic inventory conducted at 15-year intervals to a continuous inventory with a proportion of plots examined each year (Hahn et al. 1992). The AFIS project proved a catalyst for nationwide adoption of continuous FIA methods. Remote sensing of forest change for prioritization of plot visits was an integral part of the original AFIS design (Befort 2000), and RA was responsible for design and implementation of remote sensing methods for AFIS. In the course of the project, RA acquired its first satellite imagery and computer-based image analysis systems.

University of Minnesota Collaboration

Starting in 1988, RA has participated in NASA-funded remote sensing research partnerships with the University of Minnesota directed toward transfer of remote sensing technology from university laboratories to public agencies. Forestry-oriented results of an Earth Observations Commercial Applications Program (EOCAP) project (Bauer et al. 1994, Coppin and Bauer 1994) found immediate application in the change detection portion of AFIS work, and were used later in riparian harvest mapping. A subsequent collaboration under NASA's Cooperative Agreement Notice "Public Use of Earth and Space Science Data Over the Internet" developed the Internet facility by which RA makes all its aerial photographs, satellite imagery and real-time forest fire data publicly available (http://www.ra.dnr.state.mn.us/ , http://fornet.gis.umn.edu/). NASA-funded cooperation continues in the multidisciplinary Upper Midwest Regional Earth Science Applications Center (http://RESAC.gis.umn.edu/) and the eForest (http://eforest.gis.umn.edu/) project.

Gap Analysis Program

RA acquired its first complete Landsat Thematic Mapper multispectral satellite coverage of Minnesota, and its first experience in large-area vegetation classification, as a primary contractor in the U.S. Geological Survey's Gap Analysis Program (GAP). As a participant in the Upper Midwest GAP partnership (http://www.umesc.usgs.gov/umgaphome.html) RA carried out high-detail vegetation mapping of the entire state in accordance with the Upper Midwest Gap Analysis Program Image Processing Protocol (http://www.umesc.usgs.gov/umgap/documents.html). Minnesota GAP vegetation maps are now available to DNR users as part of DNR's Level 1 dataset library (http://maps.dnr.state.mn.us:8080/gis/md_list.jsp?tier=1.)

2001 Combined Project

Objectives

In late summer 2001 Resource Assessment was directed to proceed with a project that would take a combined approach, based on satellite image change detection, to Guideline Implementation and riparian harvest monitoring. The project would be conducted on a biennial schedule, covering the entire state every two years. The Commissioner's Office, after evaluation of the previous year's products, further requested that riparian harvests be placed in context by comparing them against all harvests over the same interval. With this additional requirement, RA faced three major tasks:

- Identify at least 120 recent harvest sites statewide, suitable for GIM field visits,
- Estimate total riparian acres affected by timber harvest statewide, and
- Estimate total timber harvest acreage statewide.

Any aerial data acquisition would have to take place before snowfall obscured the harvest sites, and satellite change detection would have to precede at least some of the aerial work. On account of the tight schedule, project planning and execution were telescoped.

Data Acquisition

Satellite Image Selection

The two Landsat satellites presently in service (Landsats 5 and 7) provide 30-meter 7-band multispectral Thematic Mapper (TM) images of Minnesota in five overlapping orbital paths, revisiting each path every 8 days in a sun-synchronous orbit. As shown in Figure 1 below, 19 "scenes" along these paths — each covering about 110 x 110 miles — take in the entire state. Looking ahead to change detection work, DNR had already purchased 1999-2000 Landsat 7 coverage statewide to serve as baseline ("Time 1") imagery. The main selection criteria in this purchase were late-summer dates and absence of cloud. Late summer is favored in change detection applications because of the relative stability, and thence year-to-year comparability, of vegetation conditions at that season. Cloud complicates analysis of TM imagery, and wholly cloud-free images are rare.

To serve the needs of the combined GIM/riparian project, RA projected an image acquisition schedule in which alternate paths of late-summer imagery would be purchased each year: even-numbered paths in even years, and odd-numbered paths in odd years. Because of orbital path sidelap this pattern would cover 70 per cent of the state annually; and although clouds might occasionally prevent acquisition of suitable images in a given season, no portion of the state would be likely to escape surveillance for more than three years. In accordance with this plan, post-harvest imagery for summer 2001 ("Time 2") was purchased along paths 27 and 29.

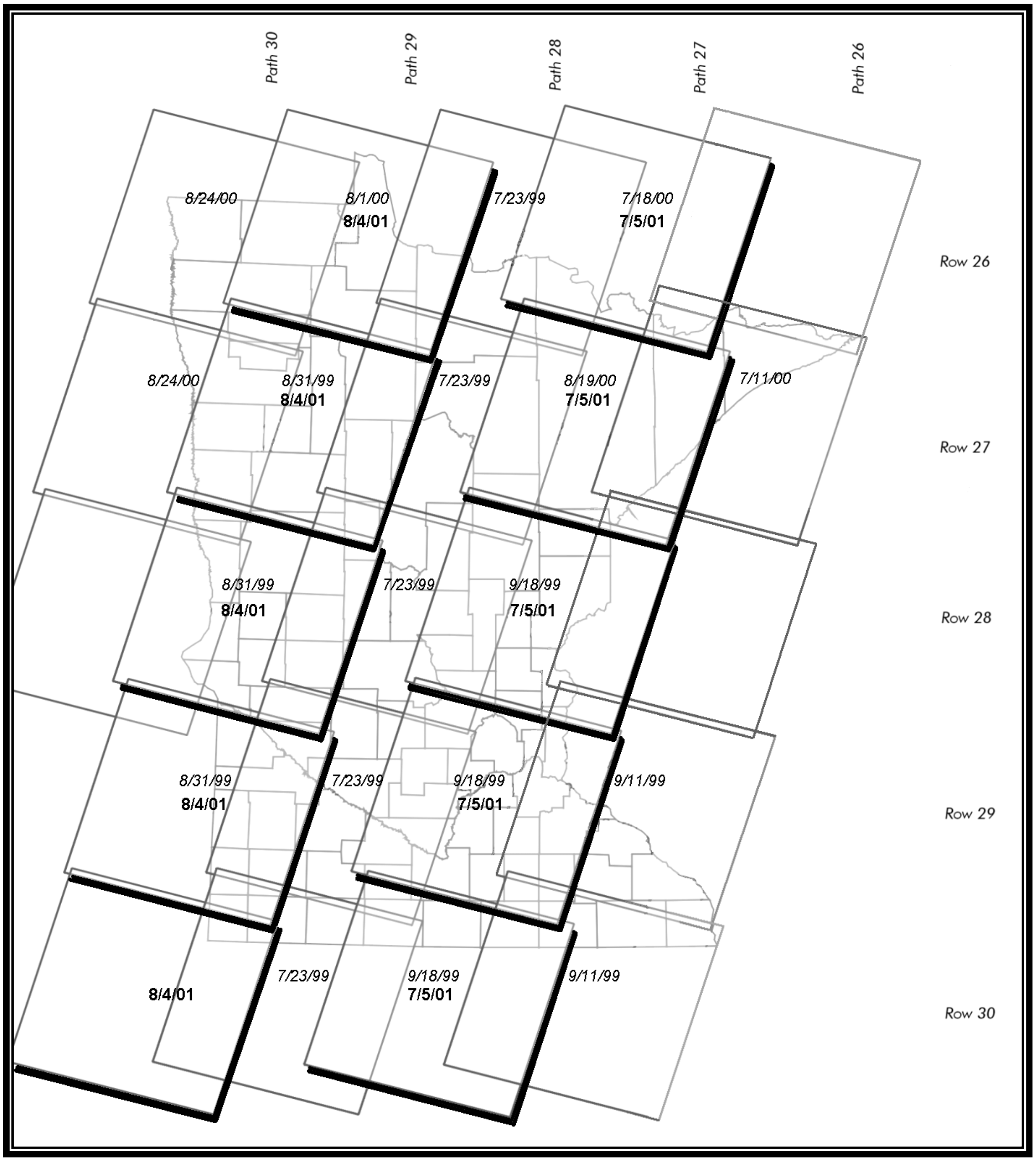

Figure 1. Landsat 7 satellite scene dates acquired for *Time 1*-**Time 2** change analysis.

<u>*Satellite Change Detection*</u>

Paired Time 1-Time 2 scenes in paths 27 and 29 were analyzed to detect timber harvests, by use of change detection methodology applied earlier in EOCAP project work at the University of Minnesota (Coppin and Bauer 1995) and in the U.S. Forest Service AFIS project:

<u>Preprocessing</u>: Much irrelevant variation must be filtered out before multispectral scanner scenes from different dates can be compared to detect particular types of vegetation change. Steps under the heading of "preprocessing" are directed towards ensuring that detected changes represent actual alterations of ground reflectance rather than unrelated mismatches between images. Acquisition of relatively cloud-free scenes, obtained with the same sensor at the same time of day on near-anniversary dates during a season in which foliage conditions are stable, is in effect the first stage of preprocessing.

Scenes must then be geometrically registered to the ground and to one another. In Minnesota RA procedure, TM images are purchased in Space Oblique Mercator projection, then transformed to Universal Transverse Mercator projection, North American Datum of 1983, and registered to the standard statewide Minnesota Department of Transportation roads coverage. A master image is designated for each scene location, and other images are given a final image-to-image fitting.

Clouds and cloud shadows are obvious perturbing factors in any multidate image comparison. As noted above, scenes completely free from cloud are few. Clouds are detected and "masked out" of the images by use of two alternative University of Minnesota-developed "normalized difference cloud index" techniques, one based on differences between clouded and cloud-free scenes and the other on the thermal band of a single image. (Geometric registration and cloud-masking procedures are accessible to DNR users on RA's internal "LabDocs" site.)

Radiometric calibration and haze correction are the final preprocessing steps. Radiometric calibration adjusts for changes in sensor functioning and sun position, converting raw digital brightness values of satellite picture elements (pixels) to radiance and then to exoatmospheric reflectance (Markham and Barker 1986, Chavez 1989) using current data supplied with the imagery. Corrections for atmospheric scattering effects are scene-dependent and require at least minimal information about conditions at the time the imagery was acquired. With appropriate selection of reflectance targets, sufficient information may be gathered from the scene itself: dark-object subtraction, which employs low-reflectance objects in the imagery to estimate haze effects (Chavez 1988,Teillet and Fedosejevs 1995), is the method normally used by RA.

<u>Harvest Detection</u>: Using seasonally matched images that have been geometrically and radiometrically corrected and adjusted for atmospheric effects, the analyst may be reasonably confident that differences in image brightness from Time 1 to Time 2 represent reflectance differences on the surface. Various methods have evolved for identifying areas of change and relating reflectance changes to surface conditions of interest (Yuan et al. 1998). Minnesota RA employs a relatively straightforward image differencing approach, in which the sums of Time 1 vs. Time 2 differences from selected sets of spectral bands are employed as indicators of vegetation increase and decrease.

Before these change algorithms can be usefully employed to detect forest disturbances, a further masking step is necessary. In Minnesota, the greatest vegetation changes between successive summers take place on agricultural lands, as crops and cultivation methods rotate from field to field. To avoid confusing these bold shifts with the subtler patterns of forest change, it is necessary to distinguish forest from nonforest areas and exclude the latter from consideration. Discrimination of forest from nonforest land cover is a major undertaking in itself. Fortunately at least two usable forest/nonforest GIS coverages existed at the outset of the combined project: the National Land Cover Dataset (NLCD) produced by the U.S. Geological Survey (Loveland and Shaw 1996, Vogelmann et al. 2001), and the Minnesota Gap Analysis vegetation classification noted above. RA decided to employ the GAP vegetation layer as its mask for exclusion of nonforest areas in change detection.

Within the forested portions of the scenes in paths 27 and 29, two fairly straightforward differencing algorithms for detecting vegetation changes between Time 1 (T1) and Time 2 (T2) were employed (Rack et al. 1999): a 3-band difference using Bands 3 (visible red), 4 (near infrared) and 5 (first middle infra-red), and a 2-band difference, omitting Band 4:

3-band = (T1 - T2, Band 3) + (T2 - T1, Band 4) + (T1 - T2, Band 5)
2-band = (T1 -T2, Band 3) + (T1 -T2, Band 5)

Applying either of these across the scene produces a "change image" consisting entirely of pixel-by-pixel difference scores. These scores usually display a frequency distribution that is nearly normal, with most of the values clustering around a mean of "no change," as illustrated schematically in Figure 2. Provided that the analyst has selected and combined band differences appropriately, the position of a given pixel in such a frequency histogram should be proportional to the kind and degree of change that has taken place at its location on the ground between the two satellite image dates. The analyst may then map changes by specifying threshold values corresponding to different levels of gain or loss in vegetation density. Accurately specifying threshold values and labeling changes requires familiarity on the part of the analyst with the type and expected distribution of changes in the area of interest.

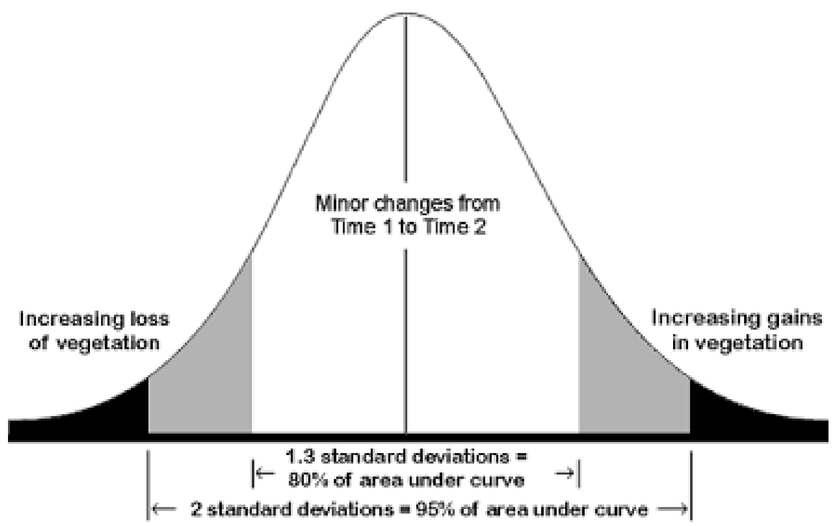

Figure 2. Generalized distribution of picture elements in change image.

In the present case, interest was confined to the left side of the frequency distribution, representing vegetation losses. A high degree of analyst expertise was required in setting appropriate thresholds, which varied considerably from scene to scene. Detection of harvest sites was complicated in 2001 by an extremely heavy summer infestation of forest tent caterpillar *(Malacosoma disstria)*. Defoliation by this insect pest in deciduous forests, particularly in the aspen cover types common across northern Minnesota, produces foliar reflectance effects closely resembling those of partial harvests.

The use of two algorithms yielded two difference images for each scene. On each of these a 3x3 low-pass filter was run to minimize misregistration effects, and thresholds discriminating timber removals from other foliage losses were then set interactively. Any site exceeding either threshold was labeled a "removal.” The combined map was cleaned by clumping and sieving to eliminate sites below 5 acres, and the remaining sites were buffered to compensate for edge effects. A total of 5238 sites showing significant disturbance (reduction of forest vegetation) were detected and mapped within the two satellite orbital paths. A high proportion of these were expected to represent actual harvesting operations.

Aerial Photo Sampling

In addition to satellite detection and mapping of forest disturbance, an aerial photo sampling stage was necessary for both GIM and riparian purposes. In GIM, photos were needed 1) to identify the detected sites positively as harvests, 2) to serve as primary data sources for several photo-measured site variables, and 3) to guide contractor crews performing field surveys. In the riparian work, photos would serve as a double sample to refine satellite-derived estimates of riparian acreage affected by harvests. Two separate sets of photographs were taken: on 200 removal sites identified by satellite change detection, and on 80 1x6-mile blocks selected independently without reference to the satellite image work.

80 Survey Blocks: These 1x6-mile sites were selected from the entire Minnesota population of north-south tiers of sections within Public Land Survey townships, selection probability being proportional to forested acreage as depicted in GAP vegetation mapping. The blocks comprised approximately 307,000 acres, of which 172,000 were classed as forest. The photographs were intended to serve a) as an independent check on the accuracy of satellite-based harvest detection, and b) as an alternative source of GIM sites in the event that satellite detection failed to produce sufficient numbers. As it happened, they were not required in the latter role. The photography was collected while satellite image analysis was in progress; the southernmost site was at Mankato and the northernmost in the Northwest Angle. About 1200 color-negative 645-format (nominal 6x4.5cm negative dimensions) stereophotos were taken on Kodak Portra 400VC color-enhanced film at 1:40,000 scale, and printed in 8x11" format at 1:8000 scale.

200 Removal Sites: Of the 5238 removal sites identified by satellite change detection, 2597 were placed in a “riparian” stratum on the basis of proximity of disturbance to Riparian Management Zones (RMZs) already delineated statewide (DNR Resource Assessment 2000), and the remaining 2641 in a “nonriparian” stratum. Then 200 sites were randomly selected for photography, 120 of them from the riparian stratum. Locations ranged from Hennepin County to the Canadian border. The same cameras and film were used; larger scales and lower flight altitudes were prescribed in the interest of improved detail. Photos were taken in October and early November.

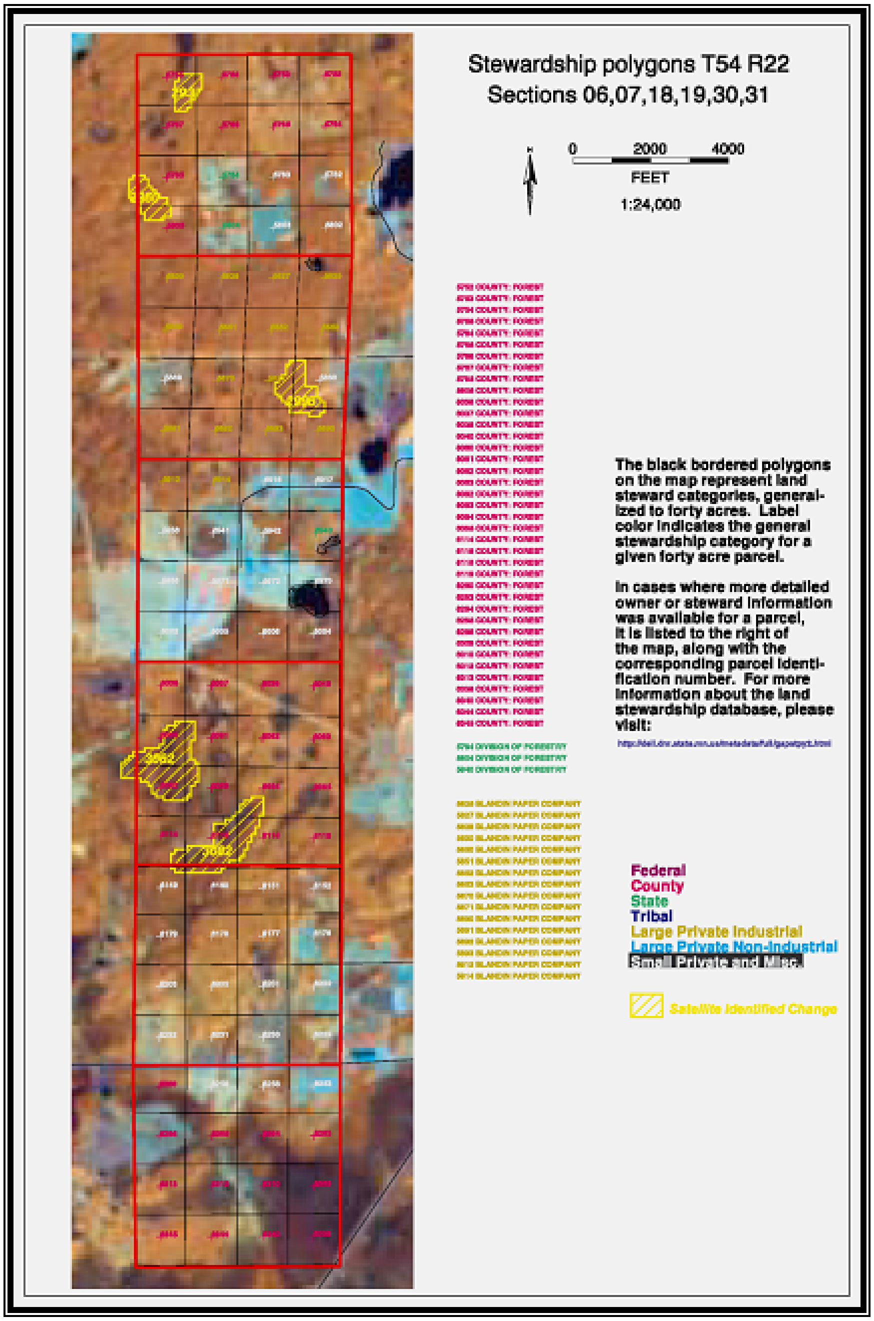

Figure 3. One of the 80 1x6-mile blocks, with satellite-detected removals in yellow.

Data Analysis

GIM Site Selection and Interpretation

The two sets of photography were interpreted separately. Those of the 1x6-mile blocks were interpreted independently and then compared against satellite imagery; those of the 200 removal sites were interpreted in conjunction with satellite imagery.

<u>80 Survey Blocks</u>: Photography of each 1x6-mile block was stereointerpreted and all apparent recent harvests delineated. In addition, field information about harvests within the previous two growing seasons was gathered by questionnaire from federal, state, county and private land managers in each block. Satellite-detected harvests were then overlaid on imagery of the blocks and compared against photo/field data to evaluate reliability of detection methods (Figure 3).

<u>200 Removal Sites</u>: To assist interpretation, photos of each of the 200 sample sites were paired with satellite images showing the corresponding satellite-detected disturbance (Figure 4).

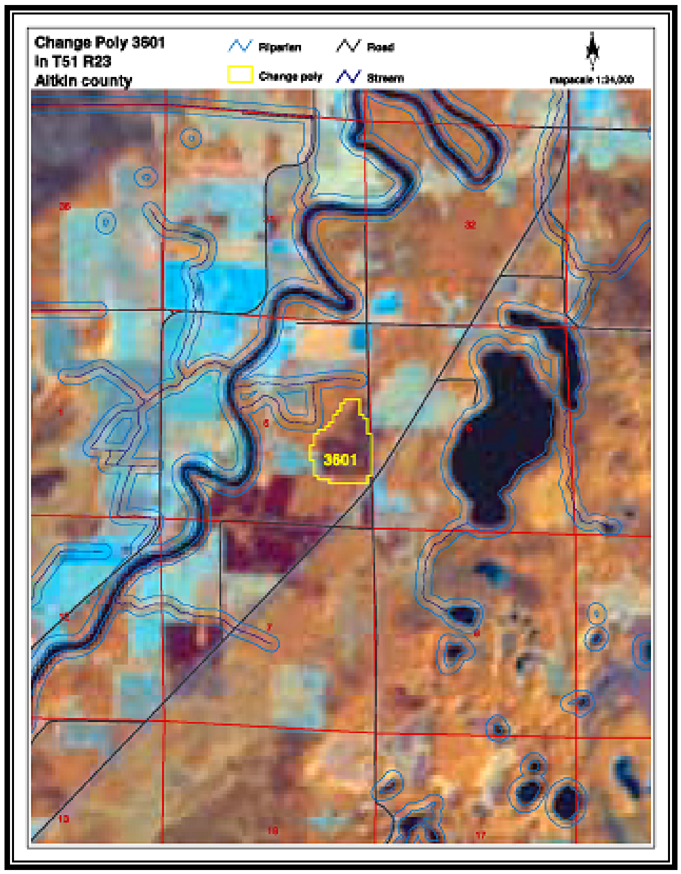

Figure 4. One of the 200 removal polygons, in yellow. Riparian zones appear in blue.

Photos interpreted as showing recent harvests were scanned and rectified, and the boundaries of the visible cutting area were delineated using ArcView GIS software, as shown in Figure 5. The rectified images were stored for further GIM interpretation and use by field crews.

Figure 5. Rectified photo of site in Fig. 4. Harvest in yellow, adjacent RMZ in blue.

Statewide Harvest Acreage Estimation

To estimate the statewide rate of harvest, satellite-detected removals were first annualized: their acreage was divided by the years separating the two images from which they had been detected. The similarly adjusted photo-measured acreage of each double-sampled harvest site was then regressed on annualized satellite-estimated harvest acreage, and total annual harvest acreage was calculated from the regression relationship. The two strata were regressed separately, site selection in the riparian stratum having been somewhat heavier than in the other. Cloud-masked forest areas were assumed to have been harvested at the same rate as visible forest areas. As the outcome applied only to Landsat paths 27 and 29, harvest area was expanded by the ratio of total GAP forested acreage in the state to GAP forested acreage under those paths, to obtain a statewide figure. The Boundary Waters Canoe Area Wilderness (BWCAW) and Voyageurs National Park, in which no harvesting is permitted, were excluded from acreage calculations.

Riparian Harvest Acreage Estimation

Photointerpreted harvest areas in both strata were intersected with the existing statewide RMZ coverage (as depicted in Figure 5) to obtain harvest acreage in riparian zones. The ratios of annualized RMZ harvest to annualized total harvest within each stratum were used to calculate statewide acreages.

Results

<u>*GIM Site Selection and Interpretation*</u>

Satellite change detection followed by aerial photo sampling of 200 sites identified more than enough suitable harvest sites for Guideline Implementation Monitoring. While the 80 1x6-mile blocks were not ultimately required for this purpose, the two aerial photo phases provided a useful cross-check on the reliability of TM-based change detection in selection of sites for GIM.

- Usable photographs were taken on 197 of the 200 sample sites. (Camera malfunctions occurred on three.) Of these, 159 were determined to show recent removal of forest growth; the remaining 38 were false-positives arising from insect defoliation, misclassification of agricultural land as forest, and other circumstances. Of the 159 removal sites, 148 were identified as harvests, the remaining 11 as land use changes.

- Photointerpretation of the 1x6-mile blocks yielded the following results:

Eligible harvest sites mapped in 80 1x6mi blocks		By Satellite	
		Mapped	Not mapped
By Photo	Mapped	44	1
	Not Mapped	7	N/A

Ineligible sites mapped in 80 1x6mi blocks		By Satellite	
		Mapped	Not mapped
By Photo	Mapped	N/A	43
	Not Mapped	12	N/A

  Most of the ineligible disturbances mapped by photointerpretation had occurred outside the time frame specified for GIM.

- Local managers did not consistently identify harvests within the 1x6-mile strips, especially on private lands. Managers reported no sites that went undetected by remote sensing, whereas several recent removals not identified by local managers were detected by photo or satellite. Several harvests identified by local managers had occurred outside the time frame of interest. It proved difficult to design a query that would elicit consistent answers from a random assortment of federal, state, county and private land managers.

Statewide Harvest Acreage Estimation

The linear regression relationships (Figures 6 and 7) between annualized satellite-detected and photo-measured harvest acreages in the "riparian" and "nonriparian" strata were applied to the stratum means and then expanded:

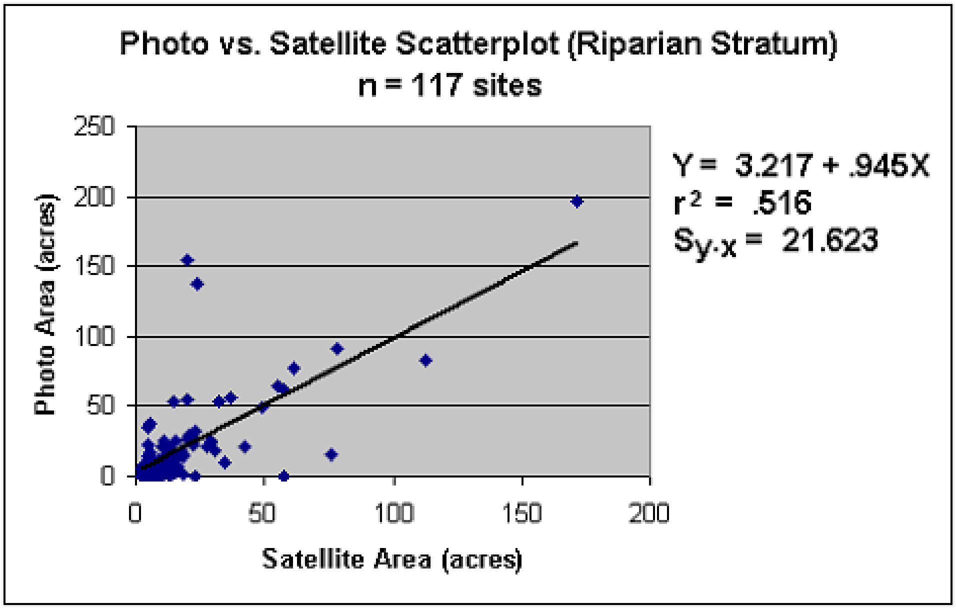

Figure 6. Photo removal area regressed on satellite-detected removal area, riparian stratum.

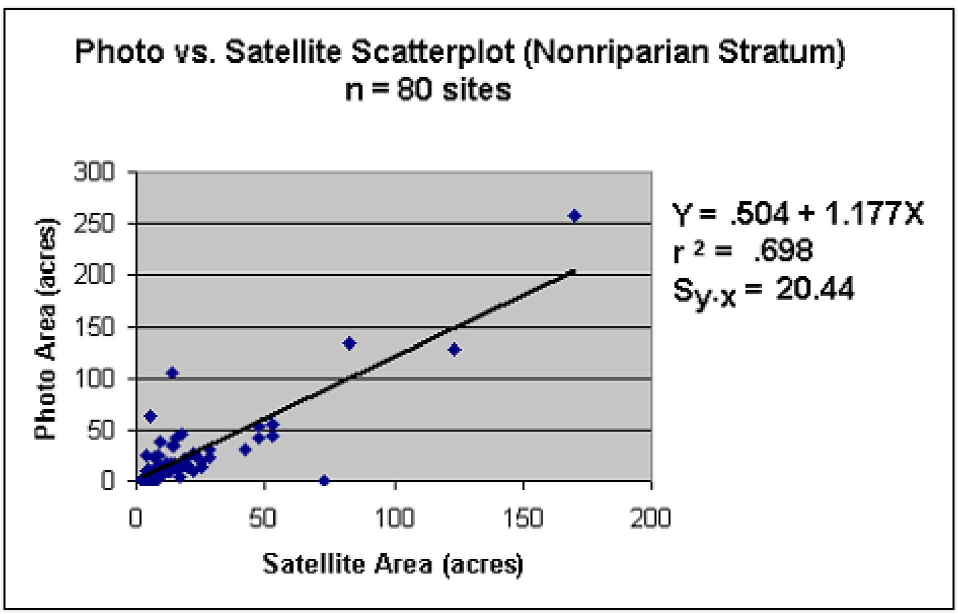

Figure 7. Photo removal area regressed on satellite-detected removal area, nonriparian stratum.

1) Riparian stratum:

3.217 + (.945 x 20.92 satellite acres/site) = 22.99 acres/site, $s_{\bar{y}Rd}$ = 1.98
22.99 acres x 2597 sites = 59,705 harvest acres in TM paths 27 and 29, 10,182 at 95%

2) Nonriparian stratum:

.504 + (1.177 x 15.86 satellite acres/site) = 19.17 acres/site, $s_{\bar{y}Rd}$ = 2.26
19.17 acres x 2641 sites = 50,628 harvest acres in TM paths 27 and 29, 11,878 at 95%

The total of GAP-classified forest in Landsat paths 27 and 29, excluding BWCAW, Voyageurs Park, and forest masked from disturbance detection by cloud, is 10,185,788 acres. Across the entire state (again excluding BWCAW and Voyageurs Park) GAP identified 14,272,595 forest acres. The expansion ratio is thus 14,272,595 / 10,185,788 = 1.4012. Applying this yields (59,705 + 50,628) x 1.4012 = 154,599 harvest acres statewide.

A further adjustment was made to account for the single eligible harvest missed by satellite change detection and captured in the 1x6-mile block photointerpretation. As noted, blocks had been selected with probability proportional to forested acreage. When this 20-acre harvest site in question is expanded to a statewide estimate, it represents an additional 2613 acres not included in the satellite-based total, raising the statewide sum to 157,212 acres.

Riparian Harvest Acreage Estimation

In the riparian stratum, 10.6% of photo-measured harvest was within mapped RMZs; in the nonriparian stratum, 1.8%. Applying these percentages to total annualized harvest in each:

Riparian = 59,705 x .106 = 6329 acres
Nonriparian = 50,628 x .018 = 911 acres

Expanding these statewide: (6329 + 911) x 1.4012 = 10,145 acres of harvest within RMZs. The site missed in satellite survey contributed no additional acres.

Plans for 2002-3

Experience gained in the first iteration of satellite-supported statewide forest harvest monitoring and acreage estimation will be applied in 2002-3 to reduce costs and improve precision. Late-summer satellite imagery from paths 26, 28 and 30 will be acquired and analyzed. Use of Kauth-Thomas transformation data (Collins and Woodcock 1996) and change vector analysis (Borak et al. 2000) is expected to improve reliability of satellite change detection. Earlier generation of satellite image maps of sample sites will further systematize gathering of photographic data. Recent University of Minnesota work (Kloiber et al. 2000) has opened the way to integration of statewide lake trophic status monitoring with forest change work.

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