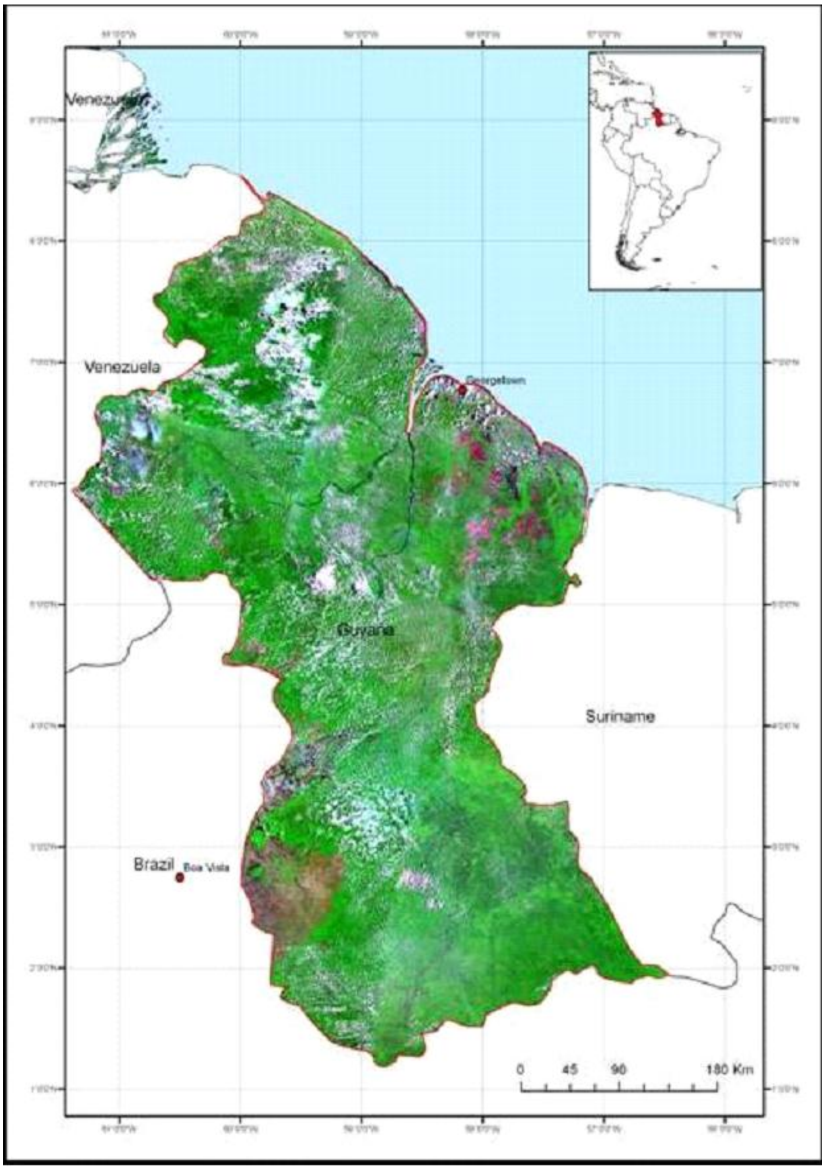
Final Report

38A09905
21 May 2009



Guyana Forestry Commission/ITTO
Supporting Forest Law Enforcement
Using Remote Sensing and Information Systems

PREFACE

This purpose of this report is to document the development and implementation of the satellite-based Forest Change Detection System.

The report covers the imagery and GIS datasets, processing of these data, indicators of illegality and development of the Forest Change GIS system.

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Dr Pete Watt
SENIOR CONSULTANT

Dr Mark von Veh
CONSULTANT

Contact

Pete Watt
Level 5, HSBC Building
1 Queen Street
Auckland,
New Zealand
Tel. +64 9 918 1090
Fax +64 9 918 1105
E-mail: pete.watt@poyry.com

SUMMARY

Pöyry Forest Industry (Pöyry), on behalf of GFC, has designed and implemented a forest change detection system for recording and updating Guyana's roads and forest disturbance from satellite data. A series of tools have been developed that run within an ArcGIS 9.2 framework which assist with the detection process and management of the workflow.

A key aspect of the system is that GFC takes control of the process and maintains and updates the datasets on an ongoing basis. Pöyry has provided documentation (see manual) that describes the various steps associated with the image processing, GIS system and subsequent interpretation and mapping of change.

The initial source of satellite data for Phase 1 was 30 m resolution Landsat TM and ETM+ imagery. Full coverage of Guyana requires 17 Landsat scenes. These datasets are currently freely available from the Brazilian National Space Agency (INPE).

Phase 1 imagery was principally used to update a base map by recording road networks and forest changes that had occurred prior to 2008. This map was also used to identify a number of highly active areas (hotspot areas).

Over these areas higher resolution datasets were ordered. Initially Formosat 8 m imagery was tasked from August 2008 to March 2009. This acquisition was unsuccessful due to persistent cloud. Subsequently, secondary datasets, including 2009 radar and late 2008 optical data (ASTER 15 m and CBERS 20 m) were acquired. Overall these datasets are adequate for monitoring of change.

A decision tree was developed to assist in determining the legality of detected forest and roading activities. Its purpose is to support decisions regarding appropriate response by GFC to detection of changes in forest cover determined from medium resolution satellite images. At this scale, change can be categorized as linear or polygon features – equating to roads and canopy gaps (approximately 1 ha or greater), respectively. The location of change is the primary determinant of whether it is likely to be illegal activity related to logging. Reference to proposed operations presented in Annual Operations Plans (AOPs) will be necessary to support a decision on the probable legality of any activity detected.

The success of future monitoring and documentation of forest change depends on the acquisition of cloud-free data. While the Formosat tasking was unsuccessful this sensor still offers the highest probability of success due to its daily revisit capability. Other data such as 32 m DMC imagery also provide the opportunity to track larger-scale forest events and detect newly constructed road. Roads are considered one of the main drivers in forest change as they increase the accessibility of forest areas. Radar data is also seen as an alternative, but is often more problematic to process and interpret.

A logical enhancement to the forest change system would be the integration of concessionaires' Annual Forest Plans and timber tracking information. This would improve the GFC's monitoring capabilities.

GFC should also seek to build links with space agencies (JAXA, NASA, ISRO and INPE) and data providers (SPOT and DMC) to increase the frequency of national and local coverage.

CONTENTS

1 INTRODUCTION

Guyana has a total land area of 21.5 million hectares (ha), of which around 75% is forested. The forest industry is an important component of the Guyanese economy. In 2006 the forestry sector contributed 3.85% to Guyana's GDP, generating USD59.5 million in export revenue and providing employment for around 26 000 people. Total log production in 2006 was some 393 968 m^3 with just under half (190 783 m^3) being exported. The remaining production is processed mainly for sawn timber and plywood manufacturing. The forests are diverse in terms of species mix (~1 000 species), however only a relatively small number (~30) are considered by the industry to be “commercial species”.

Regulation of forest management has been rapidly evolving in Guyana and the Guyana Forestry Commission (GFC) takes an active and vigilant role in monitoring and promoting sustainable forest management practices.

Reliable information on illegal forest harvesting activities is often difficult to obtain. Left unchecked, illegal logging and subsequent trade of timber represent a substantial threat to sustainable forest management in many countries.

The purpose of this project was to support forest law enforcement in Guyana using Remote Sensing technology and Geographic Information System (GIS). The project sought to improve sustainable management of forest resources, and to identify areas where illegal harvesting of tropical timber is taking place by collecting accurate geographical information on deforestation. Remotely sensed data (satellite images spanning from 2005 to 2009) have been used to detect deforestation activities and generate GIS layers documenting logging activities and road networks. Such information will assist GFC in targeting areas of change and mobilising the necessary resources to undertake enforcement measures.

Specific project goals include:

1. Conduct satellite image analysis to detect logging, mining and road clearing activities.
2. Determine legality indicators that will clarify whether or not deforestation activities carried out under concessions are legal.
3. Establish an integrated geographic database for the storage and maintenance of the acquired satellite imagery and GIS layers in order to detect and monitor forest disturbance. The GIS is designed to store and permit queries of temporal attributes of these layers.
4. To better allocate resources required for forest law enforcement, and provide training on operating and maintaining the above tools and on handling such datasets.

In covering these goals a series of manuals have been produced that cover the system design and provide training materials for the administrator and operators (see manual).

1.1 Use of Satellite Data for Detecting Change/Forest Harvesting

Several studies have investigated the effectiveness of satellite data for detecting change/forest harvesting events. Operationally there are a number of examples that use a range of temporal satellite data for detecting forest change.

In the region, Brazil has been actively monitoring forest clearance activities since 2000 (Stone & Lefebvre 1998, Morton *et al* 2002). This research includes the evaluation of Landsat (30 m) to lower resolution MODIS (250 m) datasets. This work has shown that, even using Landsat, selective harvesting is often difficult to detect using automated classification routines owing to the subtle changes in spectral response at this resolution, and that larger scale deforestation events are often missed if coverage is infrequent.

Detection is markedly improved by increasing temporal coverage (<2 years) and using visual interpretation methods. For example, even lower resolution datasets such as MODIS (acquired daily) are effective for rapid identification of larger-scale forest change (>15 ha). However, Morton *et al* (2002) also state that MODIS-based analyses are not a replacement for high resolution analyses that estimate the total area of deforestation and identify small clearings.

In other studies, DeFries *et al* 2005 agree with the findings of Morton *et al* 2002 and 2005, stating that global sensors such as MODIS provide timely detection of large deforestation events and highlight regions of increased forest clearing activities. They also note that higher-resolution sensors such as Landsat identify smaller scale (<10 ha) deforestation events more accurately. Zhan *et al* (2002) also agree that 250 m MODIS data cannot accurately map smaller scale deforestation events.

Accurate classification of clearfell patches for small (<10 ha) areas requires a combination of field checks and higher-resolution, more expensive satellite data such as SPOT 5 (10 m) or Formosat (8 m) data. The benefit of high resolution data is its ability to identify selectively harvested forest. However, it is clear that in a tropical environment the understorey of disturbed forest very quickly regenerates and within two years it is difficult to detect the harvesting intervention (Souza and Roberts, 2005). Soil compaction caused by construction of roads and log landings retards regeneration so often provides a better indicator of harvesting activities.

The optimal solution appears to be a combination of frequently acquired medium resolution data such as Landsat coupled with high resolution data (SPOT 5 or Formosat) and field and aerial inspections.

1.2 Forest Change GIS System Design

The forest change system is designed to operate within a GIS framework. It builds on GFC’s existing GIS and mapping skills to capture and monitor forest disturbance.

The main features of the system are:

- Integration of GIS data derived from satellite images and existing GIS layers.

- Control of the data-capture process. Operators are provided with satellite images.
- Mapping and recording of information for each observed feature (operator name, date mapped, date the feature is first observed, and dimensions of the object).
- Implementation of quality control measures to ensure the topology of areas recorded is free from errors (i.e. polygon overlaps).

Tasks are divided into administrators and operators roles depending on complexity. The system administrator controls the process of acquiring and preparing the satellite images and maintaining and updating a master geodatabase of forest change.

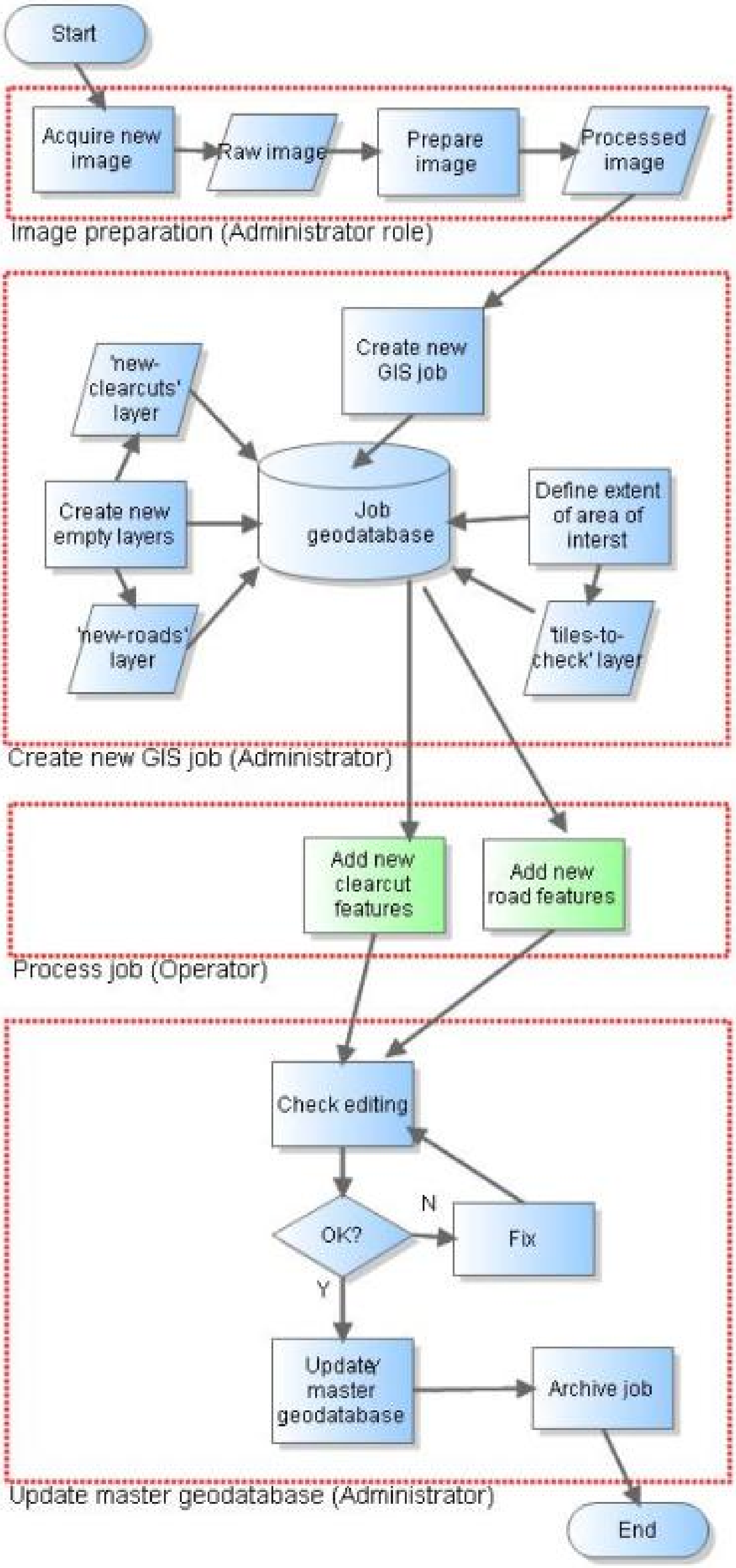
For each new image the administrator sets up a job folder that contains the processed image and a temporary job geodatabase for the new data to be captured. The job geodatabase contains a tiles_to_check layer that identifies the image areas to be inspected for change, and new_roads and new_clearcuts layers.

The job folder is then assigned to a GIS Operator who captures new road and forest disturbance features from the image. This is done with reference to historical imagery and previously captured data in the master geodatabase.

Each new feature is automatically tagged with the name of the operator, the name of the image in which the new feature was observed, the image date, and the date of data capture. The Operator returns the job folder to the Administrator.

The Administrator then checks the completed job for topological errors (overlaps, gaps, dangling nodes) and updates the master database if the digitizing is error-free. The workflow is illustrated in Figure 1-1.

Figure 1-1:
Forest Change System Design



1.3 Indicators of Illegality

A number of illegality indicators have been developed to assist GFC in determining if the forest clearance is legal or not.

Guyana already has a prototype Legal Assurance System that covers the production and trade of wood products. This definition has a hierarchical structure based on an umbrella statement of legality which expands into a series of principles and indicators for assessing legality of operations. In keeping with legality definitions developed elsewhere in the world, the definition encompasses requirements in the welfare, social, environmental and occupational health and safety sectors in addition to laws and regulations pertinent to the forestry sector.

An assessment of legality against such a comprehensive definition clearly requires on-the-ground inspections by qualified auditors. Nevertheless, remote detection of change in certain forest characteristics can play a supporting role in the assessment and ultimately enforcement of legality in the forestry sector. The legality indicators that can be tested using satellite image analysis will be restricted in a general sense to those that have a geographical element, though the scale and resolution of the imagery will be influential.

Using medium-scale imagery, change detection is possible for new forest roads and canopy clearings of around 1 ha (100 m x 100 m) or more in extent. However, it is often not possible to determine from images the purpose of such changes; i.e. whether the canopy disturbances are due to forestry activities or are related to other causes such as mining or agriculture. In cases where change is detected, decisions can be supported by using other GIS data such as active forestry concessions, mining properties and agricultural leases. The use of images for change detection can thus serve as a mechanism to alert GFC to possible forestry activities and provide a rational basis for targeted ground-truthing or tasking higher-resolution satellites.

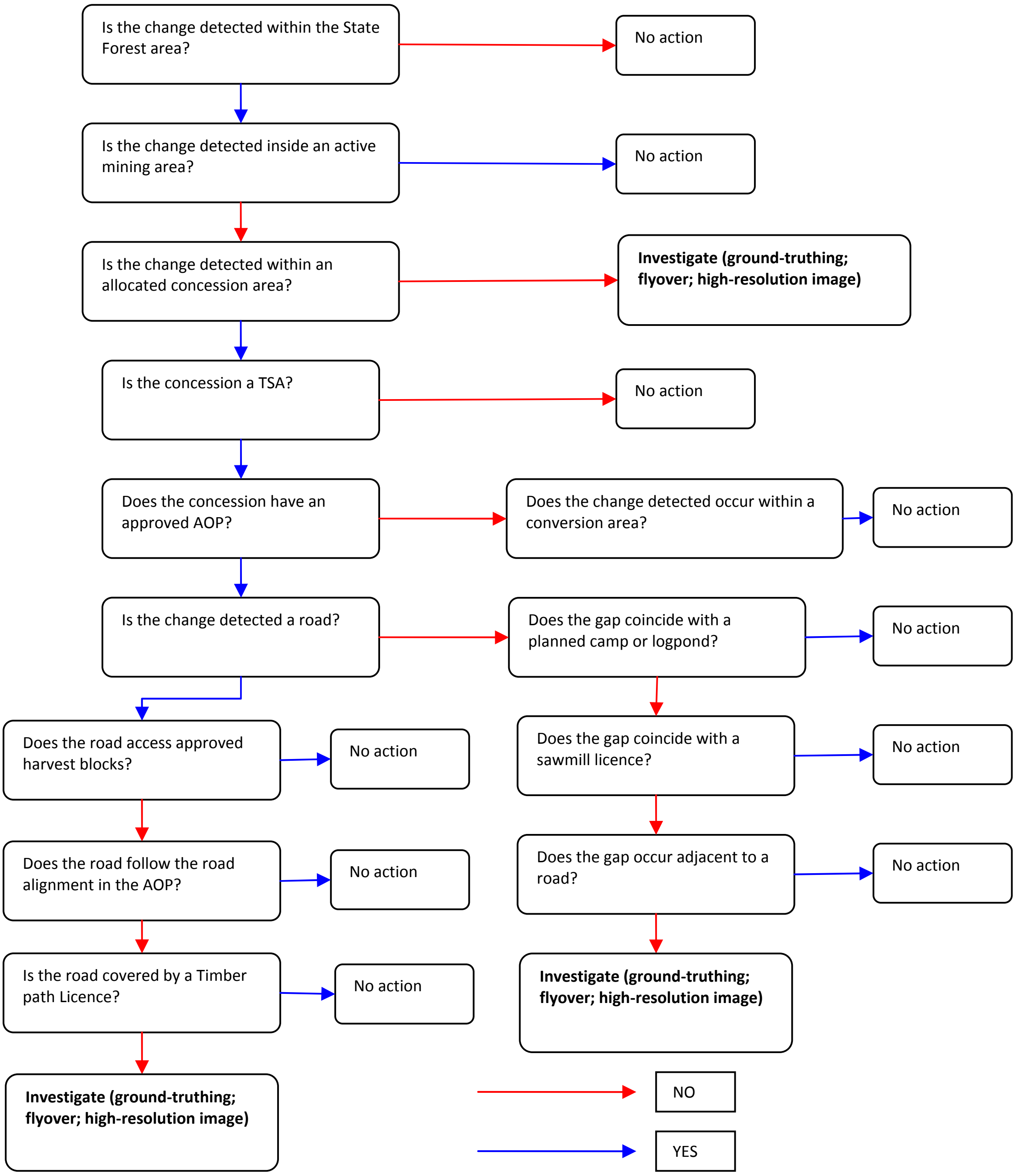
Reference to forestry annual plans can suggest whether activities detected in the forest are occurring within approved blocks or not. Similarly, roads should have been planned and approved in annual plans and, if passing through adjacent concessions, should be subject to a Timber Path Licence.

Higher resolution images, where available, should allow a determination of the nature of the change (i.e. forestry, mining, agriculture, residential) as well as a more profound assessment of compliance with some of the stipulations of the Code of Practice such as:

- Road widths
- Canopy openings
- Creek pollution
- Location of camps
- Vegetation clearance around bridges
- Skid trails

A prototype decision support flowchart (decision tree) has been developed (see Figure 1-2). The flowchart is a tool to support decisions regarding appropriate response by GFC to detection of changes in forest cover determined from medium resolution satellite images. At this scale, change can be categorized as linear or polygon features – equating to roads and canopy gaps (approximately 1 ha or greater), respectively. The location of change is the primary determinant of whether it is likely to be illegal activity related to logging. Reference to proposed operations presented in Annual Operations Plans (AOPs) will be necessary to support a decision on the probable legality of any activity detected.

Figure 1-2:
Decision Support Flowchart for Legality Enforcement Response

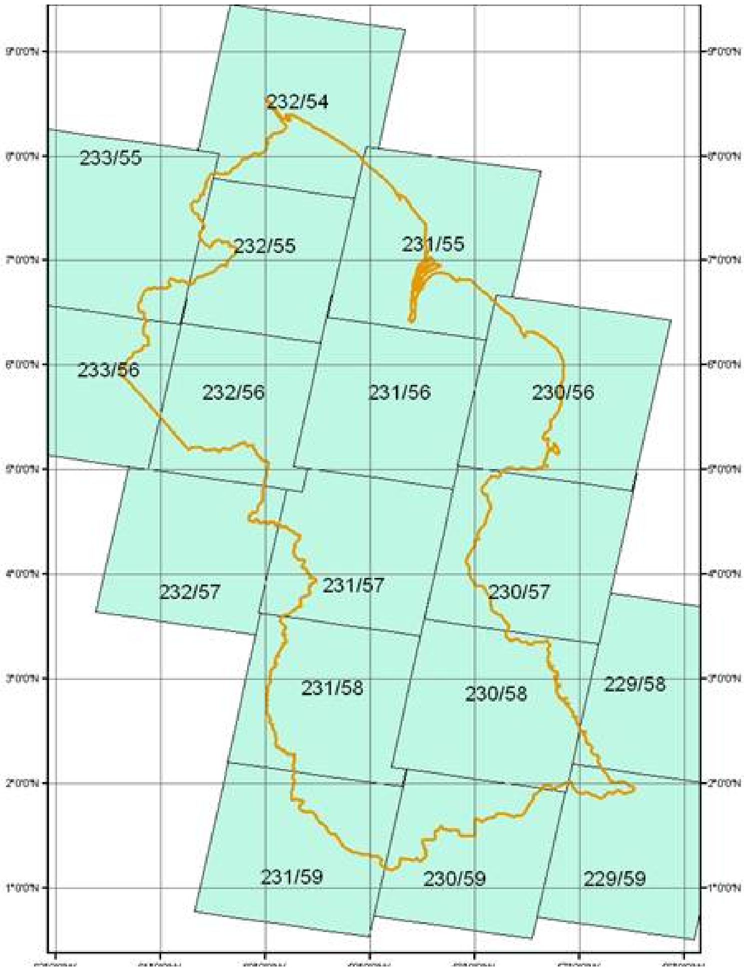


1.4 Datasets and Analysis

Two datasets were compiled during the project. The Phase 1 dataset provided a national coverage of medium resolution imagery. This coverage comprised 30 m Landsat imagery, spanning two time periods, 2005 and 2006-2008. To cover Guyana a total of 34 Landsat scenes (17 for each time period) are required.

These data were delivered in April 2008 along with the Forest Change GIS System. Initial training was provided to the GFC that covered image processing, data management and training to GIS operators in the identification and mapping of forest disturbance.

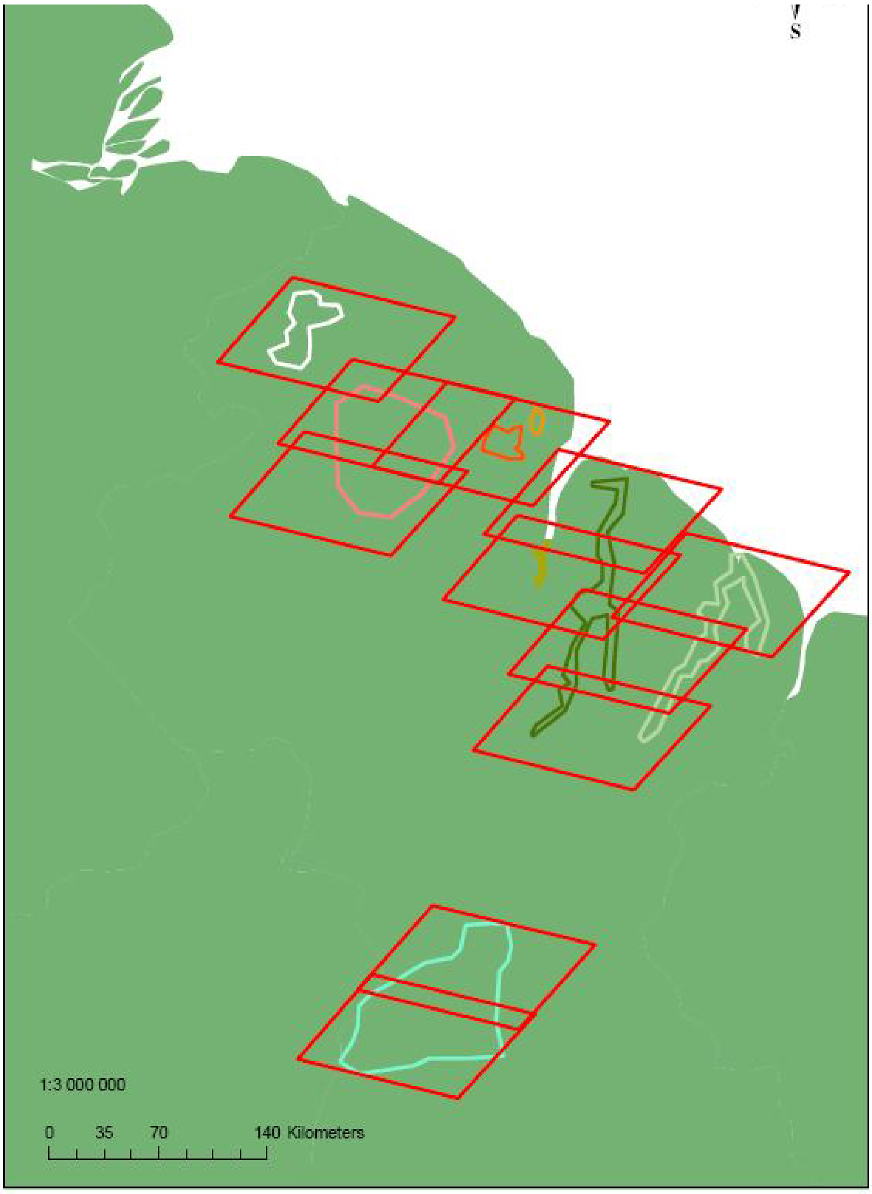
Map 1-1:
Landsat Coverage over Guyana



From the Phase 1 dataset areas with high levels of activity were selected. For the hotspot areas defined higher resolution datasets were acquired. The sensor of choice for this phase was Formosat. The key aspect of the Formosat sensor is its ability to revisit the same location daily.

Map 1-2 shows the location of the selected hotspot areas.

Map 1-2:
Phase 2 Hotspot Locations



Tasking was scheduled from August 2008 to March 2009. Previous experience suggests that this timeframe is optimal for image acquisition. Unfortunately no cloud-free Formosat imagery was obtained so archived ASTER 15 m (late 2008) and 2009 radar datasets (a combination of 5, 10 and 25 m) were ordered. These datasets combined to provide complete coverage over the hotspot areas.

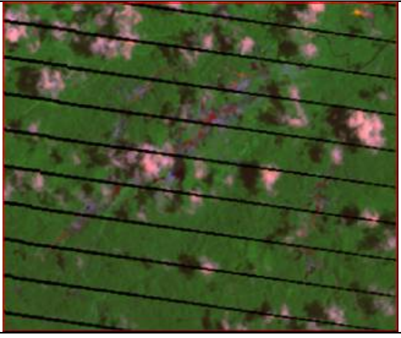
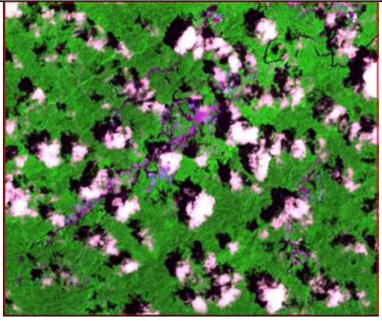
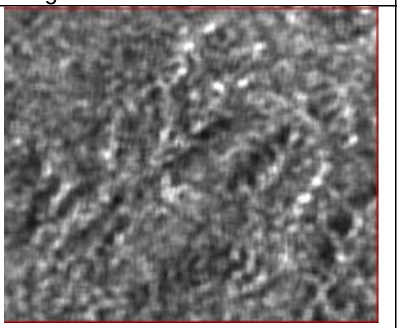
1.5 Detection of Forest Disturbance

Successful detection of forest disturbance and roading activities are related to both image quality and the type and interpretation of changes.

The Landsat dataset assembled for Phase 1 provides a broad overview of change. Overall the data should be viewed as answering the question “Where are the changes occurring?” A rule of thumb for the relation of the pixel size and the map scale is 0.05 up to 0.1mm pixel size in the map scale (meaning 30 m resolution) equals an equivalent map scale of 1: 300 000. This scale is suitable for high level detection and provides an excellent base layer for targeting and mobilising resources.

The datasets assembled for Phase 2 provide specific detail on the size and type of the forest change.

By way of example, the same forest area is used to show how the level of detail increases, moving from recognition[1] where uncertainty still exists as to the boundary and cause of the landuse change (as in Phase 1) to identification, where the boundary is more certain (Phase 2 dataset). From the left are examples of interpretation levels using Landsat ETM+ (30 m), ASTER 15 m and radar 25 m datasets.

	Image Phase 1- Landsat 30 m	Image Phase 2 – ASTER 15 m	Image Phase 2 – Radar 25 m
Mining Activity			

Edges and gaps are better defined as the spatial resolution increases. Also, different spectral band combinations enhance certain features; i.e. red areas on Landsat and ASTER identify recent mining activity. The radar dataset provides confirmation of the change, but often requires the inclusion of other reference sources to provide certainty the change is material.

On the radar generally bright areas represent areas of forest change. It is well known that the radar response can be complicated by the orientation of the radar wave, roughness of the forest canopy, topography and presence or absence of water.

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[1] The interpretation of an object is organised in four hierarchical levels:
1. **Detection** is the discovery of an object without recognition.
example: there is a white linear feature in this corner of the image.
2. **Recognition** is the ability to fix the identity of an object within a group type.
example: this green feature is a block of trees
3. **Identification** is the ability to place the identity of an object as a precise type.
example: this block of trees has gaps

1.6 Practical Indicators of Change

Medium resolution data like Landsat (30 m resolution) is able to detect areas ≥1 ha. In this project, a majority of these areas were caused by mining activity. Smaller or lower intensity activities can be detected but are difficult to confirm with certainty. In these cases local knowledge, forest inspection or higher resolution will reduce this uncertainty.

Roading activities are also possible to detect. Skid tracks are often constructed off existing road or river networks, so it is important to maintain an accurate GIS base map of existing roads to ensure new tracks are detected. GFC routinely records this data during field inspections and methods should be developed to integrate this data into the GIS system

Several spectral bands are well suited for enhancing spectral characteristics associated with roading and harvesting activities. A three band image composite comprising green, near infrared and shortwave infrared provides the best contrast. In Landsat satellite imagery this would comprise of bands 2, 4 and 5 and CBERS bands 2, 4 and 1.

A series of examples that show road construction and the different land clearing operations identified from 30 m Landsat satellite data.

Figure 1-3:
Detection of New Roading

2005 Image

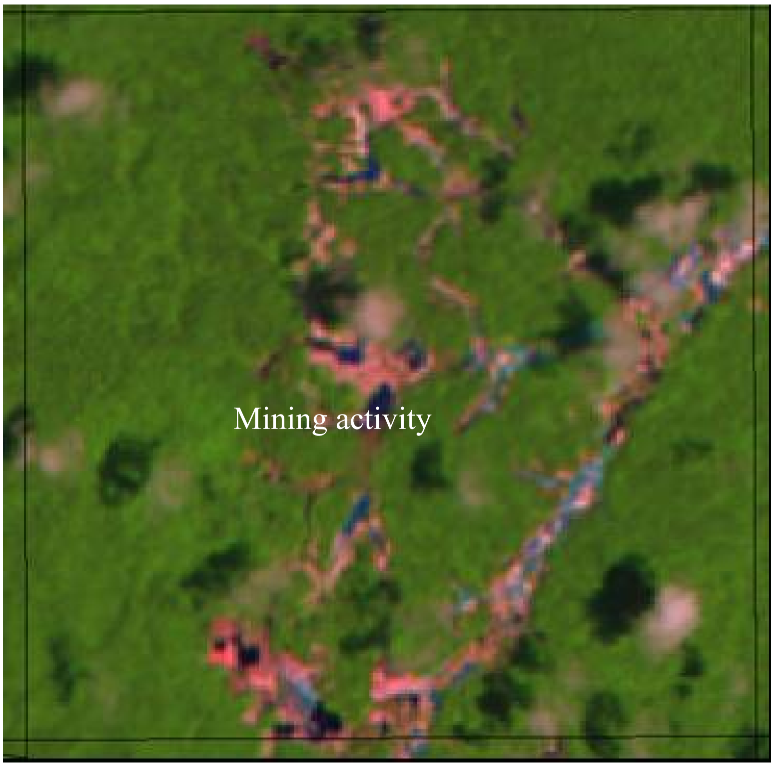
2008 image

Recent forest clearing appears red in colour which is the expected spectral response from bare soil.

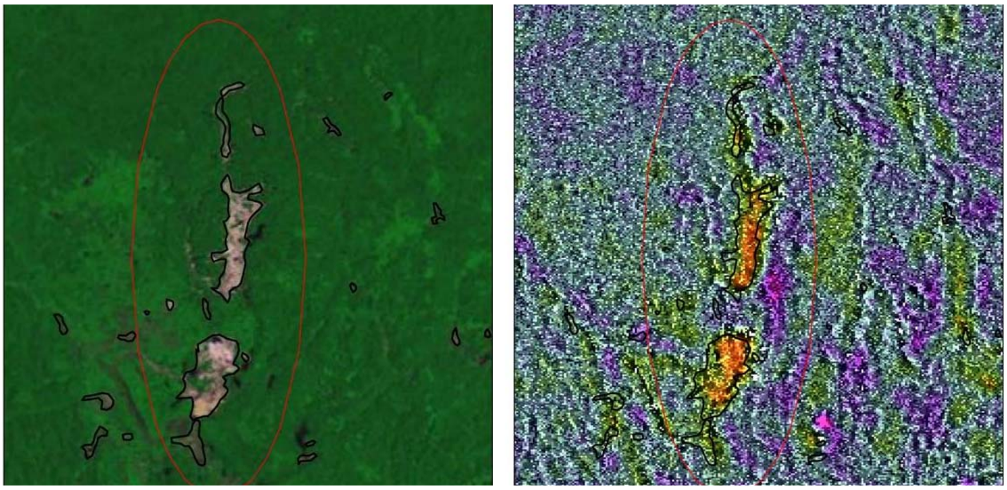
Figure 1-4:
Recent Forest Clearance

Mining activities have a distinct spectral response and appear red/grey or blue in colour. Activity will often be located close to rivers and streams. Blue areas depict water, and red bare soil.

Figure 1-5:
Mining Clearance



Radar data used in Phase 2 in conjunction with optical data also assists in the monitoring of existing forest clearance areas. The following example shows a mining area detected using Landsat data and the same area detected using 2009 5 m radar data.



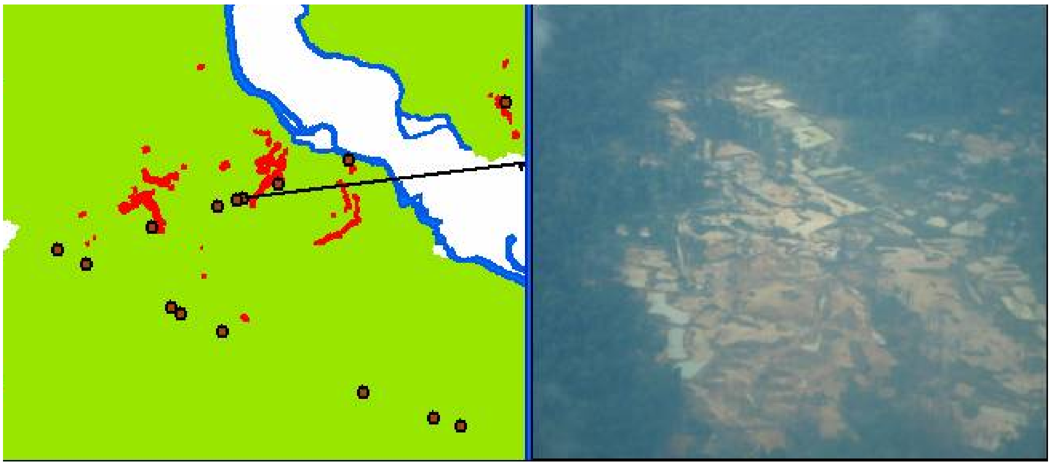
2 VERIFICATION OF CHANGE

To verify changes detected by GFC's operators during Phase 1 an aerial inspection was conducted. The overflight covered a range of forest disturbances including road construction, agricultural clearing and mining activities. Areas of falsely detected change were also covered.

ASTER and radar were provided to assist with the verification of examples of changes detected from Landsat. In addition, real time tracking via GPS linked to the GIS enabled changes to verify against the satellite imagery. Photographic evidence was also captured and positions of the photos automatically referenced using the GPS.

This process documents and provides rapid confirmation of forest change and further assists in ensuring compliance.

Map 2-1:
Confirmed Forest Clearance Activity from the Overflight



3 SYSTEM CONTINUITY

The key to the success of the system is the availability and continuity of reference information to identify and verify forest change. This information is available from a range of sources including satellite imagery, timber tracking records[2] or regular updates from GPS traces.

A logical approach would be to integrate these sources into the current system in order to provide an effective mechanism to track temporal forest changes. This is particularly important over hotspot areas.

Imagery updates can be obtained from a number of sources as detailed in Table 3-1). The table divides the satellite imagery by application in descending order of resolution.

Table 3-1:
Available Satellite Imagery

Sensor	Resolution (m)	Image Cost (USD)	Approx Area Covered (km)	Application	Website
MODIS	250	Free	Guyana	Countrywide monitoring	https://lpdaac.usgs.gov/lpdaac/get_data
Landsat	30	Free	185 x 185	Large area detection & monitoring	http://glovis.usgs.gov/
Landsat					http://www.dgi.inpe.br/CDSR/
DMC[3]	32	0.164/km^2	660 x 4100	Large area detection & monitoring	http://www.dmcii.com
CBERS	20	Free	113 x 113	Large area detection & monitoring	http://www.dgi.inpe.br/CDSR/
IRS	1 to 40	Unknown	varies	All monitoring levels	www.isro.org/
Palsar radar	5 to 25	300	70 x 70[4]	Large area detection & monitoring	https://cross.restec.or.jp/cross/
ASTER	15	80	60 x 60	Hotspot monitoring	http://glovis.usgs.gov/
SPOT	2.5-20 m	3000 to 8000	60 x 60	Hotspot monitoring	www.spotimage.fr
ALOS	10	300	60 x 60	Hotspot monitoring	https://cross.restec.or.jp/cross/
Formosat	8	2500	60 x 60	Hotspot monitoring	www.spotimage.fr
QuickBird	4	20/km^2	16.5 x 16.5	Hotspot monitoring	http://www.digitalglobe.com/
IKONOS	2.2	20/km^2	11 x11	Hotspot monitoring	http://carterraonline.spaceimaging.com

3.1 Countrywide Monitoring

At the largest scale MODIS offers the ability to detect broad changes >20 ha. The advantage of this dataset is that it is free and only two images are required to cover Guyana. Brazil and New Zealand use this type of data to monitor change as the daily images are freely available. In New Zealand's case cloud cover is also an issue so daily images are acquired for a three month (90 day) period and then a mosaic is generated to give cloud-free coverage.

The following map provides the result of the mosaic process. For reference, a smaller 10 000 ha area is shown that provides a comparison between MODIS 250 m data and ASTER 15 m data. Areas in red on the MODIS map are forest harvesting events with the corresponding areas shown in blue on the ASTER scene.

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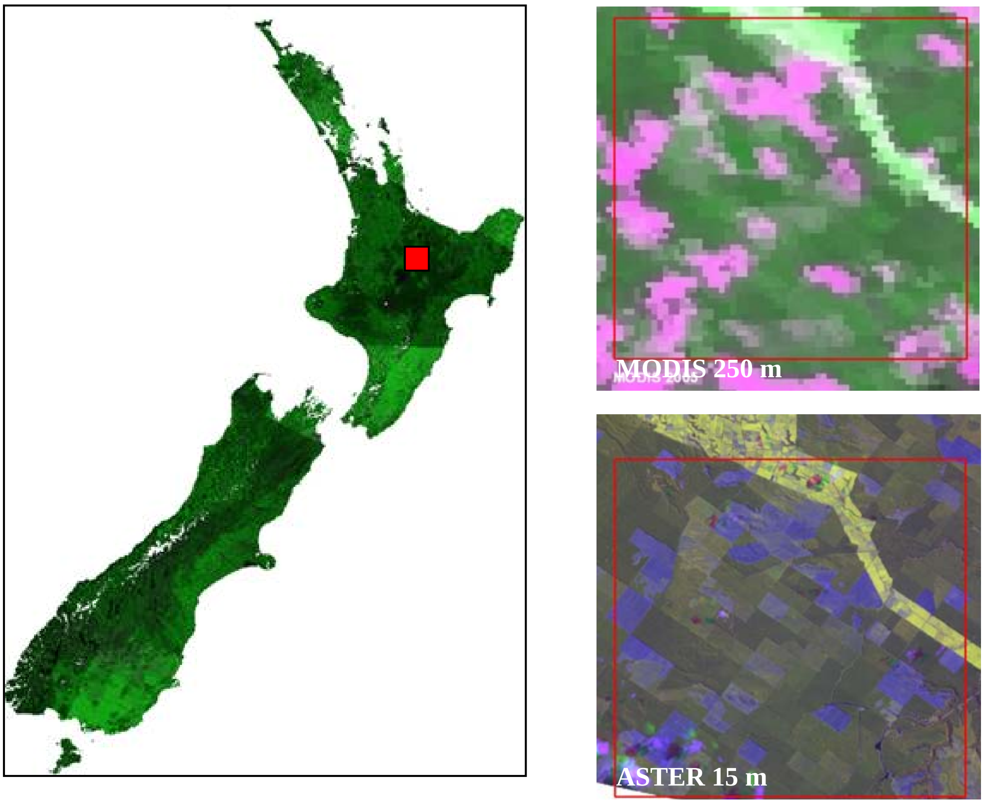
[2] The existing ITTO-funded timber tracking system could be integated into the forest change system to provide additional timber compliance checks on active Timber Survey Agreements (TSA).

[3] DMC proposes to launch a higher resolution 22 m imagery in 2009. Price provided is for tasked imagery.

[4] Palsar footprints vary by acquistion mode; 5 m data covers 70 x 70 km and 25m data approximately 360 x 280 km.

Map 3-1:
Example MODIS 250 m Coverage and ASTER 15 m Comparison



3.2 Countrywide & Intermediate Monitoring

Several datasets exist that are suitable for large area detection and monitoring - some are free. The issue with free or low cost datasets is that the coverage is infrequent and the data is often not regularly archived into an online image catalogue.

In the region, CBERS and Landsat data is made available by INPE Brazil. Cloud cover is still an issue which leads to infrequent coverage that can require a span of two years to provide a complete countrywide coverage. To be effective the monitoring system requires at least annual coverage over highly active areas.

To achieve cloud-free coverage, satellite imagery will need to be tasked and where necessary augmented with radar data from Palsar[5].

3.3 Hotspot Monitoring

High resolution satellite datasets are well suited to improved detection and mapping of small scale changes (< 1 ha). A common attribute of these satellites is that they do not routinely collect imagery and need to be tasked. This requires a monitoring schedule to be defined and an order to be placed. Climatic data suggests that ordering should target the August to March period as these are the least cloudy months.

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[5] Radar data on its own is not recommended due to difficulties in interpretation

Cheaper data is provided via ALOS and ASTER sensors although the acquisition schedule for these satellites is not regular. An opportunity exists to apply to NASA and Japan Aerospace Exploratory Agency (JAXA) to request more frequent data coverage.

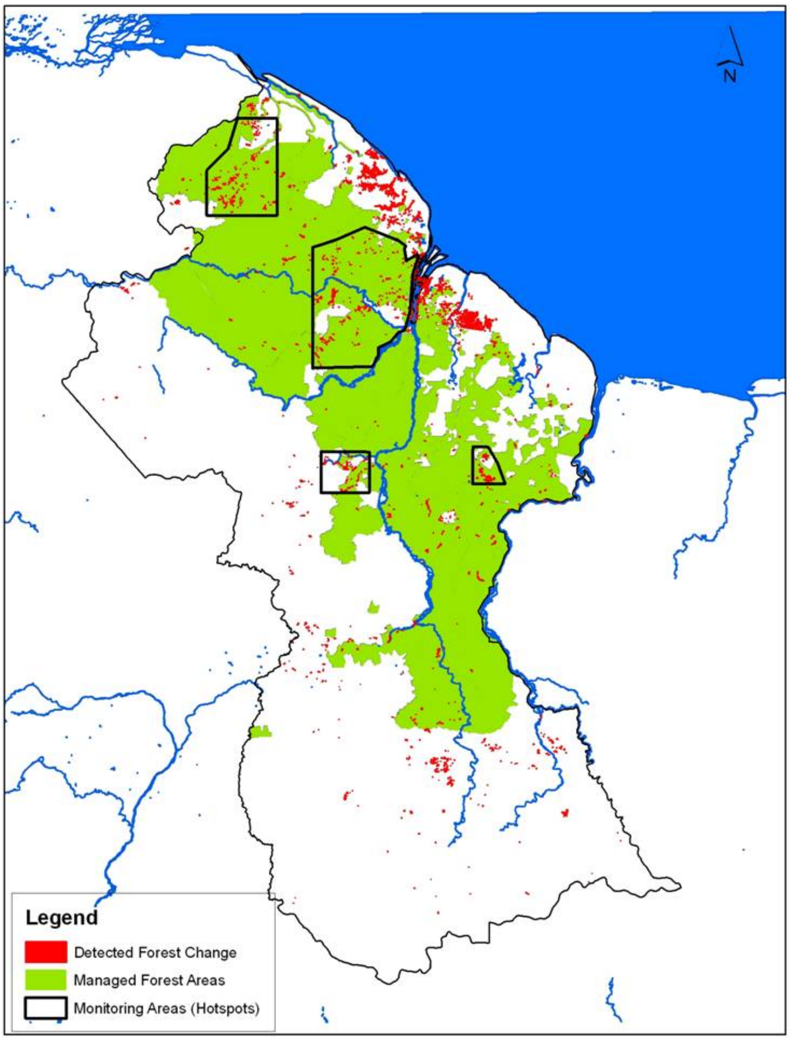
4 IMAGE ACQUISITION STRATEGY

The acquisition strategy uses a combination of datasets to provide coverage at countrywide and hotspot areas. It assumes that currently inaccessible areas will not be subject to the same rate of change as areas close to access routes such as rivers and existing roads.

Hotspot areas located in the managed forest estate are identified in black on Map 4-1. These are active areas of change identified during this project. The monitoring region has been enlarged as it is anticipated that these areas will continue to expand over time.

Remaining areas can be covered using countrywide and intermediate datasets.

Map 4-1:
Countrywide & Hotspot Acquisition Strategy



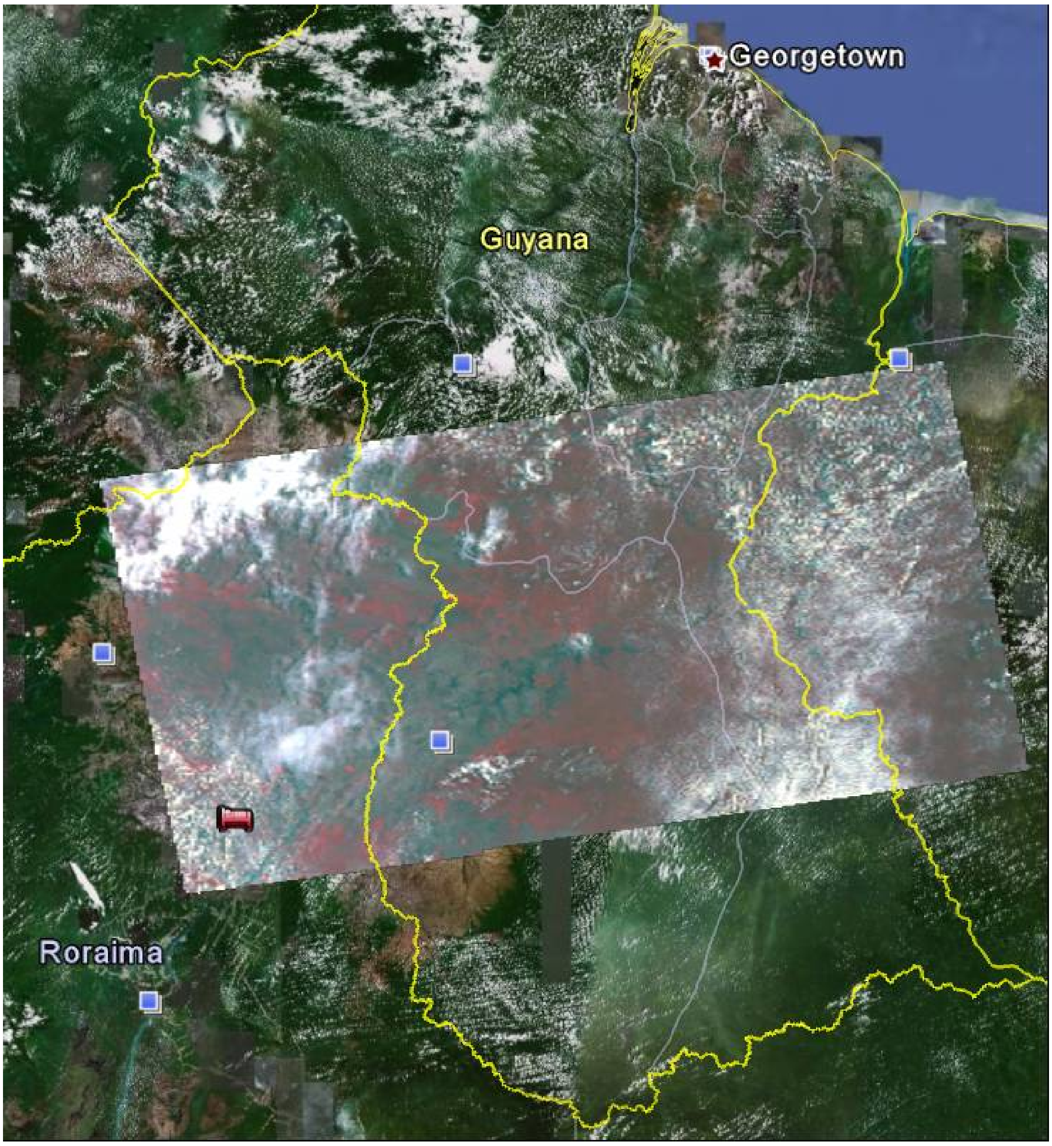
Countrywide & Intermediate Monitoring

Countrywide coverage of MODIS should be acquired in the August to December period and processed to provide a cloud-free mosaic. The purpose of this dataset is to provide cloud-free annual coverage and to monitor large-scale change in order to better focus the acquisition of higher resolution datasets.

Inaccessible areas are allocated to the countrywide and intermediate monitoring category and will be monitored using MODIS and freely available medium resolution imagery (Landsat).

Landsat data provides the optimal intermediate dataset to detect areas of forest change, given its resolution and spatial extent. DMC data (32 m) also provides this function and has the added advantage of having a wide foot (resulting in fewer scenes to process) and tasking the satellite to acquire cloud-free coverage.

Map 4-2:
Example DMC Coverage



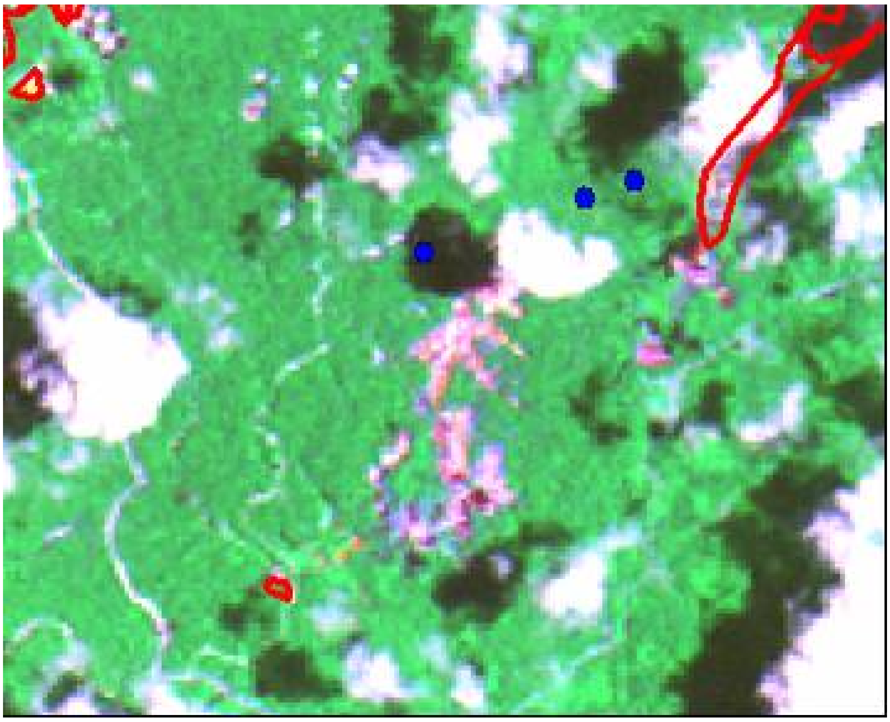
Hotspot Areas

Highly active areas, principally mining areas will be covered using higher resolution imagery from CBERS, ASTER, ALOS and tasked SPOT or Formosat.

A new service offered by SPOT allows greater autonomy of the image capture process. Users are able to track progress via a customised website and alter the programming request as required (see http://www.spotimage.fr/web/en/2294-myformosat-2-a-service-tailored-to-users-of-formosat-2-imagery.php)

For example, as new hotspots emerge it would be possible to prioritise the capture of these areas. Figure 4-1 shows areas mapped during the project (red outline) and emergence of new mining activity since this mapping.

Figure 4-1:
Mapped & New Activity



Additionally, if image catalogues are constantly monitored it may be possible to reduce the area that needs to be tasked.

A reserve option would be the acquisition of Palsar radar data to fill in areas of persistent cloud cover.

5 ADDITIONAL IMPROVEMENTS

The following recommendations seek to build on the existing system to incorporate additional functionality and integrate further satellite imagery.

Integration of existing GFC datasets could include:

- Integrate block allocation and roading plans from the Annual Operating Plans into the GIS. This would enable monitoring of compliance within TSA concessions.
- Timber tracking information for active TSA into the GIS to enable spatial representation of species and volume information.

Acquisition of satellite imagery to provide cloud-free coverage

- Building closer links with various space agencies and data providers: INPE in Brazil to better utilise free CBERS satellite data; Indian Space Research Organisation to better utilise available satellite data; JAXA and NASA to provide programmed collection over hotspot areas.
- Task Formosat imagery to acquire data from August 2008 to March 2009 to cover hotspot areas. GFC will be contracted to purchase all data containing ≤ 25% cloud cover. Control the acquisition process by using my-Formosat service.
- Investigate tasking DMC datasets (32 m resolution) to enable change detection to continue in 2009. Current terms and conditions for tasking require 22% non-refundable fee to be paid upfront and the remainder paid on successful delivery. Three acquisitions are attempted and imagery must be purchased if it contains <20% cloud cover. The minimum order is 160 x 160 km (similar extent as Landsat). At 2009 prices this equates to USD4200/scene. It is estimated it would cost USD60-70 000 to cover Guyana.