Feasibility of a Monitoring Programme for the Guiana Shield Initiative

V.T. Schut

NETHERLANDS COMMITTEE IUCN THE WORLD CONSERVATION UNION

Amsterdam 2004

GUIANA SHIELD GSI INITIATIVE

Schut, V.T. (2004). Feasibility of a Monitoring Programme for
the Guiana Shield Initiative

E-mail: schut@sarvision.com

Layout and cover by Edith Cremers
Produced by Dave Zwaan and Cas Besselink, NC-IUCN
Cover image: Vegetation hot spot over Suriname. Credit: Jacques Descloitres,
MODIS Rapid Response Team, NASA/GSFC.

The dark spidery blob shows the W.J. van Blommestein Lake (Brokopondo Lake) in Suriname. Also clearly visible are for example, Paramaribo (Suriname's capital), St. Laurent du Maroni, French Guiana (just east of the Marowijne River) and (on the back cover) a part of Guyana is shown.

The bright green streak near the lake is called a vegetation hotspot. The term implies that the reason for this distinct coloration is that this region's vegetation is hotter than the surrounding vegetation. However, this is not the case. This hotspot is actually a light phenomenon; light from the sun strikes the leaves on the vegetation at such an angle that light bounces off of them and directly into MODIS' eye, which creates the streak of brighter color.

ISBN 90-75909-13-6

Published March 2004
by the Netherlands Committee for IUCN
Plantage Middenlaan 2K
Amsterdam, The Netherlands
Websites: www.iucn.nl; www.guianashield.org

Printed in The Netherlands by Leeuwenberg

TABLE OF CONTENTS

PREFACE

With 25% of the world's remaining tropical rainforests, 15% of the freshwater reserves of the earth and an extremely rich and highly endemic biological diversity, the Guiana Shield eco-region is a key element in the global ecological infrastructure.

A map based on the consensus of more than 100 scientists, showing where the priorities for conservation of the unique biodiversity of the region are located, was published in August 2003. The process of producing the map began in August 2001 and was led by Conservation International, applying their priority setting methodology in partnership with the Guiana Shield Initiative based at the Netherlands Committee for IUCN and the UNDP offices in the region. The Priority Setting Workshop in April 2002 in Paramaribo, Suriname was the highlight of this process. It brought together biological scientists, socio-economists, indigenous communities' resource persons and many policy-makers of the region.

While having science-based priorities is an essential condition for guiding conservation policies, they constantly need to be checked against the most recent observations in order to make the necessary adjustments in policy process and to ensure it stays on the right track.

Here is where monitoring enters the picture and this is the reason why the Guiana Shield Initiative (GSI) is so very happy to present their report which proposes an advanced monitoring system for the Guiana Shield region.

The system would use both remote sensing techniques and ground truthing procedures; the scientists of the six countries of the region would work closely together with the local authorities and communities. The role of the local, often indigenous, communities with their intimate ecological knowledge is vital in this respect.

At the GSI monitoring workshop of May 2003 in Belém, Brazil, these two elements came together, with presentations by the Brazilian radar monitoring system of the Amazon (SIVAM, *Sistema de Vigilância da Amazônia*), by the scientific communities from all Guiana Shield countries and by the Global Forest Watch Programme of the World Resources Institute in Washington, DC.

The FORESEEN network (Forest and Remote Sensing Exchanges Network) started as an initiative from Valéry Gond, one of the participants of the GSI Monitoring Workshop and has received valuable contributions from the other participants. It will be tremendously helpful in setting up the more formalized system at a later stage (a summary of the Belém workshop with additional information from the six countries is included in the report).

We very much appreciate the willingness of SIVAM to share their unique methodology and expertise with the other countries of the Guiana Shield and also feel fortunate that we could engage the services of SarVision with their extensive experience in monitoring tropical rainforests to be the main author of this report.

Only with effective monitoring can a priority become a reality.

Major General (retd) Joseph G. Singh
Executive Director, Conservation International Guyana
Member Steering Committee, Guiana Shield Initiative

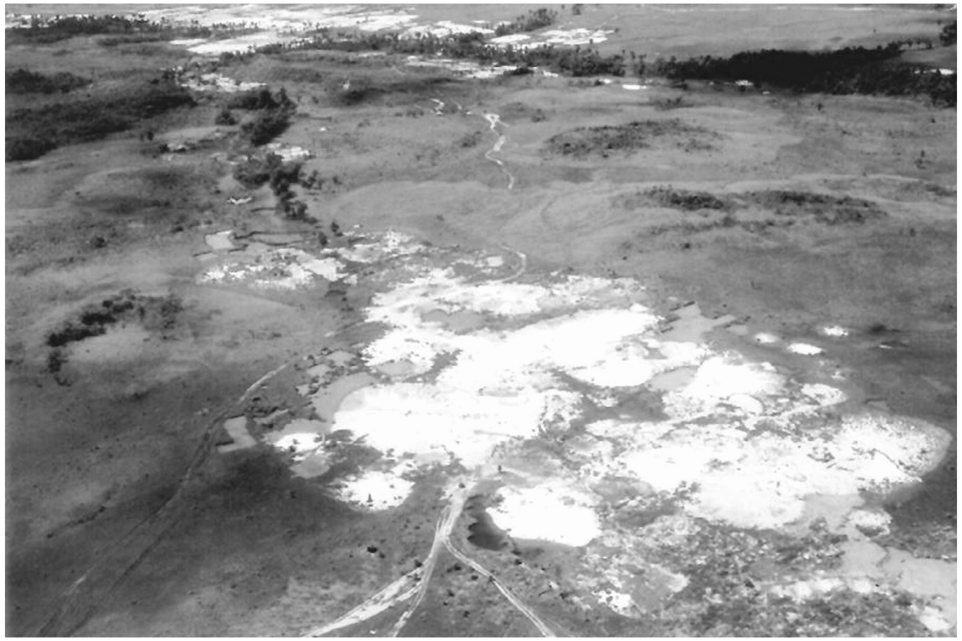
1

INTRODUCTION

The Guiana Shield region in South America, as defined by the participants of the Priority Setting Workshop in Paramaribo, April 2002, is the transboundary region that is bounded by the Amazon River in the south, the Japurá-Caquetá River to the south-west, the Orinoco and Guaviare Rivers to the north-west, the Atlantic Ocean to the (north) east, and the Serranía de Chiribiquete to the west. It covers parts of Brazil, Colombia, and Venezuela and the whole of Guyana, Suriname, and French Guiana. More than 25% of the world's tropical rainforests are located in this area, of which 80-90% are still in pristine condition. The area is known for its high rate of biological endemism, its great variety of ecosystems and large cultural diversity.

Though deforestation rates are still largely below those in South East Asia, human induced forest degradation remains a threat to the Guiana Shield region, with illegal mining, forestry activities and cropping as its main causes. The Guiana Shield Initiative (GSI), a project currently funded by the Ministry of Foreign Affairs of the Dutch Government, is an ecoregional project with the aim of setting up a regional compensation system for environmental services, such as the regulation of hydrological cycles and climate, as well as the preservation of biodiversity. The GSI is trying to preserve one of the ecologically most important and unique areas of the earth.

In order to do so, the countries of the Guiana Shield need accurate and up-to-date information about the state of preservation of the Guiana Shield region in general and the identified areas of importance in detail – a greater part of which could be fulfilled by the development of a suitable monitoring system for the region based on Remote Sensing methods. The aim of this working document is to outline the approach to monitoring that could be taken when contracts are established between local ecosystem managers and the Guiana Shield regional financial mechanism. In this report, information needs, feasibility and cost of monitoring at a regional level are identified and a proposal for a multi-scale monitoring system is made. Results of the Priority Setting Workshop (2002) and the GSI Monitoring Workshop held in May 2003 will be referred to when applicable.



Impact of mining in the Guayana area of Venezuela. Photo: Hemmo Muntingh

2

MONITORING GOALS AND CHALLENGES

2.1 Monitoring targets

Preserving the current ecological richness of the Guiana Shield region means two things: firstly, the ability to frequently check the Guiana Shield region for the occurrence of ecologically threatening activities, such as forest cutting, illegal cropping, illegal mining, etc., to identify areas under threat. Secondly, more specific in pertaining to the goals of the GSI, the ability to verify at certain times that established conservation contract duties have been fulfilled, such as maintenance of current carbon storage, preservation of biodiversity by maintaining important ecosystems and guarding river water quality and important watershed areas in order to maintain a healthy hydrological cycle. This means detailed inspection of previously identified areas on a regular basis, perhaps once or twice per year.

Additionally there are the areas that recently have been identified as areas of importance during the 'Guayana Shield Conservation Priority Setting Workshop' held in Paramaribo, Suriname, in April 2002, and was organised by Conservation International, NC-IUCN/GSI, and UNDP[1]. These priority areas were determined because they are of high ecological importance (i.e. unique ecosystems, areas with a very high biodiversity) or because they have been identified as being under pressure from socio-economic activities, or a combination of these. These 41 priority areas cover 1.2 million km^2 of which 512,000 km^2 falls within conservation areas. Based on these priority areas and other criteria, the GSI will eventually set up contracts with local ecosystem managers for the provision of ecosystem services. For these areas at least a detailed investigation will be necessary and probably an update once or twice a year is desirable.

2.2 Relating monitoring targets to remotely detectable features

Not all of these threats or environmental indicators can be detected or followed directly using airborne or space borne monitoring. Characteristics that can be measured by monitoring sensors usually relate to land cover type, inasmuch as they only measure the amount of reflected light or radar waves by the earth's surface. The wavelength characteristics of these reflections (i.e. the 'colour' and brightness of the resulting image pixels) are influenced by some physical (radar)

[1] For the results of the 'Guayana Shield Conservation Priority Setting Workshop' see the workshop report: Conservation International, GSI/NCIUCN and UNDP, 2003. Conservation Priorities for the Guayana Shield: 2002 Consensus and wall map: Guayana Shield Conservation Priorities 2002.

or molecular/atomic (light) characteristics of the part of the earth's surface that encompasses the current pixel. This means that forest cutting, plantations (concessions), cropping areas, mining and similar activities that occupy enough space will be visible using remote sensing techniques, but poaching, carbon absorption, water quality and biodiversity will not be directly visible, no matter what sophisticated high resolution system is used for these problems, indirect indicators must be found. Many of these non-detectable features are related to human activities, which usually imply a certain degree of human impact on land use (settlements, roads, small agricultural fields, etc.) large enough to be seen by remote sensing techniques. Carbon storage can be related to forest and eventually peat soil conservation. Biodiversity must first be confirmed by field research, but after this has been done, the identified biodiversity hotspots can be monitored using remote sensing for changes in land cover.

In order to check the possible illegality of certain land cover changes, additional datasets will be needed, like concession area and reserve boundaries. When considering water quality, river water sediment increase will be visible when using an appropriate remote sensing system. Chemical water quality however, such as possible mercury pollution by mining, can only be detected by direct measurement. On the other hand, the main processes from which these threats stem are usually easily visible using common remote sensing techniques; intensive mining, increasing agricultural activities and deforestation all imply a possible increase in the pollution of local and downstream freshwater resources with chemical pollution and more sediment, or both.

When monitoring specialized environmental indicators (*e.g.* biodiversity), collaboration with local inhabitants will be the best way to obtain accurate and current information. The Venezuelan NGO ACOANA (*Asociación Venezolana para la Conservación de Areas Naturales*) is already using this approach in collaboration with the Global Forest Watch programme of the World Resources Institute.

2.3 Creating an all-weather system

The total area to be monitored is large, and climatological characteristics are not ideal for frequent monitoring using traditional techniques based on visual or infra-red light reflection: areas in dense rainforest are often covered with clouds or haze, preventing visibility of these areas for months or even years on end. The use of a combination of different sensors will solve this problem. A radar sensor can be used independent of the weather conditions because radar can look through clouds. A sensor using 'normal' light (visible and infra-red frequencies) is not able to penetrate clouds and haze, but usually gives more and easier to interpret information about current land use. A combination of these sensors would be ideal; using the optical sensor accurate information about land cover

can be obtained, but can probably not be updated very regularly, while the radar sensor can produce a new map every time which perhaps does not contain all land cover information but will certainly suffice (may even be more suitable) for land cover change detection. This change detection can be done by using sophisticated algorithms to compare current and earlier remote sensing data and can be partly or fully automated. In this way, using two different sensors, accurate land cover map updates can be produced frequently regardless of weather conditions.

2.4 Tackling transboundary issues

As the Guiana Shield region comprises six countries, transboundary issues might arise in several stages of monitoring. Firstly, a large amount of baseline data will be needed from all of the Guiana Shield countries. Besides the fact that some countries might be somewhat hesitant about granting rights to use their data, data from different countries usually tends to be in different formats and geographic projections. This means that the GSI or a dataset managing organisation must check the several datasets for mutual consistency and eventually alter the data to build a solid basic dataset. Secondly, transboundary issues will play a role in the monitoring itself because countries could be reluctant to allow surveillance with (military) airplanes from abroad, e.g. the Brazilian SIVAM/SIPAM system, and data possession by and analysis in neighbouring countries. Although, according to SIVAM, military from the country being observed will be allowed to join the flight and data will be handed over directly to them after the flight. This eventual reluctance can partly be circumvented by using, when possible, existing satellite systems which have the right to operate internationally.

When very high detailed monitoring is needed, satellite systems will not suffice and countries need to agree on some kind of territorial fly over, including the sharing of data rights, especially because Brazil appears to own a very suitable (and probably the only one in the region) airplane remote sensing system. If data processing cannot be centralized due to national policy reasons, processing may have to be done in several countries separately. The GSI must make sure then that the methods and quality of processing is the same regardless of the place of processing in order to maintain a constant high quality output and to obtain data and statistics that are mutually comparable. Thirdly, the possibilities for follow up (i.e. legal actions) might differ between countries. This, contrary to the former issue, might suggest a separation by nation of high detail data processing, to facilitate a country-specific follow-up. When data processing is done centrally, a smooth follow-up in the national legal context could be guaranteed by establishing agreements to this end between the GSI and national governments.

GSI monitoring workshop, Belém (Brazil), May 2003. Photo: Dave Zwaan

3

IDENTIFICATION OF INFORMATION NEEDS

The area of the Guiana Shield is vast, approximately 2.5 million km^2 spread over six countries, the ecosystems are diverse and current knowledge about the area is variable. (For gaps in biological knowledge, see the earlier mentioned outputs of the Priority Setting Workshop of April 2002.)

Successful protection of the Guiana Shield region will depend on access to the right information at the right time. Both the kind of information needed, and the timeliness of it, depend on the specific goal and the area involved. Therefore, information needs can roughly be split up in three kinds: baseline maps, large-scale overview maps, and detailed maps of areas of importance.

3.1 Baseline information

Good quality topographic maps, altitude maps, administrative maps and/or databases (GISs: Geographic Information Systems) are indispensable for ecological monitoring in combination with law enforcement. Accurate base maps can function as a spatial reference; other information sources, like administrative maps or remote sensing images should be linked or linkable with these maps.

Accurate altitude information is of importance for watershed research and water quality monitoring, ecological zoning and habitat identification and monitoring. Moreover, the eventual use of satellite-based radar remote sensing requires additional altitude data for pre-processing of the satellite data and the accuracy of other (non-radar) satellite systems will increase considerably when altitude data can be added. In the case of river water quality monitoring, it is crucial to have height maps that are accurate and consistent with the topographic maps, thus enabling the user of the system to track down the possible sources of pollution and eventually start a lawsuit against the polluting company. Furthermore, this altitude information will allow the user to forecast possible impacts of water pollution and take precautions against it.

Political and administrative data, notably (when applicable) country, province and district boundaries, official land use planning including nature reserve areas and concession area boundaries are required for effective monitoring and protection. These data should match the available topographic maps and be of indisputable quality. Eventually, the combination of these data with the processing results of the remote sensing data should be of such quality that it can stand up in court, e.g. data sources should be well-known and trustworthy and the processing chain should make use of validated algorithms.

These data, especially the altitude data and administrative boundaries, should preferably be available in digital format, which will enhance the possibilities of combining these data with (processed) satellite data, facilitating the generation of more conclusive and accurate reports. Moreover, the availability of these data in digital form will in the end enable the monitoring system to be partly automated, ensuring up-to-date of reporting and constant quality. Furthermore, the respective national datasets should be standardized to allow linkage or merging into one Guiana Shield-wide dataset.

During the GSI Monitoring Workshop in Belém, Brazil, in May 2003, it became clear that the availability of accurate and up-to-date baseline maps, like topographic maps and altitude maps, varied strongly between countries. If a functioning monitoring system for the entire Guiana Shield area is to be built, these discrepancies in geographic baseline information should be eliminated. This is the foundation of an ecological monitoring system. It should contain all data that are not to be monitored and that do not change (or not much) on a day-to-day basis, but to which the ecological monitoring information can and should be linked geographically in order to enable solid reporting and eventual timely contract duty enforcement by law.

3.2 Regularly updated large-scale overview maps

The Guiana Shield area is too large to be fully monitored at high temporal and spatial resolutions. Furthermore, the variety of ecosystems and monitoring goals require a more specific approach per identified area of importance. Different monitoring information needs may require the use of different sensors and processing techniques. To have all this detailed information for the entire Guiana Shield region would be serious data overkill, not to speak of the enormous costs involved. However, some information might be needed for the entire region in order to be able to analyse region-wide processes and to identify current and possible future areas that are of interest for the GSI. This will be level 1 of the monitoring system; the detailed mapping and monitoring will be level 2 and builds on level 1 (though it is possible to do without level 1 and use other information sources as selection criteria for level 2 monitoring areas). At the first level, large-scale overview maps should be produced and updated regularly. These large-scale overview maps can be generated by a semi-automatic satellite based system. The necessary overview maps can be characterized by the temporal resolution, the spatial resolution and the ecological indicators that are to be measured.

While this first level does not focus on the monitoring of specific areas of interest which are under contract management for the provision of environmental services, a region-wide monitoring level is also essential for the GSI because it provides additional information for the selection of possible areas of interest. Furthermore, it might be of interest for many of the various stakeholders in the region. It is included because, from a remote sensing point of view, it complements the other levels of the proposed monitoring system by adding a true, region-wide, monitoring component (constant, consistent and timely data production and comparison) reflecting the eco-regional integrity of the Guiana Shield.

3.2.1 Temporal resolution

Large-scale overview maps should be updated frequently. For serious monitoring applications, a temporal resolution of three to six months should be envisaged, permitting reasonably fast identification of areas that are to be monitored in more detail. Hereby, equilibrium has to be found between the need for fast detection of threatened areas and the possibilities and limits of the available and affordable remote sensing systems that are suitable for this type of large-scale monitoring. Usually, several overpasses (e.g. images) of the satellite in question are needed to produce an image of usable quality due to persistent cloud cover (especially over tropical rainforests), meteorological influences, atmospheric and sensor noise, etc. An updating frequency of less than once per three months should be considered hard to achieve; less than once per month should be considered very hard. The benefits of more frequent updating might not outweigh the costs, both in money and in accuracy. Keep in mind that this seemingly long time between regular updates only applies to the overview maps of the entire region. Known areas of interest could of course always be mapped more frequently using more specialized systems, especially suitable for the ecology and monitoring goals for that respective area.

3.2.2 Spatial resolution

For large-scale overview maps, too much spatial detail means higher processing and archiving loads, producing data that is not really necessary for overview generation and threat detection purposes, thus needlessly increasing costs. On the other hand, too little spatial detail means the inability to detect smaller land cover changes, less accuracy of the regional statistics calculation and overview maps, and possible difficulties with accurately linking detected features with other, more detailed, geospatial data. A well-chosen spatial resolution helps to discriminate between objects that should be detected and 'noise': features that are too small to be of interest, that originate from processes that are natural (seasonal changes) or are harmless. Depending on available suitable sensors, sensor characteristics and data processing possibilities, suitable resolution for the Guiana Shield region overview maps could be between 1 km and 250 m. Good results have been obtained with a 1 km resolution monitoring system by SarVision B.V. in Indonesia which is mainly used for forest cover monitoring and soon be upgraded to 250 m resolution. Though forest cutting in the Amazon region tends to be slightly patchier than in Indonesia, experiences gained from this system could apply to the production of overview maps for the Guiana Shield region. It appeared that large-scale clear-cutting could be monitored using this system. Using a time series of images, even smaller scale forest degeneration is detectable. Due to the unique characteristics of the developed algorithm, the accuracy of this system tends to increase with time. For quick detection of smaller disturbances as would be of importance for the Guiana Shield region, a higher resolution like the mentioned 250 m might outweigh the costs of more expensive satellite data and a 16 times higher load on data processing and archiving. Applying a higher resolution than 250 m for the entire region would definitely not be worth its cost and probably be counter-productive.

3.2.3 Ecological indicators

Using remote sensing, be it space- or airborne, it is difficult or impossible to directly measure important environmental services such as maintenance of river water quality, carbon fixation and biodiversity preservation. Most of these however can be monitored indirectly because remotely detectable features like land cover type, changes in land cover type, and (to some extent measurable with radar sensors) biomass can give enough clues to function as the backbone of an environmental monitoring system.

Likewise, some of the threats that apply to the Guiana Shield region such as deforestation are more easily visible from space than others, like poaching. Of course it is possible to enhance a remote sensing monitoring system with other sources of information, notably from ground surveys. This, however, is not very easy in the case of a large-scale, highly automated and frequently updating system and might be of more value for small-scale detailed mapping or monitoring. Besides, there is usually one factor that encompasses all or most ecological threats: human impact. By defining some good indicators, it is possible to monitor the amount of human activity in an area and, thus, indicating a degree of ecological degeneration risk. Heavy human activity usually involves changes in land use (forest cutting, burning, converting forest to agricultural fields, etc.) and infrastructure (logging roads, illegal airstrips, villages). Most of these features can be detected using relatively simple satellite data in combination with some selective algorithms that enhance the difference between the natural state of the area and human impact indicators. This means that a system focusing on vegetation type, land use and land use changes will also allow for the identification of threatened areas that are not directly measurable using satellite data, such as forest thinning. Frequent mapping of land use and vegetation type will also allow for habitat monitoring (if combined with known habitat boundaries) or even potential habitat identification (if combined with knowledge about specific habitat characteristics that can be represented by measurable vegetation type and eventually other indicators like altitude or the distance to the nearest river).

Meanwhile, mining is not only an ecological threat because of the easily measurable landscape degradation, but also because of water pollution resulting from both large-scale industrial mining and the small-scale *garimpeiro* mining, with which the Guiana Shield as a whole is confronted. Maintenance (or restoration) of a healthy hydrological cycle is not only of ecological importance but also of general human importance because freshwater is one of the main resources of human life. Therefore, water quality is an important ecological factor that should be measured for all main rivers of the Guiana Shield region that might suffer from mining pollution[2].

Using satellite or airborne systems it is very hard to measure water quality directly, especially the chemical quality of the water. A satellite system can however play an important role in identifying mining areas – usually the main source of chemical river water pollution – and changes in land use that will probably generate an increase in waste water or run-off water with higher sediment loads. Currently available remote sensing systems cannot measure the amount of certain toxic substances in the water. Therefore, if a region-wide regularly updated overview of the quality of the river water is to be obtained and included in the Guiana Shield monitoring system, this should be accomplished by building a network of measuring stations (including the already existing stations) alongside the main rivers of the area.

In summary, most of the larger threats to the Guiana Shield region can be related to large-scale land use (change) and vegetation type (change) maps. A system that frequently produces updated land cover maps at a resolution of 1 km to 250 m would allow for land cover change analysis. Areas with large and/or persistent land cover change can be marked as areas of importance and eventual follow-up steps such as more detailed land cover analysis or investigations for possible contract management to maintain or restore environmental services, can be carried out. These land cover maps need to be linked to accurate baseline information, such as topographical maps and habitat maps.

Satellite imagery should not be relied upon to include water quality in the regional monitoring system. Therefore an additional measurement network is needed. Data from this network should follow the same course as the land cover (change) maps. Geographic linkage with topographic, altitude, administrative and ecological maps will allow for risk analysis, support tracing the source of the pollution and be of invaluable help when planning protective measures or legal action.

[2] For further reading on the subject of pollution, see chapter 4 of the GSI publication: *Hydrology in the Guiana Shield and possibilities for payment schemes* by Judith Rosales (December, 2003).

3.3 Small-scale detailed information

Detailed information will be needed in three possible cases:

- Land cover changes found in large-scale continuous monitoring give reason for more detailed investigation of an area, e.g. to find out the exact nature of the land cover changes and to assess ecological impact.
- An area that has been marked as an area of importance for continuous monitoring, either due to ecological importance and/or because it has been identified as a high risk area. Although this is not the direct interest of the GSI, several stakeholders in the region might want to monitor high risk areas independent of the existence of management contracts.
- An area that is under contract management where information about the area is needed to verify that the contracts are upheld.

These three cases differ mainly in frequency: in the first case, detailed investigation is ad-hoc (and thus mere mapping instead of monitoring). Depending on the results of the investigation (or on other decision parameters), an area can be classified as an area of importance and thus fit into the second category. Areas in the second and third category will be monitored in the strict sense of the word: the production of frequent and almost real-time updates of maps of these areas. For the second category, the frequency of updating is mainly defined by an assessment of the risk in combination with the ecology of the area involved. In case of lower risk, update frequency could be the same as of the low resolution system. Its main added value will then be in a higher timeliness and, more important, much higher detail (both in resolution and in land cover type discrimination). In case of high risk, a higher update frequency could be envisaged, allowing for a faster response. For the third category, which is most relevant for the GSI, the monitoring frequency will depend on the nature of the contract and the management measures that should have been taken and are to be controlled. An updating frequency of once or twice per year seems suitable.

Most of the information needed for small-scale monitoring could be obtained by generating the same kind of maps that are made by the large-scale system (e.g. land use and land use change maps), but with a higher spatial resolution and a better and more detailed discrimination of land cover types. Furthermore, in-field investigations, either by local inhabitants, reserve management, or national or regional fieldwork teams could be considered in order to add information that cannot be gathered by space- or airborne remote sensing systems. The latter option is the only one available in the case of water quality monitoring which cannot be done using normal remote sensing methods. For information about biodiversity and carbon sequestration specialised field surveys will be necessary because these cannot (or hardly) be measured using remote sensing. Once enough information about carbon sequestration and/or biodiversity for a certain area has been gathered, high resolution remote sensing monitoring will suffice in

most cases to detect changes in the measured situation. For areas that are classified as high risk areas for water pollution, additional baseline data production in the form of a more detailed altitude map (DEM) should be considered, insomuch as this will enhance catchment and water flow analysis.

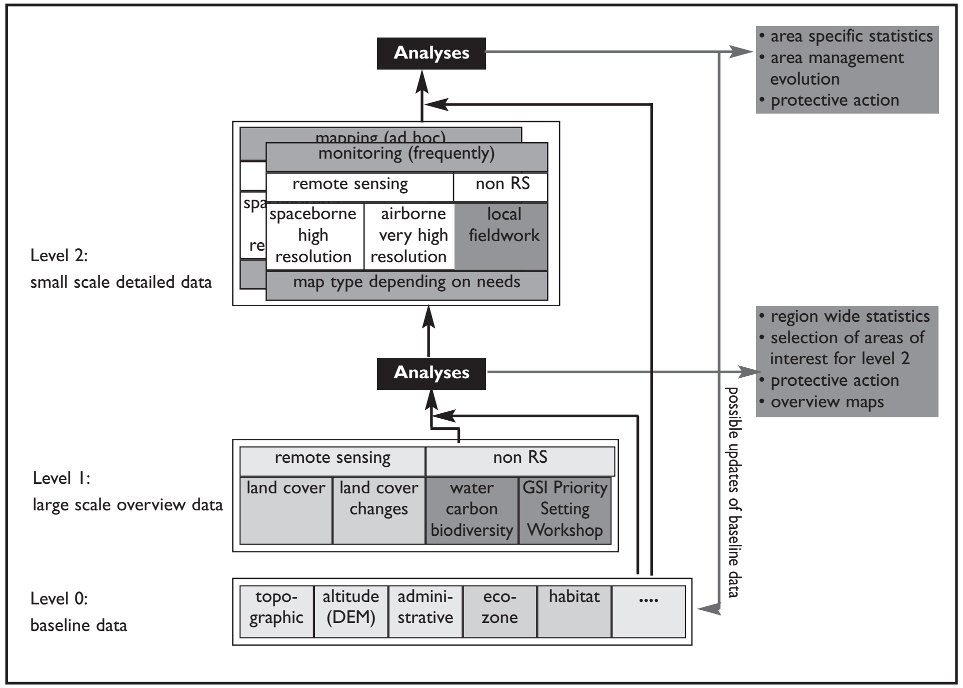
3.4 Summary of information needs: outline of a monitoring system

Many of the ecological risk factors can directly or indirectly be related to land cover and land cover change, both of which are easily mapped using (satellite) remote sensing. However, in-field measurements are required for the initial measuring of carbon sequestration and biodiversity. Once these have been established, remote sensing can usually deliver suitable indicators for the further monitoring of carbon sequestration and biodiversity. Chemical water quality can only be measured and monitored by measurements in the field.

Because of the huge area involved, a 2-level monitoring system is proposed, using a regional low-resolution overview level (level 1) and an area-specific high-resolution level (level 2). From a remote sensing monitoring point of view, this two-level approach will confine processing and data load, while gaining flexibility. The goal of level 1 is the frequent production of updated land cover and land cover change maps at a resolution suitable for detection of areas that are under environmental threat. This process should be largely automated. After processing and combining the level 1 data with baseline data, the identification of certain land use changes can lead to the decision to classify some areas as areas of importance that should be mapped or monitored at level 2. Areas that apply for level 2 monitoring could also be selected by other (non remote sensing based) mechanisms, like the Priority Setting Workshop.

At level 2, only areas that apply for more detailed investigation are mapped, once or, if needed, more frequently. The frequency, resolution and type of mapping should be decided on a per area basis, insomuch as different ecological characteristics, eventual environmental services to be provided by the areas management and possible ecological threats will require different approaches. Reasons for initial mapping of an area could be the first detection of possible problems or risk factors in level 1 in combination with a high environmental value of the area and eventual promising ecological management possibilities. Reasons for an area to classify for monitoring (frequent re-mapping) could be the confirmation of problems or risk factors at level 2 mapping or the verification of proper area management for areas that are under contract management by the GSI.

The quality of the maps and data produced at level 2 should be good enough to stand up in court when necessary. The baseline data should be accepted as of good quality and representing the true current situation. Processing of the remote sensing data should be done using validated algorithms (preferably previously published ones, e.g. in a scientific magazine.)



1. *Schematic outline of the proposed monitoring system for the GSI and the Guiana Shield region*

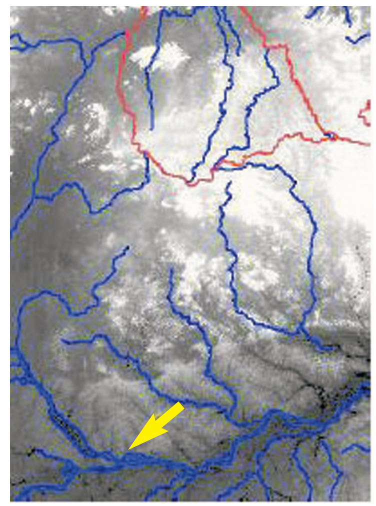
The structure of the monitoring system, including main data flows, is depicted in illustration 1.

4

CURRENT SITUATION OF MONITORING IN THE GUIANA SHIELD REGION

4.1 Status of baseline information for the Guiana Shield countries

The availability of the required baseline data for a functioning monitoring system for the Guiana Shield region differs strongly from country to country. Basic data like topographic maps seem to be available region wide, although the quality and mutual consistency (standardization) of these are questionable and need to be checked. For example, Guyana's most recent maps are thirty years old. These maps are inaccurate and riddled with mistakes. Availability of other data, like nature reserve boundaries, concession boundaries, etc. was compiled for the 'Guayana Shield Priority Setting Workshop'; Conservation International is preparing a list of these datasets which will shed some light on the availability and usability of these for monitoring purposes. Furthermore, the datasets gathered at the 'Guayana Shield Conservation Priority Setting Workshop' held in Paramaribo, Suriname, in April 2002 (which are mainly of ecological character) are available on CD-ROM[3].



2. *SRTM data overlaid with national borders (red) and main rivers (blue). The country in the upper middle is Guyana. The arrow points at Manaus. The altitude is shown as black (low) to white (high). This image has been made using only freely available data.*

During the monitoring workshop in Belém the lack of and need for good height maps (DEMs) was mentioned several times. Nevertheless, it is not advisable to begin gathering all possible height maps of the region because SRTM (Shuttle Radar Topography Mission) data for South America has recently become publicly available for only US$ 60.00 per DVD (it will probably fit on one or two DVDs). These data have a horizontal resolution of 90m and are very accurate in altitude. Moreover, they are available for the entire region as one dataset, which eliminates the chance of errors that can be introduced by coupling several national datasets. Illustration 2 gives an example of the new SRTM altitude data.

[3] CD-ROM, Conservation Priorities for the Guayana Shield, 2003 by Conservation International Foundation (CI), the Guiana Shield Initiative of the Netherlands Committee for IUCN (GSI/NC-IUCN), and the United Nations Development Programme (UNDP).

The accuracy and degree of standardization of the administrative data (province and district boundaries, reserves, concession boundaries, infrastructure) is yet unknown and should be investigated. If necessary, GSI should seek special permission from national governments to use these datasets. These data should be in digital form to allow overlaying with the level 1 and level 2 data for an accurate and fast response possibility.

4.2 Summary of existing monitoring activities in the Guiana Shield countries

If monitoring is defined as frequent and long term remapping the same area in the same way in order to detect changes on time, monitoring of (parts of) the Guiana Shield region currently is rare or non-existent. Only INPE (*Instituto Nacional de Pesquisas Espaciais*, Brazil's National Institute for Space Research) brings out a yearly update of the state of the Brazilian rainforests. Excellent research work was presented at the GSI Monitoring Conference in Belém, usually using Landsat imagery in combination with GIS data, but all of these refer to short-term mapping or investigation rather than monitoring. The work of Valéry Gond (French Guiana) comes closest to this strict definition of monitoring. Gond developed a methodology (similar to that developed at SarVision) using Spot Vegetation data for land use type mapping and eventual short-term monitoring. While these projects are extremely valuable and can deliver precious data about the ecological state of certain areas, they need to be translated into an operational monitoring system – they are of course already very relevant as a level 2 data source – which might certainly profit from these projects because the developed methodologies and algorithms could be used when designing the standard level 2 data production methods.

A brief overview per country of the existing monitoring related activities as presented at the GSI Monitoring Workshop held in Belém is given below.

4.2.1 Brazil

SIVAM/SIPAM (*Sistema de Vigilância da Amazônia/Sistema de Proteção da Amazônia*) is already partly operational and should be fully operational in 2005. The available airborne remote sensing sensors (see also section 4.3 for a more extensive overview of the possibilities of SIVAM/SIPAM) are currently in a testing/semi-operational phase and will be available for both Brazilian governmental as well as public (environmental) services. This system will also be used for environmental investigations. Use of the system for environmental mapping in other Guiana Shield countries becomes a definite possibility if agreed on by neighbouring governments. President Ulribe (Colombia) and President Chavéz (Venezuela) have already expressed their interest in using SIVAM in their respective countries.

INPE has developed its own GIS/remote sensing processing software. One of their projects is the PRODES project: Monitoring the Brazilian Amazon Gross Deforestation. In this project, which started in 1974, gross and yearly deforestation is monitored using Landsat imagery. Though processing of Landsat is more cumbersome than Spot Vegetation, and therefore the production of deforestation statistics by INPE is rather late compared to the proposed level 1 Spot Vegetation based approach, their accuracy might be better than the Spot Vegetation based products. The maps and statistics of Brazil produced by INPE might be a valuable addition to a GSI monitoring system.

IMAZON (*Instituto do Homem e Meio Ambiente da Amazônia*, Amazon Institute of People and the Environment) is conducting research projects with the objective of fostering the sustainable use of natural resources in the eastern Amazon and tries to promote alternative, more sustainable approaches to resource use. In collaboration with World Resources Institute/Global Forest Watch IMAZON produces maps of logging pressure upon protected areas.

IBAMA (*Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis*, Brazilian Institute of the Environment and Renewable Natural Resources) focuses on deforestation in national parks and reserves. They hope to work closely together with SIVAM. During the GSI Monitoring Workshop held in Belém, IBAMA expressed the need for more detailed maps with a scale of 1 to 100,000 instead of the currently available 1 to 250,000.

4.2.2 Colombia

Illegal crops and roads are considered the main problem for the Colombian rainforests. Instituto Humboldt has developed a model to create an ecosystem map of Colombia, which also gives information about the ecological degradation using their biodiversity indicator pilot system. Socio-economic aspects were taken into account and they also want to investigate the possible effect of political actions. While investigating the possible effects of political actions, this system takes socio-economic aspects into account. Follow-up with monitoring is envisaged. Therefore the Institute has created the Environmental Exploration and Monitoring Group (GEMA, in Spanish). GEMA will coordinate expeditions and field trips to poorly known or important biodiversity areas and has an extensive database of the work undertaken at the Chiribiquete National Park which is one of the highlights of the Guiana Shield.

A proposal to integrate Colombia in the landscape monitoring network of the GSI in the next phase has been developed by Dolores Armenteras and Milton Romero, both GIS researchers at the Humboldt Institute.

4.2.3 Venezuela

In Venezuela ACOANA (*Asociación Venezolana para la Conservación de Areas Naturales*), a research NGO working with Global Forest Watch of the World

Resources Institute, focuses on monitoring with indigenous people. Currently, mammal distribution and food security are looked at and studying the malaria problem is intended. Because malaria is related to the habitat of the malaria mosquito which again is related to local ecological and hydrological circumstances, GIS and remote sensing techniques could be used to gain insight into the relationship between land use/management and malaria.

World Resources Institute/Global Forest Watch has published in 2002 a report on the state of the Venezuelan forest: *The State of Venezuela's Forests: A Case Study of the Guayana Region.*

Contacts between the Venezuelan Ministry of Foreign Affairs and Brazil about possible integration of Venezuela in SIVAM have been established. Though the main goal of this integration may be non-environmental, Venezuela might as well make use of the full environmental monitoring possibilities of SIVAM.

4.2.4 Guyana

GINRIS (Guyana Integrated Natural Resources Information System) is a consortium of Governmental Agencies and NGOs that has a central database of digitised information (GIS) on natural resources (forest types, soil types, etc.) and infrastructure of Guyana. Sharing of this information however is limited to members of the consortium and permission has to be sought from the Government of Guyana by others wishing to access such information.

The GIS techniques in Guyana (at GINRIS) are very recent and were funded initially by donor, mainly German, capital. The State has since taken up the funding responsibilities. The lack of good baseline data is the major problem. The maps that GINRIS are using are thirty years old. Decision makers are mostly unfamiliar with the usefulness and utilisation of GIS techniques in development planning, monitoring and enforcement. This is an inhibiting factor which needs to be addressed through training and capacity building. There is consequently only limited monitoring taking place and this is mainly carried out by the Guyana Forestry and the Guyana Geology and Mines Commissions.

The Iwokrama International Centre for Rain Forest Conservation and Development which manages the Iwokrama Forest in central Guyana has developed an operational GIS. This includes information on the forest and neighbouring areas. It has been used in community resource mapping, road management planning and ecotourism development. Initial prototype spatial models for Greenheart distribution and tree growth were also developed, in addition, to having examined the application of satellite radar for the delineation of seasonal under-storey flooding of the forest (for further information we refer to the Iwokrama summary report 1998-2002, which the GSI has funded).

River pollution by mining (bauxite, gold and diamond) through poor management, monitoring and enforcement practices that lead to a build up of suspended solids and leaching of effluent (such as occurred in the Omai Gold Mines Ltd disaster in 1995), illegal mining, chain saw logging, wildlife poaching and other anthropogenic disturbances, such as deliberately set fires in the savannah grassland areas are identified environmental problems.

The transboundary nature of the narcotics trade, together with gold and diamond smuggling activities, have spawned the development of illegal light aircraft landing strips, particularly in remote areas of the hinterland. These are difficult to detect and are discovered more by chance than by deliberate monitoring mechanisms.

4.2.5 Suriname

CELOS, the Centre for Agricultural Research in Suriname, has a GIS and Remote Sensing division which supports NGOs with maps and interpreted satellite data and carries out field work.

Informal discussions about SIVAM-Suriname participation have already taken place. Although initially this participation is probably not meant to focus on environmental monitoring, once established it could be extended to include environmental monitoring.

Identified problems are related to food security, land degradation, and logging. Maps are relatively recent (2000) but updates are needed. Especially for the Central Suriname Nature Reserve (1.6 million ha.) and the Sipaliwini Nature Reserve frequent data updates are important; SIVAM could play a role in this. CELOS is interested in becoming a member of SIVAM's User Centres network.

4.2.6 French Guiana

At CIRAD (*Centre de coopération internationale en recherché agronomique pour le développement,* French Agricultural Research Centre for Developing Countries) a good approach has been developed for the processing and classification of Spot Vegetation images to generate land cover and land cover change products. Several maps of French Guiana and neighbouring countries have been produced. The approach is similar to the method developed by SarVision to monitor Indonesian forests and could probably be used as a basis for level 1 processing.

4.3 Evaluation of the possible role of SIVAM/SIPAM

Brazil has developed, as part of their SIVAM/SIPAM system, a very high resolution airborne mapping system which could be used as part of level 2 of the monitoring system when there is need for very high resolution investigation of an area.

SIVAM and SIPAM are described as follows by the Brazilian Government:

SIVAM: Consists of the infrastructure of technical and operational resources (sensors of various types such as fixed and mobile radar, stations for gathering environmental, weather and other data) aimed at collecting, processing, compiling and providing data that are of interest to the organizations that make up SIPAM (public institutions within the municipal, state and federal structure, such as universities, agencies for environmental protection and the prevention of illegal activities, among others).

SIPAM: Consists of the systemic organization whose links are the various federal, state and municipal agencies that carry out governmental activities in the Amazon Region and whose objective it is to integrate, evaluate and provide data needed for the performance of general and coordinated activities in the Amazon Region in order to enhance the outcomes resulting from their implementation.

Several components of SIVAM could be useful for a Guiana Shield monitoring system:

- an airplane remote sensing system that consists of a Multi Spectral Scanner (MSS), a Synthetic Aperture Radar (SAR), and a Optical and Infra-red Sensor
- a water monitoring network consisting of measurement points including the relevant communication infrastructure
- 150 'portable units' and 150 additional 'vehicle units': fieldwork suitcases that enable an on-line connection with the SIVAM/SIPAM network
- several User Centres where SIVAM users have access to SIVAM data and software

These will be briefly described and their potential use as part of the Guiana Shield monitoring system will be discussed in the following paragraphs.

4.3.1 Multi Spectral Scanner (MSS)

This instrument has 50 spectral bands in the visible and middle infra-red region. The looking angle is 90° (looking exact vertically downward), swath width angles are –45° to 45°. A 31-band mode and a 11-band mode (with band frequencies compatible with Landsat bands) also exist. The resolution depends on the flying altitude and speed. Maximum resolution is approximately 1.1 m when operating at very low altitude and speed. Normal operation resolution is around 6 m.

This sensor is suitable for very detailed mapping, both spatial and spectral. Many different types of land cover can be discriminated because of the high spectral resolution. It will however suffer from cloud cover, haze and smoke.

4.3.2 Synthetic Aperture Radar (SAR)

The SAR sensor operates at 2 different bands (L-band and X-band), each with its own specific detection characteristics. The combination of these bands will allow for a better feature discrimination such as differing between two kinds of vegetation. These 2 bands can operate fully independently at the same time. The X-band system is single pass interferometric, which means that it is able to generate very accurate altitude maps (DEMs): the maximum horizontal resolution is 3 m with a vertical (i.e. height) resolution of 2-5 m. The L-band radar is fully polarimetric (HH, VV, HV, and VH polarizations) which means a considerable enhancement in land cover type discriminating capabilities and better possibilities to relate radar data to biomass figures (with some additional fieldwork). Both systems can operate at 3 swath widths (the width of the image strip generated by one flight) with their respective horizontal resolutions: 20 km swath width with a resolution of 3 m, 40 km with a resolution of 6 m and 120 km with a resolution of 18 m. Besides this, the X-band system is able to map a small area of 1.5 x 1.5 km^2 with a resolution of 1.8 m by automatically focusing a longer time on this area: the so called 'spot imaging mode'. During this mode normal continuous X-band mapping is disabled. This spot imaging mode will probably not be of much use for normal monitoring purposes.

The SAR instrument is very suitable for high resolution mapping or monitoring purposes due to its all weather usability. In contrast with optical sensors which are working in the visible or infra-red spectrum, radar sensors are not hindered by clouds, haze or smoke. Therefore this way of mapping has a great advantage over other methods because the possibility of mapping is not dependent on weather conditions. Correct interpretation which makes full use of the capabilities of these instruments is a little more difficult (and less common) than interpretation of visual light or infra-red imagery and should, therefore, be done by a team of experienced and well-trained people.

4.3.3 Optical and Infra-red Sensor (OIS)

The OIS consists of an infra-red video camera with a narrow, medium, and wide field mode, and a colour video camera with zoom function. Vertical movement ranges from 30° to –120°, horizontal movement is unlimited (360°). The purpose of this instrument is mainly tactical and, therefore, of limited value for a monitoring system. It might however be possible to gather additional evidence to be used in court. For a judge, a video is simply easier to interpret than a radar image or land cover change map.

4.3.4 Water Quality Measurement Network

Brazil already has a quite widespread water quality measurement network which measures some important, though not very specific, indicators for river water quality. These sensors are linked with a nation-wide communications network so data can be easily transferred to processing facilities and can be accessed from many places. The sensors would probably need enhancements, to measure important ecological indicators. This network could function as a blueprint for other Guiana Shield countries to build their own water quality monitoring network or it could be integrated in a Guiana Shield wide network by extending it into countries lacking any water quality monitoring network and joining already existing networks elsewhere in the Guiana Shield region.

4.3.5 Portable Units

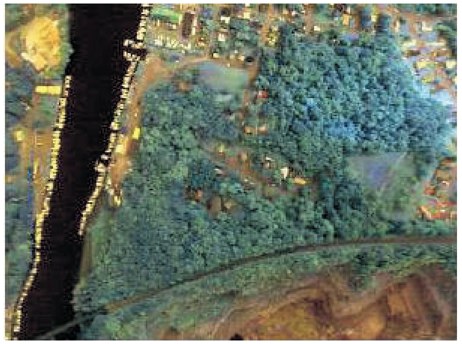
SIVAM/SIPAM has 150 portable units which are suitcases with an integrated computer, GPS, and wireless network connection to the SIVAM/SIPAM network. Additionally, there are 150 vehicle units. These units are used in the field to directly enter data into the computer network and to communicate with base stations or other portable units and share existing data. This functionality might also be of use for the Guiana Shield monitoring system if additional fieldwork is necessary in level 2 to obtain very precise data or data that cannot be seen from space or air.

4.3.6 Conclusion

The SIVAM/SIPAM system has good potential for monitoring in the Guiana Shield region. For water quality monitoring, the main infrastructure in Brazil already exists and could be copied by, enlarged into or linked to other Guiana Shield countries. The airplane based remote sensing instruments offer good possibilities for very high resolution mapping. For continuous monitoring of areas however this system might be a bit too sophisticated and processing and archiving the large amounts of data that these sensors produce (approximately 1.5 MB per km^2) will be relatively expensive depending on available expertise and capacity and on the specific goal of the monitoring, which can vary from area to area. The actual data acquisition is not really expensive compared to similar commercial products: approximately US$ 1.2 per km^2. An easier and cheaper solution could be found in high resolution monitoring using existing satellite systems, preferably also using a combination of radar and visible/infra-red sensors. The SIVAM airplane remote sensing system could then be used when a very high resolution is needed, or when investigation of an area is needed as soon as possible.

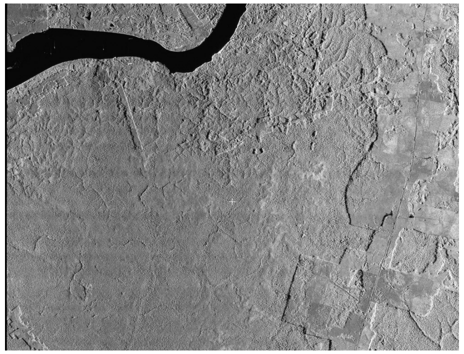
4.3.7 Examples of SIVAM/SIPAM remote sensing images

3. True colour image from the Multi Spectral Scanner.

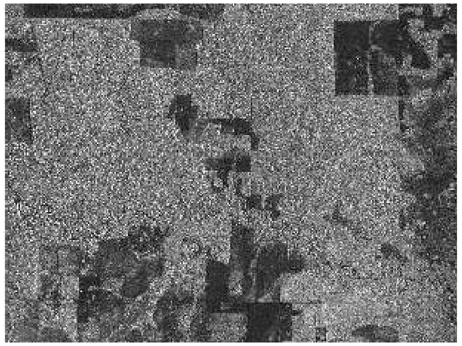


4. False colour composite from the Multi Spectral Scanner.

5. Another false colour composite from the Multi Spectral Scanner.



6. Radar image from SIVAM/SIPAMs SAR instrument.



7. More detailed image from the SAR. Note the visibility of the agricultural fields.

8. False colour image made from different polarization channels from the SAR instrument. Multi-polarization images like this one offer great benefits compared to single-polarization SAR images (like image 7.), because much better feature discrimination is possible. Several landscape types that cannot be discriminated from each other on single-polarization images, can clearly be distinguished on multi-polarization images.

5

PROPOSAL FOR AN OPERATIONAL MONITORING SYSTEM FOR THE GUIANA SHIELD REGION

5.1 Baseline data

A geographical database of baseline data must be built before the monitoring system can become fully operative. These data should be of unquestionable quality because they could be used to generate lawsuit documentation, e.g., by combining land cover maps with administrative boundary data. When several versions of certain datasets appear to exist, GSI data must be such that it is considered the only valid dataset. To acquire this level of quality, GSI must closely work together with the national governments involved. The team that is going to gather and maintain these data must consist of experienced GIS and remote sensing engineers and people that have a good knowledge of the region and its politics concerning (administration of) land use rights, nature conservation, etc. The dataset should consist of the following items:

5.1.1 Administrative boundaries

GIS data of country boundaries, province and district (when applicable) boundaries for each country involved must be available, as must data like towns, rivers and water bodies and infrastructure. These will probably be obtainable from national governments in digital or in paper format. If they are received in paper, they should be digitized to allow GIS functionality and combining with remote sensing data. GIS data of land use planning, mining and forestry concession areas, nature reserves etc. for each country involved is needed for analysis of the remote sensing data. These data should also be available from all respective governments.

Note that Conservation International, as a result of the Priority Setting Workshop, has built a list of available datasets and their usability[4], although for the above mentioned data not many problems regarding availability are expected. Datasets should however be checked for standardization and mutual consistency because they eventually are going to be used as one region-wide dataset.

5.1.2 Altitude data

A region-wide altitude dataset must be assembled from the recently available SRTM 90 m (3 arc second) resolution data. These can be downloaded from the Internet manually in small tiles. This data can be ordered for the entire area

[4] CD-ROM, Conservation Priorities for the Guayana Shield, 2003 by CI, GSI/NC-IUCN, and the (UNDP).

directly from the United States Geological Survey for US$ 60.00 per DVD. The Guiana Shield region will probably fit on one or two DVDs. These data could be converted to a usable format for the GSI baseline dataset in order to produce several useful derivations such as contour line maps, slope maps and watershed boundary maps.

5.1.3 Additional datasets

Several other datasets could turn out to be useful for classification of land cover, habitat identification and monitoring, ecological risk assessment, etc., for example, soil maps, habitat boundaries of threatened species or ecological zonation maps. Datasets like these would certainly add extra value and possibilities to the baseline dataset, especially concerning environmental issues like habitat or biodiversity monitoring. Many of these datasets are available on CD-ROM as a result of the Priority Setting Workshop of April 2002.

5.2 Level 1 data production

Data production at level 1 should be stable over a long period, weather independent and require relatively little labour. Level 1 products would probably not deliver too much detail, but should suffice to effectively distinguish between main land cover types (from an ecological point of view) and detect important changes. Due to the necessity of all-weather capabilities, a system that is a combination of visual/infra-red (suffering from cloud cover but easier to translate to land cover types) and radar (penetrates the clouds) is proposed. A comparable large scale monitoring system of this sort has been built by SarVision for Indonesia which could be used as a model for the Guiana Shield region system. Valéry Gond from CIRAD (French Guiana) has developed a land cover mapping algorithm that is based on data from the same satellite sensor using a slightly different processing algorithm.

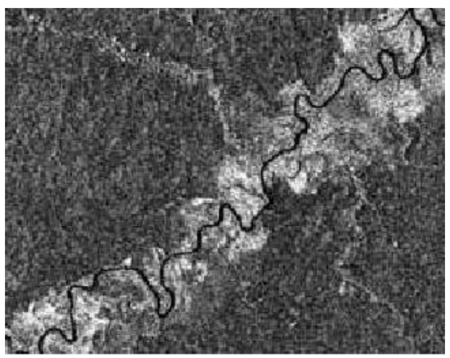
The Indonesian system is currently based on Spot Vegetation S10 data which have a spatial resolution of 1 km in 4 spectral bands. The data suffer from cloud and haze because the spectral bands lie in the visual and infra-red range. A special algorithm has been developed to aggregate one year of data into a fully cloud-free contrast enhanced product that can easily be classified. An update is made every three months. The Indonesian system will be upgraded soon to a spatial resolution of 250 m using MODIS data which also delivers much higher spectral detail resulting in a better discrimination of more land use types. To ensure a higher spatial accuracy, the system will be enhanced by adding ENVISAT ASAR Global Monitoring Mode radar data which will add real time cloud-free land cover information every six days and thus eliminates the need for one year of Spot Vegetation data to compose a cloud free image.

Currently data acquisition is not very expensive because a concession has been made: Spot Vegetation S10 datasets are put on the Internet when three months old; one can download these sets then for free. This means that the system is always at least three months behind, or even more for areas that were often covered with clouds during the last months (because then older information will be used for these areas). If real time data production is not necessary, this can be a cheap basis for a level 1 monitoring system. It is, however, relatively inexpensive to obtain recent S10 data (approximately US$ 335 per dataset -each 10 days- for the Guiana Shield region).

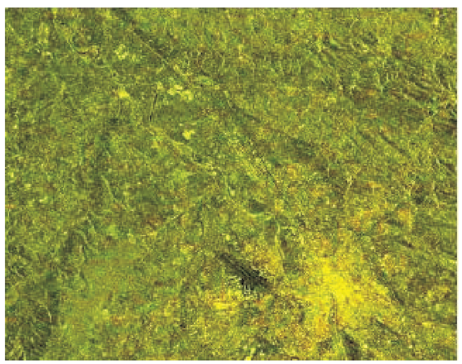
A comparable system is proposed for the Guiana Shield region. The goals and circumstances of the existing Indonesian monitoring system and the envisaged Guiana Shield monitoring system are comparable; therefore a lot of time and money can be saved by using existing knowledge and local capacity just like SarVision does in Indonesia, where a local NGO can carry out the data processing. Furthermore, this would make statistics for these two main rainforest areas on earth compatible.

5.3 Level 2 data production

Data production on this level will usually have a more ad hoc and diverse character depending on the area to be mapped or monitored and the specific mapping or monitoring goals.



9. One of the first ASAR images, showing forest loss (probably due to agriculture) alongside the Rio Mirit, a sub-stream of the Rio Negro. Horizontal image spans approximately 11 km. Resolution is 25 m, comparable with ERS. © ESA.



10. High resolution (30 m) radar image from the ASAR sensor (image scaled down). The colours are created by combining HH and VV polarization, which increases land cover type discrimination compared to non-polarization radar imagery, like ERS and JERS. The yellow part in the lower right is the city of Toulouse, France. © ESA.

The use of ERS satellite radar data and its successor ENVISAT is proposed for regular weather independent monitoring of the determined areas of importance.

Regarding ERS, a new image is taken every six weeks, with a resolution of 25 m. Implementation of the ‘Mawas Monitoring System’ by SarVision for the Mawas reserve, Kalimantan (Indonesia) has proved that this kind of data suffices for regular forest monitoring. Radar data is weather independent ensuring a real update frequency of six weeks. Data of a longer time span can be merged to increase land cover type and change classification if an update every six weeks is not necessary. In addition, Landsat TM scenes (when available without too much cloud contamination) or imagery of other high resolution optical satellite sensors (like MODIS or MERIS) can be used for validation and to add extra information for the areas to be monitored if sufficiently cloud-free images can be obtained.

It is, however, not likely that many suitable optical images will be available per year due to the cloudy nature of rainforest areas. In the near future, high resolution radar data from the ALOS PALSAR instrument or the high resolution modes of the ENVISAT ASAR instrument (see illustration 10) could be substituted for the ERS data. The quality of these data is higher than that of ERS, processing will be easier and updates will come more often (about once a week). The added interferometric and polarimetric functionality will also enhance the accuracy of the land cover classifications. However, as these instruments are new or not operational yet, implementation of the monitoring system could start with ERS and merge in ASAR or PALSAR data later.

Sometimes higher resolution mapping of a certain area may be needed or a faster response than the six weeks maximum update time for ERS/JERS data. The SIVAM/SIPAM airborne remote sensing system could be useful in fulfilling these needs. It is capable of generating very high resolution radar in 2 bands, interferometric and polarimetric, thus ensuring very good altitude and vegetation mapping and very high resolution visible/infra-red images, the latter with up to 50 spectral bands. The combination of these will ensure an almost unprecedented level of spatial and spectral detail (i.e. land cover type discrimination).

Ground surveys must be conducted for obtaining information that cannot easily be seen from air or space. Also, local inhabitants can provide a lot of valuable information and, if possible, should be included in the standard information gathering procedures. Setting up fixed field stations in local villages could greatly facilitate the coordination of field trips and communications with local inhabitants for areas that are marked as area of importance. The use of SIVAM/SIPAM mobile units will ease data collection and intercommunication during the field surveys if computer network access is available for these stations.

Field surveys will be necessary while setting up the monitoring system to collect ground truth data needed to develop and calibrate the land cover type classification algorithms, and to validate the results.

5.4 Data processing and integration

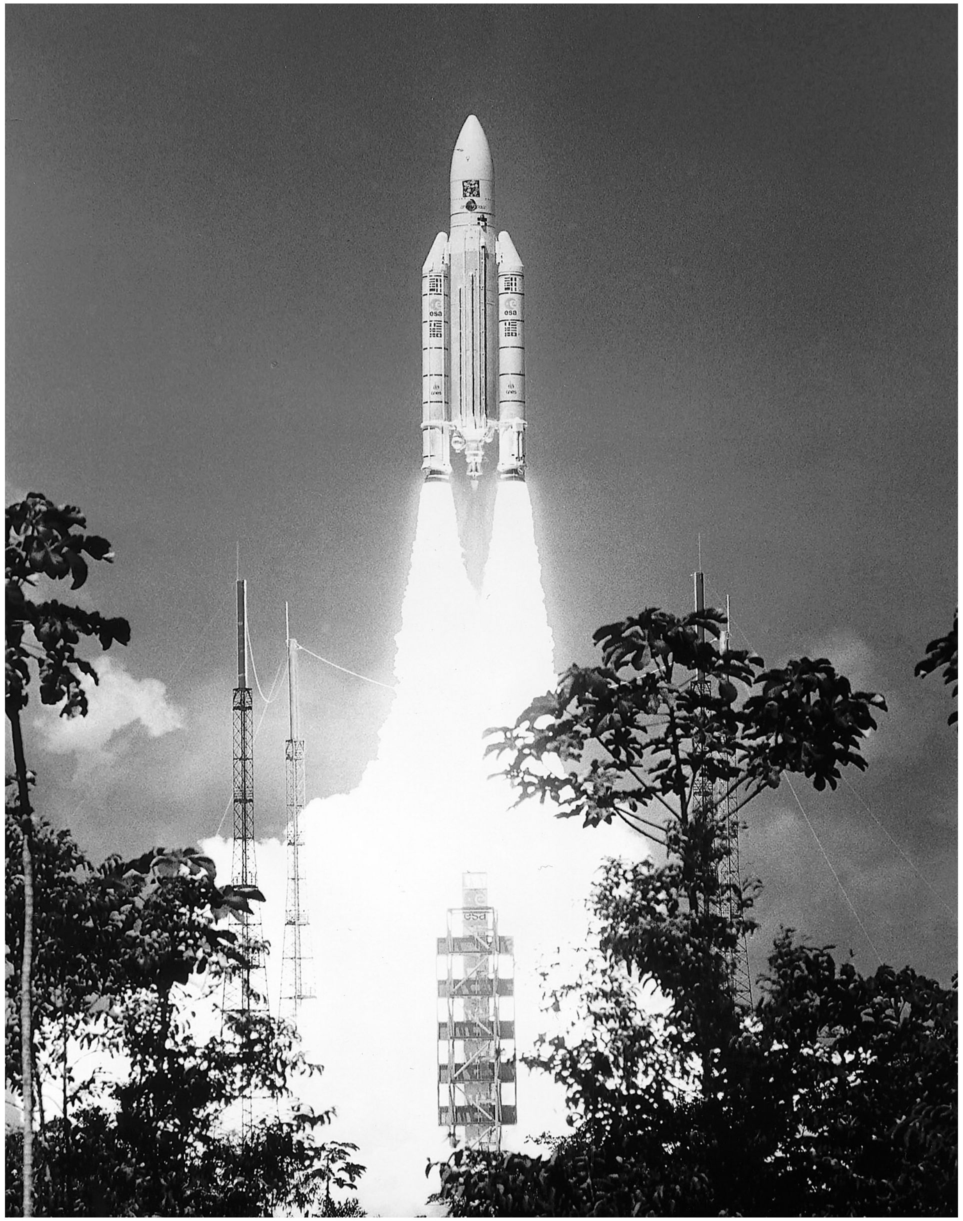
Regarding levels 0 and 1 a regional monitoring centre should be set up, either as a new facility or based at an already existing facility in the Guiana Shield. This centre will be responsible for collecting, maintaining and updating the baseline (level 0) data, for routinely generating level 1 regional monitoring data and for processing these data and linking these with the respective baseline data to create useful maps and statistics. Staff should be well trained in using the specific datasets and newly developed algorithms. Algorithm development and maintenance could be done internally or could be outsourced to a specialized remote sensing monitoring enterprise.

An inventory needs to be made of the political problems to be expected when monitoring at level 2 from one central place in the Guiana Shield region. Would one country allow another's military airplane to cross its boundaries for ecological monitoring purposes? If possible, MOUs could be made between the Guiana Shield countries to grant these rights to each other with, of course, strict restrictions of data use, etc. If the Guiana Shield countries can agree on this, the central monitoring centre can also coordinate level 2 mapping and monitoring and process the data on this level. However, if political issues appear hard to solve, national level 2 monitoring centres must be established that can coordinate level 2 mapping and monitoring for each country separately. These national or regional monitoring centres could evaluate nature reserve or concession management and the fulfillment of contract duties for the GSI. Data production therefore should satisfy the highest international quality standards.

The GSI monitoring centres must work together closely with already existing monitoring and mapping activities. In Brazil, SIVAM/SIPAM has mapping and monitoring of the Amazon Basin as one of its main goals. GSI and SIVAM/SIPAM can both profit from close cooperation and sharing of data and infrastructure. Monitoring activities are more infrequent in other countries. However, cooperation should be sought at least at the data production phase of level 2 in order to incorporate as much valuable information as possible into the final products.

During the GSI Monitoring Workshop, May 2003, a proposal was made for a data sharing network called FORESEEN: a FOrest and REmote SEnsing Exchange Network. Between the countries of the Guiana Shield region, the goal is the sharing of experience, techniques, and data. This could be a very fruitful initiative if

monitoring and research results and useful GIS datasets are freely available throughout this network. The availability of data will stimulate more and more efficient research and the exchange of information and techniques could become a major helpdesk-like data bank where people with the same interest can help each other. If and when already existing research and monitoring activities or organizations join the network, e.g. Global Forest Watch, its value will significantly increase and these organizations would profit from other peoples knowledge and data.



The European Space Agency (ESA) launches its Ariane 5 rocket from Europe's spaceport CSG in Kourou, French Guiana. Several ESA satellites have been transported this way into the orbit. Photo: ESA

6

SUMMARY AND RECOMMENDED FURTHER STEPS

6.1 Summary

For the Guiana Shield area a monitoring system has been proposed that focuses on land use and land use change monitoring and is composed of 2 levels: a frequent low resolution region-wide monitoring level and a more ad-hoc high resolution monitoring or mapping service for specific areas of importance. Both levels are of great interest to the GSI. These areas of importance have been identified by ecological research (areas of inherent ecological importance), and/or risk assessment by processing the land use (change) maps that are produced in level 1. Additionally, other sources such as a water quality measurement network (to be established) and information from local inhabitants, field surveys or other sources can be incorporated in the area selection process or can even replace the level 1 selection phase.

Level 1 monitoring will be frequent, relatively simple and, where possible, processing will take place automatically. A system based on the Spot Vegetation satellite sensor is considered due to the good experiences (of the author) while establishing a similar monitoring system in Indonesia. This level could be complemented with radar data when the ENVISAT satellite is fully operational and data from its ASAR Global Mode system is available. Using these radar data would ensure a better weather independence of the system. The building of a region wide river water sensor network is proposed, because of the need for water quality monitoring, which is difficult using satellite data. All data at level 1 (satellite generated land use – change – maps, water quality data and information from the local inhabitants) will be combined and processed in a central monitoring centre which will generate frequent region wide statistics and decision support information for selection of areas of importance.

Level 2 monitoring focuses on the defined areas of importance. These will be mapped or monitored (frequently mapped and compared) depending on the nature of the area and the environmental risks involved, using the best suitable system from the range of available options: high or very high resolution satellite monitoring, using radar (weather independent) or optical (better feature discrimination) satellite sensors, or very high resolution mapping using the SIVAM airborne sensors (also both radar and optical). The latter option is, of course, only available for countries that agree on Brazilian military airplanes crossing their borders for environmental research and monitoring. Acquisition of data about water quality, carbon sequestration and biodiversity which cannot be measured using remote sensing must be done by field surveys. Remote sensing monitoring could play a role, however, in ensuring that the field measurements were still valid. Level 2 data processing can take place in a central Monitoring Centre or in several separate national sub centres depending on what the Guiana Shield countries can agree on. In either case, a Guiana Shield wide network for data exchange is preferable, to enable all participants to profit from the monitoring systems results and to add data into the system. Data exchange between the national centres (and the region wide central centre) must be assured, especially when level 2 processing takes place at different national centres. The FORESEEN network could play a major role in this.

6.2 Recommended further steps

This document is only presenting a possible outline for an operational monitoring system for the Guiana Shield region. More information and negotiation will be needed to develop a more precise roadmap that could result in a monitoring system suitable for the GSI and the Guiana Shield region.

To begin with, more specific information is needed about the available baseline data. A proposal of the data needs has been made in this document; environmental scientists and local GIS experts should discuss this and eventually make additions to it. After an inventory has been made of what data from this list are actually available for use by the international GSI team and of the quality of that data, a proposal should be made that outlines how to complete the baseline dataset and how to integrate it into one region wide GIS database. This should build further upon the work that has been carried out by Conservation International in preparation of the Priority Setting Workshop.

Parallel to this process, the political attitude of several countries involved should be made clear and, if possible, a collective monitoring strategy should be formed. This strategy must state how to deal with national (remote sensing) information on a regional scale, what kind of transboundary monitoring will be allowed (SIVAM), whether or not countries want to be part of a multi-national network like SIVAM/SIPAM's, etc.

A more detailed plan for setting up the several monitoring services can be made, when the status of the available baseline data and the political possibilities are clear. Eventually, the low resolution region-wide level (level 1) of the system could be started before this, because the information is already publicly available and implementation should not be too difficult when the system is built upon existing knowledge (like from SarVision and/or Valéry Gond's research). During this phase, also a data access (sharing, distribution, archiving) policy should be

formed, eventually using the SIVAM network or the FORESEEN proposal, or both.

Implementation of the second level (the detailed monitoring system for identified areas of interest) will be a bit more difficult insomuch as it is more dependent on national policies and available information about current ecological conditions to indicate Areas of Interest. Also, every defined area will need specific adaptations to the high resolution monitoring process in order to optimize monitoring for specific ecological circumstances. This will probably require additional research, especially when relatively new and unknown sensors will be used like those from the SIVAM system. Per area, a specialized team will have to define monitoring goals that suit both local ecological circumstances and the sensors available. Depending on the GSI contract for a certain area and local conditions, monitoring goals should be formulated. Based upon these goals, one or more possible monitoring solutions should be proposed and evaluated and eventually algorithms might have to be adjusted and revalidated for the specific circumstances.

The system has grown mature, when the low resolution monitoring is mostly automated and routine-wise monitoring of areas of interest is possible.

ACKNOWLEDGEMENTS

The author is most grateful to all persons that gave their comments on the report or helped in another way to achieve the goal of this study and would like to thank all participants of the Guiana Shield Monitoring Workshop:

María Bastidas, María Pía Bevilacqua, Lindalva Cavalcanti, Jurandyr Fonseca, Valéry Gond, Daudi Husbands, Naseem Nasir, Minu Parahoe, Augusto Queiróz, Manuel Rodríguez, Milton Romero, Carlos Souza jr., Janice Wiles.