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TREES II Pre-feasibility Study
Final Report

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Final Report

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1.

Introduction

In early 1993, Earth Observation Sciences Ltd and the World Conservation Monitoring Centre were contracted by the CEC to undertake a 'TREES II Pre-feasibility Study'. TREES II is proposed to follow on from the current TREES I project at JRC Ispra. The TREES I project is investigating the potential of remote sensing in tropical forest inventory and monitoring. It has been underway for three years at JRC in research and development form and is scheduled for completion by the end of 1993. TREES II is to be a semi-operational system supplying useful information concerning tropical forests.

The purpose of the EOS/WCMC study is to analyse, assess and review the current and potential capabilities of TREES I, collect user requirements and prepare a work plan for TREES II. The project has been undertaken in two stages. The first stage covered an assessment of TREES I and a review of current capabilities. The output from this stage was an interim report which was presented at a review meeting in Brussels on 19th April 1993. The second stage covers user requirements analysis and the development of a work plan for TREES II. This report contains the output from both stages of the work. Five technical notes have been prepared, the first two being from stage one of the work. The five are found in the appendices to this report. The sections of this report summarise the technical notes.

2.

The TREES I Project

The two major objectives of the TREES project were to address deforestation issues at a global scale and to develop new satellite remote sensing techniques for the monitoring of forests. A 'wall-to-wall' baseline inventory has been pursued by the TREES I project to meet these goals. The production of a baseline inventory at 1km resolution and the identification, if not solution, of problems in its production can be considered as meeting the first goal. The development of new techniques is well underway. Progress in the inventory is gradually establishing suitable techniques, and new methods are being developed in the area of segmentation of SAR data.

TREES I runs until the end of 1993. It would appear that there is a good chance that the baseline inventory will be completed by this time, although much work remains to be done. The majority of the satellite data has been collected, and about one-third of the data have been classified. The S.E. Asian classification is about 50% complete; about 50% of the African work has been completed by other sources including NASA, but needs revisiting in the light of the S.E. Asian work; the analysis of the South American data has not yet begun. The remaining two-thirds could be completed by the end of the TREES I project since the data are now available and pre-processed, and classification procedures used by the JRC team have been developed.

The original time-table called for the completion of the data collection during 1991-2 and for analysis to proceed during 1992-3. This slippage is due almost solely to the inability of ESA to supply the pre-processed data to JRC as originally required. JRC staff have therefore had to invest considerable time and effort in what should have been routine work, and have been able to spend much less time on data analysis than was intended.

The current position of the TREES project in summary is:

1. The collection of raw 1km AVHRR data for the production of the wall-to-wall inventory is largely achieved.

2. Routes and procedures have been established by the project routinely to receive AVHRR data.

3. The project team has shown that it is possible to use AVHRR data at 1 km to provide classification into non-forest, evergreen forest and seasonal forest types, at least over S.E. Asia, and probably over Africa, although actual figures for accuracy are not yet available.

4. Different regional deforestation patterns have been identified. The spatial nature of these patterns is such that different techniques are required to identify deforestation in each region

5. The potential of TFIS, the Tropical Forest Information System, while not fully demonstrated, is high in two respects. Firstly that of adding ancillary data to the AVHRR composites to aid classification and secondly in presenting results to users in a comprehensible manner and with contextual information.

6. The use of ERS-1 SAR data for global monitoring is unlikely, but it is possible that it may prove useful in monitoring small selected areas. Techniques for segmentation and classification are under development.

7. The monitoring and modelling aspects of TREES require considerable further effort.

3.
Capabilities of Remote Sensing in Monitoring Tropical Forests

There is a considerable body of literature relating to the use of remotely sensed data for vegetation mapping and monitoring. There is relatively much less concerning tropical forestry. The data sources represented by the literature survey in Technical Note No. 2 were AVHRR LAC, GAC and GVI, Landsat TM, SPOT, various radar programmes and future sensors. These were examined in terms of data acquisition and management programmes and the subsequent analysis.

Data Acquisition Programmes

There have been several major initiatives for acquiring and managing these types of data either indirectly (IGBP) or directly (FAO, NASA) for general resource management, research and tropical forests usage. The use of AVHRR LAC/HRPT data is demanding in terms of management and the problem is far from solved, although recent work on catalogue interoperability and the establishment and consolidation of HRPT ground stations in tropical areas gives cause for hope. Due to the spatial and temporal resolution of LAC, AVHRR is seen by many workers as a viable mapping and monitoring source. However, other groups espouse the use of Landsat images for mapping (NASA, FAO) and possibly for monitoring (FAO sample strategy). There is therefore no consensus on the optimum data source, although there is synergy between the FAO and TREES programmes.

Data Analysis

Discriminants of parameters and classification of AVHRR and Landsat data is well established for vegetation in general in the form of the NDVI (GVI) data product. For tropical forests, the identification of discriminants is less well developed and the subsequent classification is almost totally undeveloped with only a handful of papers in the literature. Work with Radar data is somewhat separate from work with other sensors. This is partly because of the local scale of results and partly as a result of the different techniques required for information extraction (e.g. segmentation).

In relation to TREES I, the wall-to-wall inventory cannot easily be created from techniques and technology existing in early 1993. In particular AVHRR data in a consistent processed state are not readily available for all tropical areas. Discriminants of tropical forest parameters for some of the many data sources which have been discussed are known and documented. However, classification on an operational basis (which implies the ability systematically to extract the same classes across time and space) is in its infancy. The TREE S I project has therefore had to break a considerable amount of new ground and can be seen to be addressing a significant gap in capabilities.

4.

The User Community

The community involved in tropical forest issues is large and varied and the availability and quality of information on tropical forests is critical to their work. The research and information base on the state and extent of tropical forests remains generally weak, and the general proposition in the scientific community is that remote sensing is able to provide useful inputs to information needs. In order to ascertain the requirements of this community for such information a set of potential users for TREES II outputs has been identified. The user community was segmented into a set of eight groups:

The Global Change Community (A)
National Forestry Departments (B)
United Nations Agencies (C)
Intergovernmental Agencies and Programmes (D)
International non-Government Agencies (E)
National Government Agencies (F)
National non-Government Agencies (G)
The Forest Research Community (H)
Timber Traders (I)

Each of these user groups is characterised by assessing the activities of individual agencies in several senses:

- mandate
- funding position
- political affiliations
- written objectives
- track record
- information gathering activities

This characterisation is a means of understanding the community so that it can be approached and analysed for its requirements. Section 2 of Technical Note No. 3 outlines the forest activities and profiles of selected users. Because of the European basis to the TREES project this review of selected users concentrates to a certain extent on the European perspective on tropical deforestation. This analysis is also important in aiding CEC's appreciation of the political context of the various organisations. Such an appreciation is critical to the effort fully to utilise the technical solutions offered by remote sensing to the information requirements.

5.

Analysis of User Requirements

A questionnaire was specifically designed for the study and sent to 655 potential users of forest information identified from the analysis of the user community described above.

There was a relatively good response to the survey with 140 replies (21%). Using the 'user groups' defined above, the responses to the questionnaires were analysed. The best level of response came from international groups (UN, NGOs) and the research community with less response from national forestry departments and timber traders.

Potential users were able to make valuable, positive comments about the future development of TREES. Some specified their interest in becoming involved with the project, mainly via data validation and exchange. It would therefore be highly advantageous to set up collaborative links with these users. Products outlined below, which are based on the results of the user survey, could also be tested by users and their comments integrated into future planning of TREES.

A full analysis was made of the requirements for each user group. Four main conclusions arose in terms of information requirements and the form of information delivery which are listed below:

- high and medium resolution information is requested more frequently than low resolution information
- national level coverage was of principal interest followed by local scale and then smaller scale coverage
- yearly information updates were of particular interest with 3 and 5 year updates being less frequently requested
- information concerning forest boundaries, protected areas and forest types was frequently requested.

6.

Implementation of Requirements through Products

The responses gathered by the questionnaire described above were analysed into a number of requirements by user group. The requirements by user group were then analysed with respect to the following questions:

- Is the required information potentially extractable from remotely sensed data?
- Can the information be presented at the required spatial scale?
- Can the information be extracted with the required frequency?

Thus a set of parameters required by one or more user groups were extracted. There are 24 such information requirements. In addition, three non-technical requirements are described resulting from more general considerations and survey responses. All 27 requirements were then considered with respect to the capabilities, both current and potential, of remote sensing technologies.

The capabilities of TREES technology was summarised by proposing a set of outputs or products which encapsulate the maximum number of requirements in a minimum number of realisable outputs. They are summarised below. In addition to the products, two reports have been proposed which aim to interpret and place in context the information provided by the products.

Tropical Monitoring Product (TMP)
This is a yearly, pan-tropical product based on 1 km AVHRR data and principally providing estimates of the forest cover of each tropical nation in a statistical framework. These area statistics are aimed towards monitoring trends in gross coverage in each nation. The estimate of forest cover is a surrogate for boundary location. While boundary location itself is favoured by many potential users, it is not a meaningful piece of information at medium and coarser resolutions.

Boreal Monitoring Product (BMP)
This is a yearly, regional product for Boreal forest regions. It is suggested that this principally provides an estimate of the forest cover of sub-regions of Siberia in a statistical framework. The data source and uses are similar to those of the TMP.

Tropical Inventory Product (TIP)
This is a pan-tropical product output every 3 to 5 years, based on 1 km AVHRR data and principally providing cartographic output showing the location, area and boundary of a number of forest types and relationships with other legally gazetted boundaries (including protected and reserved areas).

Tropical Local Product (TLP)
This is local scale product with single outputs covering small sub-national areas (eg. 10,000 km^2). It utilises the strengths of TM and SAR to provide highly detailed graphical outputs

for areas of interest. It is not designed to be pan-tropical in extent.

Active Areas Report (AAR)
This report details forest boundary changes detected when comparing consecutive TMP, BMP or TIP products. Using auxiliary data and specific change analysis algorithms, text as well as graphical information is output.

Expert Analysis Report (EAR)
This is a means of capturing the results of human interaction with the products and a range of other data sources (which may be more important than the products) in a mixed graphical and text report.

The matrix in table 1 details the 24 requirements and shows how each is satisfied or not by the products. Where requirements are not satisfied, one of 3 reasons is given.

1 Data handling constraints (especially excessive volumes of data and costs resulting from the use of TM)
2 Technical difficulties (the information required cannot be extracted directly from remote sensing data)
3 Requirements are covered by other programmes, notably the JRC FIRE project and the NOAA GVI product)

The BMP product is not shown on the matrix. It satisfies the same requirements as the TMP and additionally the non-technical requirement (25) of covering a non-tropical area. The two reports (AAR and EAR) are not shown since they are derivatives of the products, and while they may meet additional requirements not met by the products, this is as yet undetermined. The user groups satisfied by each product can be seen in the column headed 'user groups' which refers to the user group categories (A-I) described in section 4 above.

Of the 24 requirements, 13 can be met by the products, while 11 cannot be met. Discussion in Technical Note No. 4 covers the justification for meeting or not meeting each requirement.

Requirem't Number	Requirement Description	Comments	Requirements Met			User Groups	Requirem'ts Not Met		
			TMP	TIP	TLP		1	2	3
1	fine scale, annual boundary data	This requirement would need TM data to achieve sufficient accuracy. TM has a 16-day repeat cycle, so that obtaining sufficient cloud free data could be a problem. Areas would have to be labelled as 'unclassified' if cloud free data were unavailable.				B,E,G, H	√		
2	medium scale, annual boundary data	It would be possible to achieve this with 1 km AVHRR data at a mapping scale of about 1:1,000,000, provided that it is possible to mark areas as 'unclassified' if cloud free data are not obtained during the year. Provision of areal statistics is feasible	√			B,D,E, G			
3	coarse scale, 3 yearly boundary data	This is certainly possible with 1 km AVHRR data, and cloud free data should be available during this time frame.		√		A,C			
4	medium scale, 3 yearly boundary data	The 3-year time period would mean that greater attention could be paid to the accuracy of the classification than for Requirement 1 so that the results would be more meaningful. While use of TM data would be desirable, 1 km AVHRR data would be adequate.		√		B,D,F			
5	fine scale, 3 yearly boundary data	As with requirement 1, this would require TM data with correspondingly high data volumes and costs. The 3-year time-frame would however reduce these considerably from those of requirement 1.			√	B			
6	medium scale, annual fire data	This is provided by another programme.				D,G,E			√
7	medium scale, annually, roads	This would require TM data except in areas with clearly delineated roads where 1 km AVHRR data might be adequate.				C,E		√	
8	fine scale, every 3 years, protected area monitoring	To derive these data would require the use of TM, possibly supplemented by airborne data (both optical and SAR). This would be possible, although a five-year repeat period might be more realistic.			√	B,C,D,E ,G,H			
9	medium scale, every 3 years, protected area monitoring	This would require 1 km AVHRR data at a minimum.		√		B,C,D,E ,G,H			
10	fine scale, annually, protected area monitoring	This would require TM data on an annual basis with correspondingly high data volumes and costs.				B,C,D,E ,G,H	√		
11	medium scale, annually, protected area monitoring	This would require 1 km AVHRR data at a minimum.	√			B,C,D,E ,G,H			
12	fine scale, every 3 years or more, biomass	At the required scale of less than 1:100,000 it would be necessary to use TM data, or even airborne data. It would be difficult to cover the whole tropical area at this scale, but it should be feasible to provide data for selected areas.			√	A,F			
13	medium scale, every 3 years, biomass	This is provided by another programme.				A,F			√
14	fine scale, annually, biomass	Similar comments apply as for Requirement 12. To achieve this annually would be an extremely heavy processing load.				A,F	√		
15	fine scale, annually, forest types	TM data would be required, probably supplemented by airborne SAR and airborne optical data. The data volume and costs would be very high.				All	√		
16	medium scale, annually, forest types	See discussion for requirement 15.				All	√		
17	fine scale every 3 years, forest types	This would be possible using TM data, but possibly only for selected areas (see discussion on protected areas).			√	All			
18	medium scale every 3 years, forest types	Provision of these data would be achievable with 1 km AVHRR.		√		All			
19	fine scale, every 3 years or more, timber volume	Provided the relationships exist as discussed above in Section 2.3 (TN-04) this would be achievable using TM data. It would be difficult to cover the whole tropical area at this scale, but data could be provided for selected areas.			√	C,D			
20	medium scale, every 3 years or more, timber volume	1 km AVHRR data would be a minimum requirement.		√		C,D			
21	fine scale, annually, timber volume	This would require TM data with corresponding high data volumes and costs, see also comments for requirement 19.				C,D	√		
22	medium scale, annually, timber volume	This would be possible using 1 km AVHRR data, but see comments under requirement 19.	√			C,D			
23	fine scale, every 3 years, biodiversity	TM or SPOT data supplemented by airborne optical and SAR data would be required, providing the restrictions outlined in Section 2.3 (TN-04) are overcome.				B,C,D, H		√	
24	medium, every 3 years, biodiversity	TM data should provide adequate spatial resolution providing that the restrictions outlined in Section 2.3 (TN-04) are overcome.				B,C,D, H		√	

Table 1 Summary of Requirements and Recommendations

7.

System Development and Research Requirements

The preceding analysis of users and requirements concluded by outlining a set of products and reports as a focus for TREES II development. In order to produce these outputs, a manageable system must be developed. Elements of this systems were of course developed during TREES I. However, there are several new aspects which should be introduced into TREES II.

The first of these is a more rigorous engineering approach towards the specification and development of the various components. The components identified by the study consist of software, data, human interaction and various institutional considerations. In order to develop these components into a semi-operational system, there is a clear need for a number of trade-off studies between options as well a detailed requirements specification for new software plus possible re-engineering of prototype software developed in TREES I. Two components not represented in TREES I are required; namely a data management component and a user component. The first can be developed from current prototype systems in the JRC MTV unit (IBIS) or via the CEO, while the second encapsulates the requirement for ongoing interaction with the user community. Included here are a number of suggestions for the dissemination of products and means of continuing to develop an understanding of the users and their requirements. The latter point is critical to maintaining as clear direction for TREES II.

Probably the greatest initial challenge to TREES II is the component covering the operationalisation of the supply of AVHRR data to the project. This task requires considerable effort to tap the appropriate data source and to prepare correctly the raw data for classification. The route used during TREES I was direct contact by the team with HRPT stations supplying raw data which was processed at JRC. For a number of reasons, this task is probably better now done by ingesting data from the IGBP project via ESA. Pre-processing requires specification so that appropriate software can be developed and applied. Some TREES I data may require reprocessing. Several trade-off studies are required before a firm commitment is made.

Two components given particular attention during TREES I will continue to be the focus of activity during TREES II. These are the manipulation and classification of images and the extraction of information products from the images. The latter component was set up during TREES I as TFIS. Apart from further software development, several research topics are directed at this component. These concentrate on determining the accuracy of the information derived from classified images and various auxiliary data. The work on images drives a number of further research topics, particularly the classification techniques and the selection of training sites. Eleven research topics are identified in all, of which eight are seen as critical in terms of the need to address and solve the issues while the remainder should be addressed but are not critical. There is some dependence here on the funding scenarios; in that the size of TREES II will allow or not the non-critical topics to be addressed. The research topics are:

Research topic

- Decision on the classes to be contained in TIP
- Derivation of classification technique and rules for TMP
- Derivation of classification techniques and rules for TIP
- Derivation of classification techniques and rules for BMP
- Selection and use of training and test sites for all products
- Methods for improving registration accuracy between images, and between image and coastline/national boundary data
- Determination of appropriate projections for production of areal statistics
- Methods for determining accuracy and precision of areal statistics
- Methods for determining accuracy of boundary locations
- Methods for determining change detection
- Methods for segmenting SAR data

8.

Management and Work Plan

The original TREES project focused strongly on research. Consequently the techniques and methodologies required were not apparent at the beginning of the project. It was therefore necessary to approach the problem by allowing scientists freedom to devise creative solutions to the various problems involved. With so many uncertainties in both approach and anticipated results a flexible management structure was employed. During TREES II, the nature of the project will change, moving away from research and toward operational product generation, though there will always be strong elements of research to support the operations. This change in focus must be accompanied by a change in management structures which will continue to encourage innovative research while supporting and controlling the operational aspects of the project. The key areas for attention in terms of project management and team development are planning and control, scheduling and deliverables, and human resources.

Planning and Control
A planning and reporting cycle should be maintained which allows the project leader to maintain control of the direction of the project without constraining the scientific innovation of the project staff. The cycle should begin with the generation of a project plan by the project team Monitoring of progress against the plan should be undertaken, preferably on a monthly basis.

Scheduling and Deliverables
A schedule for the accomplishment of key tasks in the project is proposed below, with the associated deliverables at each stage. The setting of milestones and deliverables within the project schedule fulfils a number of purposes of value both to the external perception of the project, and the internal planning. Many of the deliverables are demonstration or interim products, which demonstrate the progress of the project to the outside world. The remaining deliverables are research reports which are either necessary for the successful undertaking of other project tasks, or provide for the dissemination of project results or research findings to the wider scientific community.

The value of these self-imposed deadlines for the production of research reports is in maximising the personal research productivity of each of the team members. It is proposed that each of the research reports could become self-standing papers in appropriate journals. This will raise the profile of the staff involved, enhancing their research careers, and maintaining maximum motivation through the project.

Human Resources
The success of the TREES I project was partly inhibited by the difficulty and slowness of recruiting permanent scientific staff through The Commission. This made the planning of staff resources difficult, and left shortages in manpower which caused bottlenecks in the project process leading to unrealistic demands on the available staff.

The success of the TREES II project, is critically dependant upon the timely availability and motivation of staff with the correct experience and expertise. Accepting that delays and difficulties in recruiting high calibre staff are inevitable, it is necessary to pay close attention to staff planning to ensure that the key posts are filled by permanent staff (research) and contractors (operational tasks),

It is proposed that a proportion of the posts to be filled in order to execute the TREES II project be defined as the "core team", and be assigned to permanent members of staff. The core team should comprise 30-50% of the total team and be assigned roles of key scientific or organisational importance. Many of the key roles require less than a full-time person, and so could be combined within one post. The key roles are Project Leader, Project Administrator, Science and Research leader, Data Gather Leader, Data Manager, Software and Systems Engineer, External Relations Coordinator and Project Librarian.

Work Plan

The work plan is presented as three scenarios. These scenarios are based on three cost levels to the CEC; namely one, two and three million ecu per year. Within each scenario, different functionality and levels of output are achievable by the TREES II project.

Full Functionality Scenario
The full functionality scenario provides for all research topics to be investigated and reported and several products of each type to be produced. The cost table (Table 2) gives an estimate for the size of team and other costs incurred to cover the work and the timeline for the various elements is shown in Schedule 1.

The discussion of management requirements indicates the need for a management/administration team of eight staff and a research and operations team of seven staff. One of the operators could work at ESA/ESRIN where pre-processing might be sited. The second operator will become important later during the project as image classification becomes more routine. The cost of airborne campaigns is speculative in the sense that information is not easily available and the need for TREES II to fund such campaigns is undecided (collaboration with other programmes may provide input). The expert reports are related to research topics where the TREES team requires input from outside consultants. This occurred in TREES I and it is wise to continue to take such advice. The conferences and travel expenses are driven by the need to consult widely with other projects and to develop user contacts.

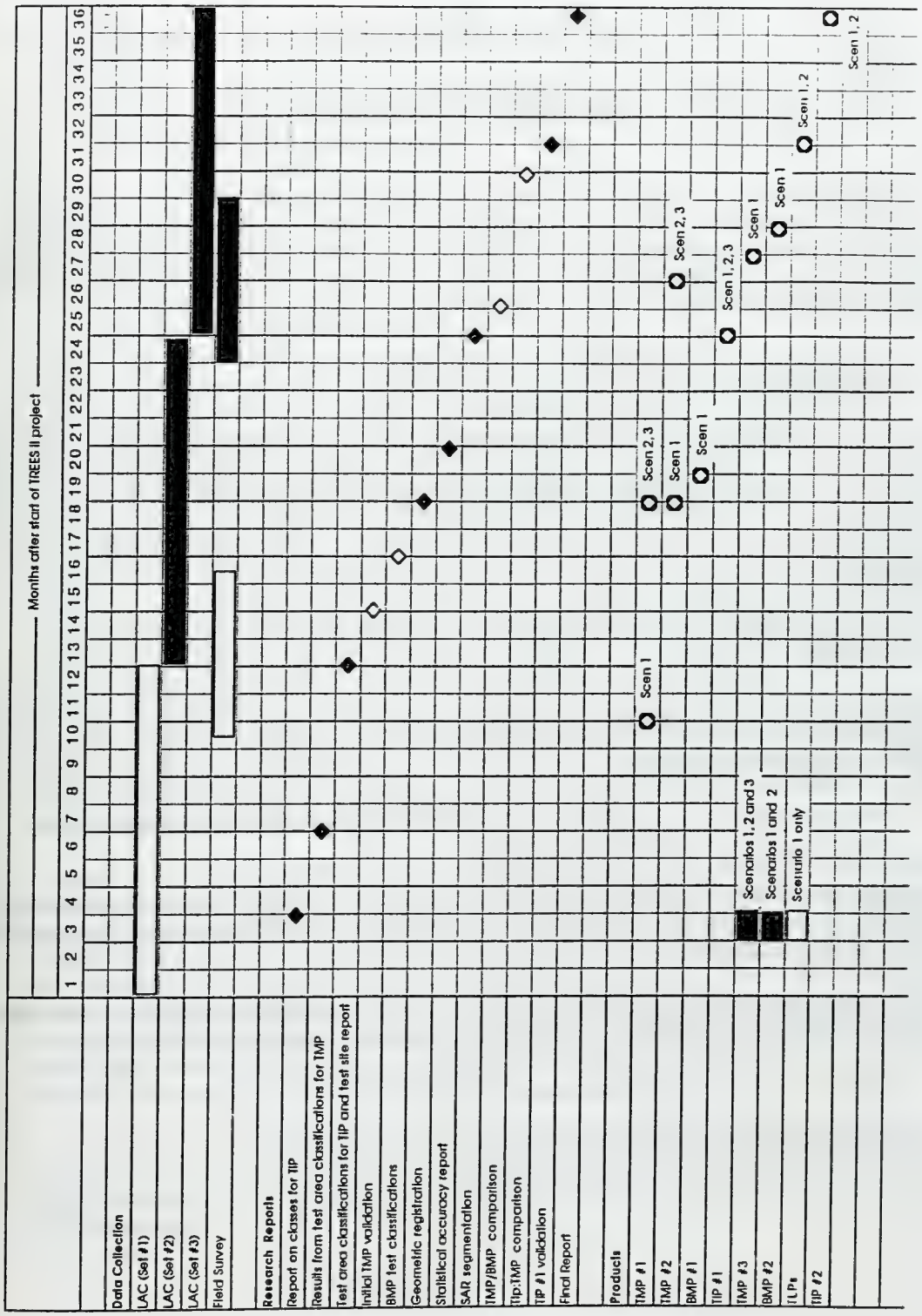
Reduced Functionality Scenario
In this option the management/administration team has been reduced by combining roles and the research and operations team reduced. The BMP product has been removed along with the research and data collection required for its production. The number of TMP and TIP products is also reduced, along with field and airborne campaigns. Other costs reduce to match the team size and needs for software development. There is of course a major political disadvantage in this option in that monitoring of a non-tropical area is a stated user requirement (see Technical Note No. 4, Section 3). The possibility of extending TREES beyond the tropical scope is considerably reduced without this preliminary 'pathfinder' effort and once TREES III is operational it becomes much more difficult to add functionality.

Basic Functionality Scenario

In the basic functionality scenario, the TLP product is removed altogether reducing data, research and several other costs substantially. In particular, airborne SAR campaigns and SAR research would not be required. There is a major disadvantage in this option is in that several important requirements are not met. The TLP products are likely to be highly valued by users who are substantially in favour of obtaining information at fine scales. They also provide information which can be used in production of the coarser scale products, which if lacking could put these products at risk.

Item	Full Scenario 1	Reduced Scenario 2	Basic Scenario 3
Management and Administration	2400	1860	960
Research and Operations	1490	990	530
Data Acquisition/Processing	690	480	270
Hardware and Software	350	200	100
Field Campaigns	300	150	150
Airborne Campaigns	1000	500	
Expert Studies	300	300	150
Software Developments	500	400	310
Travel/Meetings and Materials	430	420	295
TOTAL (Kecu)	**7500**	**5300**	**2800**

Table 2 Summary Scenario Costs



Schedule 1 Summary for Three Scenarios

9.

Recommendations

In starting TREES II, a major objective is to move from a phase which has been predominantly research-oriented to one which is pre- operational. The **system** level recommendations which seek to drive this move are:

1 **Development and specification of a set of outputs or products which meet user requirements.**

This task has been started in this report by specifying a set of products. These are not full specifications and a number of questions are outstanding which should be answered during TREES II. It may become necessary significantly to alter product specifications, delete products altogether or add new ones. The important points are that a clear link exists between user requirements and the output from TREES, and that the output from TREES II can be characterised.

2 **To engineer a set of system components which will enable products to be output.**

The system outlined in the work plan is derived from elements many of which were developed during TREES I. Additional components have been added in order to create a system which leads towards operationalisation.

3 **To study options and determine the best means of providing a routine supply of processed 1 km data to the project.**

The ingestion of these data during TREES I was a major operation which must be contained and if at all possible removed from the JRC team. This will enable the TREES II team to concentrate on the specialist areas of research and product development.

TREES I demonstrated that valuable information can be derived from the data sources used. However, a number of areas remain outstanding where additional **research** is required:

4 **A set of critical research topics must be addressed**

5 **A set of desirable research topics should be addressed**

The **management** and team development aspects are critical:

6 **Clearly identify roles and responsibilities for all team members including special positions such as data management, data gathering, systems development, science leader etc..**

The necessity to meet schedules and deliver value for money means that responsibilities must be clearly understood at technical and non-technical levels. This is not easy in an environment of permanent and contracted staff.

7 **To involve a mix of people with skills in research, operation, engineering, management, negotiation and liaison.**

The user component of the system discussion emphasised the need to communicate with users. The contact with potential users reported in this study must not be seen as a one-off. It is vital to develop a clear understanding of the user community and its requirements.

8 **Establish links with users, distribute products and monitor feedback.**

Lastly, it is necessary to estimate the financial **cost** of the TREES II project. There are however a large number of research topics and trade-off studies involved in its development. This means that the final form of a system in terms of necessary functionality cannot be determined at this stage. In turn this means that the costs of development, research, software and data acquisition can be estimated only very generally.

However, the discussions and recommendations above have been brought together into the the three options discussed in the section above. It is not possible here to recommend which of these options is taken. It is a matter for CEC to determine the value of meeting or at least probably meeting the requirements in each option.

In summary, it can be said that with the full functionality scenario, a TREES II project following the suggestions and recommendations in the technical note will almost certainly be able to meet around half of the requirements identified in Technical Note No. 4. Thus TREES will be able to make a significant contribution to the management of tropical forests and associated activities. In the reduced functionality scenario the boreal monitoring requirement is not met and research and products generation elements are much reduced. Boreal monitoring is a non-technical requirement whose value must be weighed by the CEC. In the basic functionality scenario a significant number of requirements are not met, especially those associated with SAR.

In conclusion it can be said that TREES II presents a valuable opportunity to utilise remote sensing technology in tropical forest monitoring. With clear requirements, the project can make a considerable contribution to the knowledge and understanding of this vital issue of global significance.

Acronyms

AAR	Active Areas Report
AATSR	Advanced Along Track Scanning Radiometer
ACP	African, Caribbean and Pacific
AML	Arc Macro Language
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CDC	Conservation Data Centre
CEC	Commission of the European Communities
CEO	Centre for Earth Observation
CEOS	Committee on Earth Observing Satellites
CGIAR	Consultative Group on International Agricultural Research
CIESIN	Consortium for International Earth Science Information Network
CIFOR	Centre for International Forestry Research
CIRAD	Centre de cooperation internationale en recherche agronomique pour le developement (formerly known as CTFT)
CORINE	Coordination of Information on the Environment
CPD	Centres of Plant Diversity
CSIRO	Central Scientific & Industrial Research Organisation
DAAC	Distributed Active Archive Center
DCW	Digital Chart of the World
DEM	Digital Elevation Model
DGL	Data Gather Leader
DIS	Data and Information System
EAR	Expert Assessment Report
EARSEC	European Airborne Radar Remote Sensing Capability
EBA	Endemic Bird Area
EC	European Community
ENVISAT	Environmental Satellite
EPA	Environmental Protection Agency
EOS	Earth Observation Sciences (UK)
EOS	Earth Observing System (US)
EROS	Earth Resources Observation System (of U.S. Dept. of Interior)
EROT	European Communities' Regional Fund
ERS-1	European Remote sensing Satellite
ESA	European Space Agency
ETFRN	European Tropical Forest Research Network
FAO	Food and Agriculture Organisation
FNOC	Federal National Oceanographic Center
FOE	Friends of the Earth
FRA	Forest Resources Assessment
GAC	Global Area Coverage (AVHRR 4km daily data)
GAIM	Global Analysis, Interpretation and Modelling
GCTE	Global Change and Terrestrial Ecosystems
GEMS	Global Environment Monitoring System
GHz	Gigahertz

GIMMS	Global Inventory Monitoring and Modelling System
GIS	Geographic Information System
GOES	Geostationary Orbiting Environmental Satellite
GRID	Global Resource Information Database
GSCF	Goddard Space Flight Center
GVI	Global Vegetation Index
G7	Group of 7 leading industrial countries
HTFI	Humid Tropics Forest Inventory
HRPT	High Resolution Picture Transmission
HRV	High Resolution Visible
IBIS	Image Browse and Information System
ICBP	Birdlife International (formerly International council for Bird Preservation)
ICSU	International Council of Scientific Unions
IGBP	International Geosphere / Biosphere Programme
IGBP-DIS	IGBP Data and Information System
IIED	International Institute for Environmental Development
ILWIS	Integrated Land and Water Information System
INPE	Instituto Nacional de Pesquisas Espacias
IPCC	International Panel on Climate Change
IRSA	Institute for Remote Sensing Applications
ISY	International Space Year
ITC	International Institute for Aerospace Survey & Earth Sciences
ITTA	International Tropical Timber Agreement
ITTO	International Tropical Timber Organisation
IUCN	International Union for Conservation of Nature and Natural Resources
IUFRO	International Union of Forestry Research Organisations
JERS-1	Japanese Environment Resources Satellite
JRC	Joint Research Centre
LAC	Local Area Coverage (AVHRR 1km data)
MAB	UNESCO Man and the Biosphere Programme
MARS	Monitoring Agriculture using Remote Sensing
MERIS	The MEdium Resolution Imaging Spectrometer
MODIS	The MOderate Resolution Imaging Spectrometer
MTV	Monitoring Tropical Vegetation Unit (JRC)
MSS	MultiSpectral Scanner
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NDVI	Normalised Difference Vegetation Index
NESDIS	NASA Earth Sciences Data and Information System
NGDC	National Geophysical Data Center
NGO	Non-Governmental Organisation
NIR	Near Infra-red
NOAA	National Oceanic and Atmospheric Administration
OO	Object Oriented
PAF	Processing and Archiving Facility
RAMP	Radar Mapping of Panama
SAR	Synthetic Aperture Radar
SAREX	South American Radar Experiment
SASIFY	Space Agency Forum on the International Space Year
SHARK	Station HRPT Archiving & Reprocessing Kernel
SHARP	Standard HRPT Archive Request Product
SIR	Shuttle Imaging Radar

SLAR	Side Looking Airborne Radar
SPACE	Software for Pre-processing AHVRR data for the Communities of Europe
SPANS	Spatial Analysis System
SPOT	Systeme Pour l'Observation de la Terre
TFAP	Tropical Forest Action Plan
TFIS	Tropical Forest Information System
TIP	Tropical Inventory Product
TLP	Tropical Local Product
TM	Thematic Mapper
TMP	Tropical Monitoring Product
TREES	Tropical Ecosystem Environment observation by Satellites
TREIS	Tropical Radar Environment Information System
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNESCO	United Nations Education and Science Organisation
UNEP	United Nations Environment Programme
WCMC	World Conservation Monitoring Centre
WDC	World Data Center

Technical Note No. 1

Assessment of the Current TREES Project

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1.

Introduction and Discussion

The purpose of this report is to describe the current status of the TREES I project arising from a visit by the TREES II Pre-feasibility Study project team to JRC, Ispra in March 1993. It is intended to be an assessment of the project against its stated objectives and not a critical study.

This chapter introduces the background to the assessment with an overview of the more general objectives for tropical forest monitoring within which context the TREES project is set.

1.1 Overall Objectives for Tropical Forest Monitoring

The key issues in tropical forest monitoring can be reduced to four interlinked questions, what to assess, how to assess, why assess and for whom to assess. These questions provide a background in which the TREES project objectives can be addressed, and the extent to which they have been met can be assessed.

1.1.1 What to Assess

Is tropical forest changing in quantity (extent) or quality, or both? To assess the extent of tropical forest requires that it be defined. Closed forest can be distinguished from open woodland on satellite imagery (e.g. the FAO 1980 assessment), but problems in defining the position of the boundary arise where the forest is thinned out by selective tree removal or broken into a mosaic by patches of farmland – such problems get worse as resolution of study increases. In those places where forest runs continuously from the tropics to the non tropics (central Africa, South America, IndoChina, Australia) there is no sharp ecological boundary, but a gradual transition to subtropical and then temperate forest. For this transition the Tropics of Cancer and Capricorn provide logical limits for tropical forest.

Within tropical forests there are many different forest formations defined on structure and physiognomy. These occupy distinct habitats and are sharply bounded where the habitats are, for example, peat swamp forest, forests on limestone, or upper montane rain forest. However, some transitions are gradual, e.g. between lower montane and upper montane rain forest on wet tropical mountains. Sometimes two formations exist in a mosaic at their boundary, for example evergreen rain forest extends into semi-evergreen rain forest on well-watered or fertile soils, and a similar mosaic occurs between semi-evergreen and deciduous forest formations. These boundaries and mosaics are usually complicated by human intervention.

It has not so far proved possible to detect from satellite images these different forest formations, despite much effort. In recent years radiometric boundaries have been

discovered, e.g. in southern Yunnan and Africa, however the biological significance of this has not yet been ascertained. Seasonal changes can be detected and used to map semi-evergreen versus evergreen forests. Differences between years have been detected in evergreen forest, but its biological meaning is not understood.

Tropical rain forest which is logged for timber loses some of its big trees, so the canopy top becomes very uneven. The forest is further broken up by tractor tracks and lorry roads. However, from a low-flying aeroplane it is difficult, within a year or two, to detect that logging has taken place, except for the presence of the lorry roads. If not used, these too will become re-vegetated within a few years. The amount of timber removed per hectare (and hence the amount of disturbance created) varies from 5-10 cum (cubic metres) to 100-200 cum in parts of Sabah, with 20-30 cum a common figure. The number of trees represented by these volumes clearly depends on their size, the range is about 1-10 per hectare. It is not easy for all these various reasons to distinguish logged from pristine forest. A decision must be made on the scales and frequencies (e.g. annual seasons) of assessment.

1.1.2 How to Assess

Ground survey, aerial photography and satellite imagery all have roles to play. Satellite imagery is available at various scales, and are able to discriminate different environmental parameters. Radar imagery penetrates the cloud which commonly lies over much of the world's rain forests. Amongst the satellite images low resolution (1 km) AVHRR is repeated daily. Landsat and SPOT have higher resolution (10-30 m) but are repeated less frequently (typically 20-30 days in fixed configuration). Operating in the visible part of the spectrum, cloud is a serious problem. A more detailed analysis of current capabilities for the remote sensing of tropical forests is presented in Technical Note No. 2.

1.1.3 Why Assess

There are various reasons why tropical forests should be assessed:

- Tropical deforestation is a matter of widespread concern. Agenda 21 of the 1992 UNCED Rio meeting set out the aim to have an operational decentralised global monitoring programme working in ten years.

- Forest quality is of interest - but the definition of measures of quality present problems. Also its observation from satellites has constraints, in that it has proved impossible so far to recognise the different tropical rain forest formations recognised by ecologists, and as mentioned above forest alteration by logging is a complex phenomenon, with the forest subsequently and progressively growing back to something close to its original state.

1.1.4 For Whom to Assess

The three groups of questions what, how and why to assess will have different answers for different users. Various groups can be identified:

- global change community
- government agencies of tropical countries
- United Nations agencies
- intergovernmental agencies and programmes
- international non-governmental organisations

- governments of non-tropical forest countries
- national non-governmental agencies
- forest research organisations
- timber traders.

These are further elaborated in Technical Note No. 3.

1.2 Overall Objectives of TREES in Relation to the Key Issues of Tropical Forest Assessment

With the overall objectives established, and the key issues described the objectives of the TREES project itself may be addressed.

One objective of TREES II is pan-tropical monitoring of the extent of tropical forests. This is currently based on low resolution (1 km) AVHRR data for which collection has been arranged. Steps are in hand to have preprocessing (e.g. geometric and atmospheric correction) done at a number of centres around the tropics. AVHRR images are obtained daily so the capacity exists for continual monitoring. No other body is making such a pan-tropical survey. UNCED Agenda 21 requires such a survey and there are other users with pan-tropical or regional interests. AVHRR imagery may be replaced by superior products from a French SPOT satellite in a year or two, making frequent images at the same low resolution, but (unlike AVHRR) designed explicitly for vegetation survey, and able to store data on board so that it can be downloaded for the whole of the tropics at a single station, e.g. Kiruna. TREES needs to be designed with the flexibility to keep up with this and other advances in technology. It would be useful for TREES to be consulted over the design of what this satellite system aims to deliver. This draws attention to the fact that it is the information system that is different about TREES - i.e. the determination to combine and analyse data from a range of sources, and disseminate it to many users.

The concern of UNCED with forests was not confined to the tropics. A case can be made for global forest monitoring as opposed to tropical monitoring solely.

TREES also aims to use high resolution satellite images to monitor locations of active deforestation more closely, using Landsat, SPOT or ERS-1 SAR images. This presents several problems:

- The procedures for collection and handling the data are different at different resolutions.

- For whom is such monitoring being conducted? The precise and frequent monitoring of forest extent and forest degradation of an individual nation is a politically sensitive issue, exacerbated if loci of active deforestation are referred to by the emotive 'hot spot' and the procedures for their identification are referred to as an 'alarm system', when in practice the activity might in fact be part of a land-use management plan. However, frequent monitoring at a scale that AVHRR imagery is able to deliver, may be of great advantage to the national user by indicating unexpected change in forest cover (provided the forest loss is large enough). This loss may be imperceptible from less frequently gathered higher resolution imagery such as Landsat or SPOT.

- The problems of defining forest boundaries become more difficult as the resolution increases.

- The necessity to define and measure degraded forest becomes more important at high resolution.

- The identification of loci of active deforestation needs to be done objectively, based on explicitly stated criteria. There are various approaches. These are discussed in more detail in Section 3.1.

- The final difficulty with high resolution detailed descriptions of loci of active deforestation is what one does with this politically sensitive information once it has been collected. How does one translate information into action? Who does this? Nations are sovereign states and will take umbrage at data perceived to criticise their freedom of action unless it is very carefully targeted and presented. One general issue of tropical forest assessment is whether data are collected and analysed at regional stations or a single station. This issue has both practical and political aspects. For low resolution imagery AVHRR, and even more so the French data which may soon supplement it, there is a good case for a single global station. For high resolution imagery, which is more politically sensitive, national stations may be preferable.

TREES needs to be designed in relation to other projects monitoring tropical forests. There is no one else aiming at pan-tropical coverage at 1 km resolution which has the potential to be repeated frequently. NASA Pathfinder has higher resolution, FAO aims to have higher resolution still, based on individual nations. The three projects are thus complementary. They need to maintain a dialogue. FAO hopes to get funds from CEC as does the French vegetation satellite project that would produce data similar to AVHRR. This gives TREES the chance to influence these two projects. It will also be very important to keep in touch with the Japanese monitoring project as it develops.

1.3 TREES I Technical Objectives

This section deals with more specific technical objectives of the TREES project, and sets out those specific, written objectives for the project against which the assessment in this report is made. In order to achieve the overall objectives, the project was grouped into three general items, these are described in detail in TREES Series A: Technical Document No 1, Part 1. The first item is the production of a global tropical forest baseline inventory, a 'wall-to-wall' coverage, using AVHRR 1 km data as the main data source, supplemented by ERS-1 SAR, SPOT and Landsat TM or MSS data where appropriate. Following from this are two additional items: the detection and monitoring of active deforestation areas, and the modelling of tropical deforestation dynamics.

The production of the baseline inventory was subdivided into six fundamental activities:

- data collection
- data pre-processing
- data analysis
- validation

- development of a Tropical Forest Information System (TFIS)
- research developments.

The item to monitor areas of active deforestation was also subdivided into several activities:

- development of monitoring procedures
- identification of active deforestation areas
- monitoring of these areas via high resolution satellite data
- development of an 'alarm system'.

This document has been sub-divided using the the Item and Activity headings outlined above (where work has been performed), since these formed the basis of the work activity as originally specified. In the following chapters each activity is examined separately. The current status of the work is described and related to the stated objectives.

The use of ERS-1 SAR data is a further important component of the TREES I project. Since these data have only very recently become available and methods of data analysis are still being actively researched, their use can be considered separately from the thrust of the production of the baseline inventory, which relies on established data sources and processing techniques. The use of ERS-1 SAR data for tropical forest monitoring is therefore described in a separate section.

2.

The Tropical Forest Baseline Inventory

The production of the baseline inventory was subdivided into six fundamental activities:

- data collection
- data pre-processing
- data analysis
- validation
- development of a Tropical Forest Information System (TFIS)
- research developments.

In addition, during the study a number of issues of a more administrative nature were noted, which are outlined at the end of this section.

2.1 Data Collection

The data involved in the programme is:

- AVHRR data – low resolution
- high resolution data – Landsat TM and MSS, SPOT and ERS-1 SAR.

2.1.1 AVHRR Data

The original intention of the TREES project was that the 1 km AVHRR data (LAC) would be provided by ESA using their existing receiving station network and technology. Indeed this was a major rationale for joint project funding by CEC and ESA. However, it became clear at an early stage that ESA were unable to collect the required data routinely and that no money could be specifically allocated for data collection using a non-European sensor. Considerable time and effort has therefore had to be spent by TREES personnel in routine data collection. Data are obtained both directly by JRC personnel, and by contractors identified by JRC.

There is a number of specific data requirements:

- low cloud cover over the area of interest
- the area of interest must be as close to nadir as possible in the image swath
- all five channels should preferably be available in 10-bit resolution; failing this a minimum of Channels 2 and 3
- afternoon passes are preferable
- images obtained during the dry season are preferable
- where archived data are available the most recent data are preferable.

These requirements were taken from the specifications to data collection contractors listed in

TREES Series A: Technical Document No 3.

The aim was therefore to collect as many suitable images as were available over the analysis period (1990 to present, with the exception of some African data from 1988-1991). Collection requires a detailed examination of each possible image and is highly labour intensive. This would be hard to achieve using a fully automated system, since the precise location of cloud-free areas is as important as the total amount of cloud in an image.

There are separate problems for data acquisition for different continents and these are described below.

Africa
The receiving stations at Niamey, Nairobi, Maspalomas and LaReunion provide Sharp 1A products which are routinely purchased by JRC for the MTV (Monitoring Tropical Vegetation) project. These tapes have the raw five channel data plus sets of control points for image rectification. In order to select an image as a candidate for further processing it must be examined either by displaying the full image or using a quick-look product. ESA quick-look SHARK products are also available, but are of limited value for scene selection because haze and smoke are not clearly distinguishable.

Southeast Asia
There has been a major data collection problem in this region. Stations are operational in Jakarta and Bangkok, but these do not routinely archive any data since their primary purpose is to provide data for meteorological forecasting. The TREES group have therefore either to buy a tape sight unseen, or view the image during collection and request it. For the Bangkok station they have an on-site contractor who views the images during collection and purchases those which are suitable. The data product from these stations is similar to the NOAA 1B product i.e. it is thermally calibrated, but has no orbital model. There is therefore a considerable requirement for pre-processing (see Section 2.2). Recently the TREES team has reached an agreement with CSIRO and are now routinely receiving data from the Townsville station in Australia; some data have also been purchased from the Philippines station in Manila via ESA.

South America
Data have only recently become available for this area via NOAA in Washington, USA where data are now routinely downloaded from the satellite. Previously, no data were available from Brazil despite the existence of two receiving stations; further, the commissioning of the Cotopaxi station has been significantly delayed and no data have been available. Quick-look colour composites can be examined in Washington, and data can be provided as a full NOAA 1B product. The collection activity has been contracted out by JRC to a team at the University of Reading, UK.

2.1.2 High Resolution Data
High resolution data must also be collected for validation; this mainly consists of Landsat TM imagery, although research work into the use of ERS-1 SAR data is being performed by JRC staff (see Section 5). The high resolution (Landsat TM) data are provided by JRC personnel to contractors undertaking the validation. There is also an intention to collect 4 km GAC data for use in analysing seasonal variability of the forest coverage. At present no routine system exists for this collection.

In summary, despite considerable initial problems in data collection the TREES team have managed to establish a reasonably routine data collection system which relies on a mixture of using local personnel at receiving stations, collection via archiving facilities in the USA, and use of data routinely collected for other projects. Now that this network has been established, future problems in basic data collection are likely to be much reduced.

2.2 Data Pre-processing

The initial intention of the project was that, as in the case of data collection, routine pre-processing of the data would be carried out by ESA who would then deliver a final product to JRC for analysis. In practice however, all the pre-processing has had to be carried out either at JRC or by using contractors identified and monitored by JRC. This has inevitably led to a considerable delay in data pre-processing and hence in the production of the complete inventory.

The pre-processing consists of:

- correction of the five raw spectral channels to top-of-atmosphere reflectance (Channels 1 and 2) , radiance (Channel 3), and brightness temperature (Channels 4 and 5) retaining 10-bit precision
- atmospheric correction for Rayleigh scattering
- geometric correction to a Plate Carree representation at a resolution of 100 pixels/degree and with one pixel image-to-image registration accuracy
- generation of cloud and land/sea masks, and sun and viewing angles, where possible.

However, it has emerged from discussion with JRC personnel (JRC, VO4.3400.93) that atmospheric correction is not routinely performed on data at JRC, although it is performed by at least one contractor (A. Millington, pers comm). It should be noted that without atmospheric correction any interpretation of seasonal effects in the data must be made with caution.

This phase of the data processing is relatively routine since the radiometric and geometric correction processes are well known. The radiometric calibration is carried out using the detailed procedures laid down for SHARP-2A product generation, and using calibration coefficients provided in the international journals, as opposed to preflight calibration coefficients for channels 1 and 2. Similarly, the atmospheric correction uses reference values described in specified literature. The geometric correction consists of two stages:

- orbit model correction
- interactive selection of ground control points.

Resampling is carried out using nearest neighbour resampling which is considered by JRC personnel to be superior in terms of processing simplicity and speed over the use of cubic convolution.

The TREES team have developed their own software for orbit modelling and geometric correction. The former was necessary because the S.E. Asian data did not contain the appended geographic information found in NOAA 1B data (see Section 2.1). Where pre-

processing is carried out under contract, the contractor is expected to provide the software and to use methods clearly defined in the contract. This process is apparently well monitored at JRC (although the comments made above with respect to atmospheric correction should be noted here also).

The TREES team reported that there have been difficulties with geometric correction due to inaccuracies in the coastline maps, particularly along the Ivory Coast. In the S.E. Asian data the preliminary geometric correction has a 2 to 3 km error which must then be further reduced by manual techniques. The coastline maps are obtained from the WDB-II dataset held in TFIS (see Section 2.5); it is possible that when WDB-II is replaced by the newer DCW data this problem may be reduced.

The TREES team reported that the pre-processing stage for approximately 20 images would take about 2 man-weeks for the S.E. Asian data.

In summary, data pre-processing is a routine but time-consuming component of the data assembly. Methods appear to be clearly specified, and where the work is performed by a contractor it is monitored by JRC. Inaccuracies in geometric correction could become a potential problem, particularly where multi-temporal data sets are used, since this has an impact on the potential accuracy of any change detection process.

2.3 Data Analysis

The production of a classified data set is at the heart of the baseline inventory. This stage of the analysis was originally intended as the starting point of the JRC work, however, due to the circumstances described in the preceding two sections work on the data analysis has not been undertaken for the length of time originally intended.

The actual procedure varies to some extent with image quality and quantity. In general the focus has been on image 'windows' which are derived to indicate areas with a range of forest types. Within S.E. Asia windows have been specified for Thailand, Burma and Sumatra. The Thailand window comprises the ground area covered by three AVHRR scenes containing a total of 12 images from different dates. The Burma window is formed from the ground area covered by three AVHRR scenes and contains eight images. For Sumatra the window was formed from the ground area covered by five AVHRR scenes and contains ten images. For each 'window' the ideal seems to be five or six images obtained at the start of the dry season while the vegetation is drying out. However, for some areas, restrictions on data availability, particularly with respect to cloud cover, mean that only a single image, or a restricted set of images, might be available.

The classification procedure consists of a preliminary unsupervised classification of both a single AVHRR image and of whatever time-series of images is available. This preliminary classification can produce up to about twenty separate classes. These are then grouped using data from Landsat TM or SPOT imagery. The use of data from TFIS (see Section 2.5), such as elevation, or eco-floristic zone is possible at this stage, but has not yet been fully implemented. This classification procedure has been found by JRC to produce better results than the use of supervised classifications or the use of an unsupervised classifier where the number of classes is pre-determined. However, it is a time-consuming process which requires considerable familiarity with each individual image, and is not readily standardised. The availability of supporting information, such as TM data or field visits, is

necessary for the accurate grouping of classes. Currently it is estimated that the fine tuning of the initial rapid unsupervised classification can take about a month per image window.

So far, the majority of the work has been carried out on images of continental S.E. Asia which is a region mainly of seasonal forests. Results show that in addition to the forest:non-forest classes additional classes corresponding to various types of seasonal forest can also be identified. There have, however, been significant problems associated with transitions across image boundaries where classes in one image do not match those in another.

The classifications of west and central Africa done by NASA, a region mainly of rain forests, show a marked difference from those for S.E. Asia in terms of the numbers and types of classes attainable. The differentiation between types of seasonal forest is less clear, and the major demarcation seems to be between evergreen forest and 'degraded' forest. The appearance on AVHRR of degraded forest is often similar to that of certain agricultural types, so that accurate identification of degraded forest is difficult. This does not appear to pose a problem in S.E. Asia. The classifications in the African data have been carried out using both visual interpretation and digital classifications similar, but not identical, to those employed in S.E. Asia. It is the intention of the TREES team to revisit these data using the experience gained in the S.E. Asian work

No results are yet available for S.America.

To be useful for global monitoring the classes obtained from the data should be both meaningful and realistic. Ideally, the same classes should be obtained across the globe using the same methodology. However, these preliminary results indicate that due to differences in vegetation types and agricultural/social practices on the different continents it may not be possible to develop such a standardised procedure. The scale dependence of the classification schemes is also a problem in the analysis of satellite data, as it is in any traditional classification method. Decisions must be made as to the percentage cover within a pixel that results in its assignment to a particular class. Decisions on how classes identifiable in high resolution data are represented at low resolutions must also be formalised. Despite a long history of similar problems in other fields of remote sensing, this work is still in its early stages within TREES, but the TREES team are confident that the AVHRR data can be used globally to provide three basic classes: non-forest, evergreen forest, and seasonal forest.

The TREES team have carried out some interesting work on the spatial patterns of deforestation, their relationship to seasonal variability in the forest and the image resolutions required for their detection. They have identified four basic patterns of deforestation which are applicable in different parts of the tropics:

- a broad moving front of deforestation
- small patches cleared within a forested area (typical of Laos)
- deforestation along major roads/rivers forming broad belts (central Africa)
- large patches of deforestation containing dense road networks (Rondonia).

Each type might require detection with both different classification procedures and different sensor resolutions. For the broad moving front a low resolution sensor would be adequate. The patchy deforestation in Laos can be detected with a high resolution sensor, but also can cause changes to the appearance of the AVHRR data which mimic the appearance of seasonal forest and so might be identifiable by seasonal monitoring. The use of ancillary information in the form of road/river/settlement data provided via TFIS (see section 2.5)

might provide important information which could be used in a contextual classification of the African data.

In summary, the preliminary classification results indicate that it may not be possible to apply a standardised procedure across the globe, and that any local scheme is likely to require lengthy fine tuning using a variety of ancillary information. It is one of the significant challenges to the TREES problem to reconcile the problems inherent in applying a standardised procedure with the need to account for regional differences in forest characteristics. However, it is probable that three classes can be distinguished globally at the 1 km resolution: non-forest, evergreen forest and degraded/seasonal forest.

2.4 Validation

The validation process relies on the use of high resolution TM, MSS or SPOT data, supplemented by field visits where possible. It is intended eventually to include SAR data from ERS-1, but this has not yet been achieved.

The Thailand area has been validated using five TM scenes; three in the north, one in the south, and one in the east. These scenes were chosen to encompass particular patterns of forest and of deforestation. Within each TM scene 25 regularly spaced samples are chosen, with each sample corresponding to an area of 15 by 15 AVHRR LAC pixels. The TM scene is classified by field experts using whatever procedure they consider appropriate, and using ground data as much as possible. These field experts are either contractors identified by the TREES team, or members of the team. Contractors are supplied with TM data by the TREES team. There appears to have been some difficulty in identifying sufficient experts to cover all the regions of interest. The AVHRR classification is compared with the TM classification, and statistical comparisons are made. Visual inspection indicates a striking correlation between the two data sets. Statistical results show that the AVHRR classification consistently overestimates percentage forest cover in areas of high cover, and underestimates coverage in areas of low coverage, but that the AVHRR results follow the TM classifications very closely in terms of location of the boundaries.

There is interest in the research team in developing a 'correction factor' which could be routinely applied to an AVHRR classification to enable it to correspond more closely with the TM classification. A difficulty with this is that the correction factor has, to date, been found to be highly image-specific, so that extrapolation to different times/locations is not possible.

As in the classification procedure described in Section 2.3 there is a problem in making consistent decisions across the two scales of classification. Further, it is assumed in the validation analyses that all the images used are 'perfectly' registered so that differences in classification due to mis-registration can be ignored. In the light of the mis-registration problems reported earlier, this assumption will clearly lead to problems in interpreting some of the classification results.

2.5 Tropical Forest Information System

The Tropical Forest Information System (TFIS) is an Arc/Info based GIS which is intended both to provide data for use in the monitoring procedures and as a user 'front-end'. In this phase of TREES the focus has been on providing data to assist in classification, and its use as a 'front-end' has not yet been fully developed.

TFIS allows the user to display data at a variety of scales from the global, through regional 'windows' and down to the local scale. Currently data is included covering:

- ArcWorld
- Digital Chart of the World (in progress)
- Mundocart
- World Database II
- ETOPO-5 Global Elevation
- Major Ecosystem Complexes
- Eco-Floristic Zones for the tropics
- WCMC Managed Areas
- WCMC Forest Maps
- Various local data sets.

It is intended that at the local level many more data sets could be included such as scanned photographs, press clippings etc.. Additionally, both colour composites of raw AVHRR data, and classified AVHRR data can be included, although this has currently only been done for part of S.E. Asia, and it has not yet been determined how to deal with image overlap areas. Satellite data from other sensors could also be included at the local level.

TFIS includes data from many different sources, some in raster format and some vector. At present no attempt has been made to register these data, and it is apparent that registration is not adequate in some areas. This may however be less of a problem when the DCW data set becomes available.

Ultimately it should be possible to use TFIS data for comparison of the AVHRR classifications with those from other sources (e.g. WCMC). This has not yet been attempted, and it will be necessary to re-project all the Lat/Long data in order to derive areal statistics.

The use of TFIS during the AVHRR classification is restricted at present to input of the coastline data into the geometric correction procedure. It is not yet widely used by TREES staff, partly because it is a single-user system and partly because the user-interface has only recently been developed sufficiently to be accessible to non-GIS specialists. There is clearly considerable potential for the development of contextual classification procedures which could use, for example, the elevation maps, eco-floristic zones, or road and river maps as inputs to the classifier.

2.6 Research Developments

The seasonal nature of some parts of the tropical rainforest has already been noted as an important component of the data analysis (see Section 2.3). It would appear that in some

circumstances degradation of evergreen forest gives rise to a spectral signature in the AVHRR data which is similar to that of seasonal forest. Whether this is an actual seasonality, or an effect which looks the same on AVHRR data is yet to be determined, but in any event its detection could form an important component of an operational monitoring system.

It is possible that the use of low resolution (4 km) GAC data which is collected on a daily basis could provide important seasonal information, and be used to identify forest areas whose apparent seasonality characteristics were changing. This was included in the original TREES I proposal as a specific activity area. However, it would appear that, because of the difficulties experienced in obtaining the baseline coverage little further work has yet been done in this area.

Research into the operationalisation of the data collection, pre-processing, and analysis, and the inclusion of ERS-1 data were all originally cited as areas requiring research during TREES I. It would seem that very little progress has been made in these areas.

2.7 Other Issues

A number of other issues were noted, which may have had an effect on awareness of the project and its progress, namely:

- the limited amount of technical and internal project documentation
- the lack of promotion of the project to the user community
- the difficulties experienced in establishing the project team, due to the protracted recruitment procedures
- project control and scheduling procedures relevant to a research environment.

Along with the technical issues, the above will be addressed in the Work Plan for TREES II (Technical Note. No. 4).

3

Monitoring Active Deforestation

The item to monitor areas of active deforestation was subdivided into several activities:

- development of monitoring procedures
- identification of active deforestation areas
- monitoring of these areas via high resolution satellite data
- development of an 'alarm system'.

There has been little progress or the task has been subsumed into other work, for the first and last activity area listed above.

3.1 Identification of Active Areas

There is a two-way flow between the identification of active areas of deforestation following routine monitoring, and the selection of active areas for intensive study from non-satellite sources. The TFIS can be considered as the interface between the two flows, with data entering the system from both the AVHRR classifications and from ancillary sources.

Using satellite data, active areas can be identified from routine monitoring, although it is not yet clear how frequent such monitoring should be. Very frequent updating of the baseline would be costly, but if the frequency is too low the results would only be useful for a post-mortem analysis rather than as part of an active system.

Ancillary satellite-based information to identify active areas can come from monitoring of such deforestation indicators as fires and road construction. Work done during TREES I has indicated that the optimal timing of AVHRR passes for data analysis is in the early afternoon, however the burning times tend to be later than this and so are missed. In any case after 1995 the required data will no longer be routinely available. The use of road indicators is also problematic in that in some areas of S.E Asia the logging roads are not actually open to the sky and so cannot be detected via satellite data.

Within the current TREES project little specific work has been undertaken in this area due to the emphasis on production of the baseline inventory. The identification of active areas has been pursued through a contract to Dr. N. Myers (Oxford), followed up by a second contract to Myers and Dr R. Lucas (Swansea) and on which so far only Lucas has reported. Myers' approach is summarised in his paper to a 1992 conference in Brazil (Myers 1992). In that paper he lists 14 'tropical deforestation hot spot areas' but examination of this raises questions concerning the criteria for their inclusion. For example, logging pressures are equally heavy over all Sumatra and Kalimantan not just North and East and South respectively, and Eastern Malaysian forests whilst being vigorously exploited for timber are not being deforested, and this region has presumably been included because Myers chooses

to define logging of dipterocarp forests as deforestation (Myers 1990: see Whitmore and Sayer 1992). Myers (1992, P. 13) lists criteria whereby new 'hot spots' can be identified, but all of these are based on ground observations. The question then arises as to how TREES can help pinpoint deforestation areas that are not already known.

TREES I has begun to explore means whereby loci of active deforestation can be identified from low resolution images, i.e. on low resolution images a retreating forest boundary or change in radiometric signal as forests change near to a boundary, and on high resolution images fire, increased seasonality detected as altered radiometric signal, roads or mosaics. These signs present difficulties in definition and detection. They have the merit of being objective.

Another way to locate forest areas where loss would be serious is to consider known patterns of species richness. Enough is known about faunal and floristic richness in general, and of groups such as birds, mammals and butterflies in particular to identify areas of high richness and/or endemism. This has been done by Bibby et al. (1992) and also WCMC (1992) contains much basic data. For plants there are now sample plots scattered across the tropics on which number of tree species per hectare are recorded and these plots identify where tree-species rich forests occur although there are gaps in coverage (e.g. much of Amazonia and the Guyanas).

3.2 Monitoring Active Areas

Once an active area has been identified it must be monitored. This is seen as a separate issue from the routine monitoring required to identify the areas themselves. Active area monitoring should be based upon the analysis of high resolution TM or possibly ERS-1 data. This activity has not received direct attention in TREES I, however experience with analysis of the AVHRR and TM data indicates that the incorporation of seasonal data will be extremely important to distinguish long term from seasonal effects.

4

Modelling Tropical Deforestation Dynamics

The original project plan called for activity on producing spatio-temporal models of forest change, biosphere-atmosphere interactions and ecological modelling.

Due to the length of time taken to produce the baseline inventory little work has been done on the modelling programme. The categories of spatial patterns of deforestation identified by the team and described in section 2.3 are a preliminary step in producing a spatial model of forest change. A separate research programme (FIRE) is investigating the role of fire as an agent of transformation.

5

SAR ERS-1 Data Collection and Analysis

The use of SAR data from the ERS-1 satellite is still in the very early stages of implementation so that it is considered separately here from the routine use of AVHRR. Although eventually it is intended that SAR data be included in the monitoring and validation procedures, this has not yet been attempted.

The advantage of a microwave sensor is that imaging capability is independent of both cloud cover and day/night operation. Thus data can be obtained routinely over areas which are normally cloudy for much of the time. However the disadvantage from the point of view of global monitoring is that only a relatively small area is imaged at one time, so that enormous quantities of data would be required for any large area analysis. Further, the images are severely distorted in areas of rapid change in relief and require both an accurate DEM for generation of a geocoded image and further analysis to investigate the effects of layover and shadow on the received signal. Since accurate DEMs are not generally available at sufficient resolution over the tropical forest areas the data analysis is effectively restricted to regions of uniform relief. Research into the modification of the received signal according to variations in slope is still in its early stages, as is research into the generation of DEMs from the SAR data themselves using interferometric and stereo techniques.

Currently the TREES SAR effort focuses on the development of a set of tools for information extraction. Segmentation of the image proceeds in several stages:

1. The raw SAR image is block averaged to 100 m by 100 m.
2. Within each block a gamma filter is applied to reduce speckle, and edges and lines in the block are detected.
3. Certain patterns of edges/lines are taken to represent mountainous terrain and blocks so identified are removed from the analysis.
4. The remaining data are then resampled at about 40 m resolution using the mean value for each region.
5. These data are then classified with either an unsupervised (abf or afb procedure) classifier, or a contextual supervised classifier. This produces forest:non-forest classes.
6. The resulting product can be geocoded for inclusion in TFIS.
7. Multi-temporal data are considered, but since the images have not been geocoded these must be co-registered using sampling techniques. The results of co-registration are not considered to be very accurate, this leads to problems in interpretation of multi-temporal data.

Identification of seasonal effects has not yet been very successful and still requires considerable research. It is not clear whether this is due to multi-temporal registration problems, or to some other effect.

Currently several sample sites in Brazil and central Africa are being studied in detail. These are Acre, Rio Tapajos, Manaos, Bayla and Sassandra. Not all of these sites correspond with

the detailed test sites used in the AVHRR analysis, although this is planned for the near future. Results have been encouraging, but the differentiation of shifting cultivation from degraded forest is a problem (see also Section 2.3).

Obtaining ERS-1 data has been a major problem, and data are only recently becoming available. It is felt that the data may be limited because of the steep look and the short wavelength (5 cm). A longer waveband might provide 3-dimensional information since there is more penetration of the forest canopy. For future work the focus might have to be on the use of airborne data.

6

Conclusions

The introductory discussion shows that the monitoring or tropical forests is a complex task. The requirements for assessment are confused by the variations in agency information needs and the simple fact that what can be provided by remote sensing is not yet fully clear.

The two major objectives of the TREES project were to address deforestation issues at a global scale and to develop new satellite remote sensing techniques (see Section 1). The production of a baseline inventory and the identification, if not solution, of problems in its production can be considered as meeting the first goal. The development of new techniques is well underway. Progress in the inventory is gradually establishing suitable techniques, and in the area of segmentation of SAR data new methods are being developed.

TREES I runs until the end of 1993. It would appear that there is a good chance that the baseline inventory will be completed by this time, although much work remains to be done. The S.E. Asian classification is around 50% complete; about 50% of the African work has been completed by NASA, but needs revisiting in the light of the S.E. Asian work; the analysis of the South American data has not yet begun. Therefore, overall about one-third of the spatial content of the wall-to-wall classification is complete. The remaining two-thirds could be completed by the end of the TREES I project since the data are now available and pre-processed; and classification procedures used by the JRC team have been developed.

The original time table called for the completion of the data collection during 1991-2 and for analysis to proceed during 1992-3. This slippage is due almost solely to the inability of ESA to supply the pre-processed data to JRC as originally required. JRC staff have therefore had to invest considerable time and effort in what should have been routine work, and have been able to spend much less time on data analysis than was intended.

The current position of the TREES project in summary is:

1. The collection of data for the production of the wall-to-wall inventory is largely achieved.

2. Routes and procedures have been established by the project routinely to receive AVHRR data. The effort in collecting similar data for future inventory or monitoring exercises should be much reduced.

3. The project team has shown that it is possible to use AVHRR data at 1 km to provide classification into non-forest, evergreen forest and seasonal forest types, at least over S.E. Asia, and probably over Africa, although actual figures for accuracy are not yet available.

4. Different regional deforestation patterns have been identified, leading to the possibility of using different techniques in particular areas.

5. The potential of the TFIS system, while not fully demonstrated, is high in two respects. Firstly that of adding ancillary data to the AVHRR composites to aid classification and secondly in presenting results to users in a comprehensible manner and with contextural information.

6. The use of ERS-1 SAR data for global monitoring is unlikely, but it is possible that it may prove useful in monitoring small selected areas. Techniques for segmentation and classification are under development.

7. The monitoring and modelling aspects of TREES require considerable further effort.

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Technical Note No. 2

A Review of the Capabilities of Remote Sensing Techniques and Technologies used for Monitoring Tropical Forests

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1.

Introduction

Over the past decade, there have been a number of initiatives by research and development groups, both national and international, in using remotely sensed data for the inventory and monitoring of tropical forests. There have been high level discussions in this area in a number of fora including the International Space Year (ISY), the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, the International Geosphere – Biosphere Programme (IGBP), the Committee on Earth Observation Satellites (CEOS), the United Nations, the Commission of European Communities (CEC), the G7 and many others. The resulting initiatives have followed several routes both technically and in relation to perceived requirements.

Much of this work has been technology driven, particularly by the existence of data from instruments such as the NOAA AVHRR, airborne and spaceborne radar, Landsat TM and MSS and the French SPOT HRV instument. These data have been investigated to ascertain what information can be extracted from them in terms of forest type, distribution and condition. Where such information can be extracted, the question of monitoring arises; i.e. can this information be extracted repeatedly and consistently in order to provide time series of the values of each parameter. If the use of such remotely sensed data could be established and made operational then it is hoped that the use of the resulting information could be beneficial to the management of the world's tropical forests.

These initiatives are outlined in the following chapters. The structure of the report is based on the three steps necessary for all of the initiatives; namely identifying sources, data acquisition and management and data classification and analysis which leads to the production of information concerning tropical forests. Activities at the pan-tropical scale are emphasised although regional and non-tropical work is reviewed where it is relevant.

The review material and discussion in this report is oriented towards comparisons with the current TREES I work and the overall TREES objectives (see Technical Note No. 1).

2

Data Sources

This section outlines, very briefly, the major sources of remotely sensed data which are or will be available and have been used for observing tropical forests.

2.1 AVHRR Data

The Advanced Very High Resolution Radiometer (AVHRR) of the NOAA series of satellites has produced data in five channels since 1978:

Channel	*Wavelength (microns)*
1	0.58 - 0.68
2	0.72 - 1.10
3	3.55 - 3.93
4	10.3 - 11.3
5	11.5 - 12.5

One daylight pass per day is obtained, with a swath width of 3000 km. Since there are always two satellites in operation there is potential for twice daily coverage (Hill, 1991), although the spatial distortion introduced by off-nadir viewing limits this in practice. Data are available in various forms as described below.

HRPT Data
The High Resolution Picture Transmission (HRPT) data provides reflectance and brightness temperature data to 10 bit precision in all five channels. The measurement scale of the raw data is not constant across the image, changing from a pixel aspect ratio of almost 1:1 at nadir to 1:2.9 at the scene edges. The raw data are generally transformed to a specified map projection for analysis which usually involves resampling of the data to a ground resolution of 1 km. Data coverage is limited to those areas where the satellite is in direct line of sight of a ground receiving station antenna. Until recently this has not included the whole of the tropical forest belt. The length of archive available depends upon the individual stations, and is highly variable.

LAC Data
Local Area Coverage (LAC) data are at full resolution of 1.1 km, 10 bits and are the same as the HRPT data but are recorded on-board the satellite rather than transmitted to a receiving station. Limitations in the on-board recording capacity means that only partial coverage of the Earth's surface is possible. Priority is given to emergencies, U.S. security, military and commercial use, such that scientific acquisition has a low priority (see Section 3.1), and coverage is inconsistent in both time and space.

GAC Data

Global Area Coverage (GAC) data are at reduced spatial resolution of 4 km, but still at 10 bits. They are generated by on-board sampling of the full resolution data such that for a given scan line the first four pixels out of every five are averaged, and only every third scan line is processed. Thus, although the data are generally treated as 4 km resolution, this is not strictly the case. However, the reduction in data volume means that on-board recording is possible for the whole globe daily.

The GAC data set is archived back to June 1981 and is available from NOAA. These data are not produced to a standard map projection, and hence require geometric rectification. This is complicated by the fact that the ground size of the pixels varies considerably across the swath (Townshend, et al, in press).

GVI Data

The Global Vegetation Index (GVI) product consists of the Normalised Difference Vegetation Index (NDVI) produced from Channels 1 and 2; Channels 1 and 2 truncated to 8 bit precision (for 1982 - 1984); and Channels 1, 2, 4 and 5 where 4 and 5 are converted to 8-bit GOES counts (1985 onwards).

The NDVI is calculated from the daytime passes of all 14 daily orbits of GAC data, mapped from 1985 to the present to a Plate Carree projection (16 km at the equator) or a Mercator projection (19.5 km at the equator). Only one GAC pixel is selected for each GVI pixel according to a set of well established rules, such that the maximum NDVI is retained for each pixel. This is to ensure that pixels least contaminated by atmospheric effects are obtained. The final product is a result of compositing the daily arrays over a 7–day period such that the maximum NDVI value is retained for each location.

The large undersampling of the GVI data, and the compositing into a maximum over seven days limits these data for use in global monitoring (Townshend and Justice, 1986) however, their value lies in the high frequency of coverage. Goward, et al (1990) provide a detailed description of the data limitations.

2.2 Landsat Data

MSS Data

Landsat MSS scanner data have been available since the launch of the first Landsat satellite in 1972 – the current satellite is Landsat 5. They provide data at 79 m spatial resolution in four spectral bands. The data are quantised to 6 bits.

Channel	*Wavelength (microns)*
1	0.5 - 0.6
2	0.6 - 0.7
3	0.7 - 0.8
4	0.8 - 1.1

The orbital coverage is such that the entire globe can be covered with an 18 day repeat cycle (Landsats 1, 2 and 3 had a 16 day cycle), with each image covering a ground area of 185 by 185 km.

TM Data

Landsat TM data have been available since the launch of Landsat 4 in 1982. Data are produced with the same repeat cycle and ground coverage as MSS, although the spatial resolution is 30 m, and the data quantisation is to 8 bits. The spatial resolution of band 6 is 120 m.

Channel	*Wavelength (microns)*
1	0.45-0.52
2	0.52-0.60
3	0.63-0.69
4	0.76-0.90
5	1.57-1.78
6	2.08-2.35
7	10.4-12.5

2.3 SPOT Data

The French SPOT satellite was launched in 1986, with a follow on in 1990. It provides imagery with a spatial resolution of 10 metres in panchromatic mode, and 20 metres in multispectral mode. Each ground swath covers 60 km, and there is a repeat period every 26 days.

The satellite has a pointing capability such that the detectors can point up to 27° either side of the ground track, providing the possibility both for stereoscopic imagery and more frequent coverage of a particular area.

Channel	*Wavelength (microns)*
XS1	0.50-0.59
XS2	0.61-0.68
XS3	0.79-0.89
Panchromatic	0.51-0.73

2.4 Radar Data

Satellite-borne microwave sensors are a very recent addition to the set of available satellite data which could be used for environmental modelling. The primary advantage, especially for tropical areas is that cloud cover is not a restriction. Data availability is considerably more restricted than for the other longer established sensors.

ERS-1

The ERS-1 satellite was launched in July 1991 carrying a C-band SAR which has a frequency of 5.3 GHz, VV polarisation, and a nominal ground resolution of 30 metres. The mission is divided into different phases differentiated by alterations in the orbital characteristics. For environmental monitoring the 35-day repeat phase is the most important. However, due to the high power consumption of the SAR instrument and the limitations of on-board storage the actual receipt of data is severely limited to an operation of 10 to 12 minutes per orbit and

to operation within the reception area of a ground station. Insofar as tropical forest monitoring is concerned, data acquisition is limited to the period from April 1992 to December 1993 because of demands for sea ice observation during the 3-day repeat periods.

Data products can be divided into three categories:

- raw annotated data available at the PAFs a few days after acquisition
- fast delivery products generated and distributed by the ground stations
- off-line products available via the PAFs at varying levels of processing.

Apart from the SAR on ERS-1, there is an Along Track Scanning Radiometer (ATSR) which has some channels similar to the AVHRR. However, ATSR is optimised for sea surface temperature and there are only two visible/NIR channels, of which one failed during 1992.

JERS-1
JERS-1 was launched by Japan in 1992 carrying an L-band SAR which has a frequency of 1.3 GHz, HH polarisation, and a nominal ground resolution of 18metres. The repeat period is 41 days.

Airborne Sensors
There have been many missions to map tropical forests using airborne SLAR. These are discussed in Section 3.5.

2.5 Future Satellite Sensors

'Vegetation' for SPOT 4
There is a proposal to mount a specific vegetation monitoring instrument on the next generation SPOT satellite. This would be similar to AVHRR, with the important difference that on-board recording capability would be sufficient to allow downloading of data once per day to a ground station. This would allow daily global coverage at 1 km resolution. A further advantage is that data would be exactly contemporaneous with the higher resolution data on the same satellite allowing for easier comparisons between the data.

Since this proposed system would overcome many of the inherent problems in using AVHRR data it is likely to be of considerable use for global tropical forest monitoring.

Radarsat
This is a primarily Canadian initiative with U.S. partnership, and is scheduled for launch in 1994. The satellite will carry a C-band SAR capable of an extensive range of operating modes. There will be a 16 day repeat cycle.

ERS-2
The Advanced or AATSR will be flown on ERS-2 and ENVISAT and will include more channels in wavebands suitable for land applications.

MODIS

The Moderate Resolution Imaging Spectrometer (MODIS) is a part of the U.S. Earth Observing System (EOS). In terms of its field of view and frequency of imaging it will be comparable to the AVHRR, but will have improved spectral, radiometric and geometric properties specifically optimised for land applications. However the swath width will be less than AVHRR, which means that the return period and hence the ability of MODIS to gain cloud free coverage is reduced by comparison. The spatial resolution for the land application spectral bands will be 250 m and 500 m (Townshend, et al, 1993). Launch is planned for 1998.

MERIS

The Medium Resolution Imaging Spectrometer (MERIS) is a European instrument which will have 15 spectral bands in the range 0.4 - 1.1 microns with a ground resolution of 250 m for land applications. Recording on-board of all data in each pass is planned ensuring security of data supply. A number of vegetation products are currently under investigation. Launch is planned for 1998.

3.

Data Acquisition and Management

To enable information extraction, data from the various sources requires collation, processing into standard formats and managing. Management includes cataloguing, archiving and preparation for particular applications. This section outlines the major programmes concerned with such activities in relation either directly or indirectly to tropical forests.

3.1 International Geosphere–Biosphere Programme – Data Information System (IGBP-DIS)

The 'Land Cover Pilot Project' (IGBP 1992) is a major initiative by the IGBP to gather global scale remotely sensed data sets for use in a range of projects researching global change. This obviously includes tropical forests. A series of trade-offs between data availability, coverage and temporal and spatial resolution led the IGBP to the conclusion that the NOAA AVHRR data should be the first of these sets to be gathered. This data set was regarded as the best available for the investigation of land processes for a number of reasons including:

- availability at different resolutions including the relatively high resolution 1 km LAC
- relatively broad range of the spectrum across which scanning occurs
- temporal resolution being relatively frequent for the whole globe.

In order to prepare suitable data sets, LAC data is required to be collected continuously. This is because the frequent cloud contamination of images necessitates the use of multiple images of the same area to build up complete surface observation records. There are several barriers to such a goal:

- instrument acquisition and on-board data storage capacity
- receiving station operation and location.

LAC data cannot be recorded on-board for the whole globe and are obtained largely by direct downlink of the HRPT to receiving stations in view of the satellite at the time of acquisition. HRPT is broadcast continuously to any station able to receive it.

There are more than 50 such stations scattered around the globe. The primary motivation for the national organisations receiving these data is for weather forecasting rather than land process studies. Forecast use is often satisfied by immediate interpretation of images and data are subsequently not always archived, still less catalogued. The exact status of the various stations is difficult to ascertain (IGBP 1992, Appendix 2). There are however notable gaps in national HRPT coverage in northern South America, the Middle East and large parts of Asia.

There is some on-board storage capability enabling LAC to be obtained for selected areas and downlinked, but this is relatively small (around 10-12 minutes per orbit). However, acquisition is assured for the instrument operators. Acquisition is controlled by the 'Interactive Processing Branch' of NESDIS and the coverage is prioritised, with U.S. emergency, military and commercial interests having first priority. This leaves scientific requirements as a low priority. The recorded LAC data are downlinked to one of two sites in the U.S. and re-transmitted (via satellite) to centres in Washington D.C. and the EROS Data Center. There is a further centre at Lannion in France but this is not operational for receipt of recorded LAC data. The recorded LAC data provides some 40 scenes per day for the archives.

The IGBP initiative envisages the coordination of selected HRPT stations and the recorded LAC coverage to provide continuous monitoring of land areas. This coordination would be under IGBP-DIS, CEOS or the ISY and be centred at the EROS Data Center. The selected stations, many of which are in developing countries, may require assistance to perform the necessary activities, a task which is already in hand in several cases with ESA support. The Lannion centre could also be upgraded to provide increased acquisition flexibility. By 1993, the EROS Data Center (also known as the Land Process Distributed Active Archive Centre – DAAC) had acquired 10,000 AVHRR scenes by this type of coordination of recorded and HRPT stations. In addition, browse and metadata products have been produced.

It is clear from the distributed nature of data acquisition, that management of incoming data is a major task. For this and other global data sets, the management task can be broken down into three areas (IGBP, 1992, P. 53):

- disseminate catalogue information
- assure suitable archive techniques
- enable access to the data.

The IGBP has encouraged the development of a directory based on the NASA Master Directory. This directory aims to provide a comprehensive listing and description of data sets useful for global change studies. The current status is that there are directories at a large number of data centres including NASA, NASDA, ESA, UNEP/GRID, EROS etc.. This system allows users to ascertain where data are, but not actually to obtain them. This is a matter of distribution policy.

Archiving can be centralised or distributed and carried out using a range of media. The key to efficient archiving across sites as seen by IGBP is the networking of data centres with a central node and larger regional centres as outlined above. A wider institutional framework is provided by the ICSU World Data Centre (WDC) network which has collected a large amount of data on a discipline basis since the 1960s. Utilisation of WDCs, with perhaps a central archive at EROS is possibly a suitable means to archive the 1 km data set.

There is currently no internationally accepted long term archive media other than hard copy. There are a number of options each with its own advantages and disadvantages. Capacity, life expectancy, transfer rate, cost, availability and automated handling all vary. For example, exabyte is inexpensive and capacious in comparison with 5.25-inch optical disc; although the latter has greater robustness and longevity. The 1 km data set itself comprises approximately 1 terabyte annually which gives an indication of the volume of data from such global data sets.

For tropical forest monitoring using AVHRR (and future data sets) these issues are clearly critical. If the management of these data can be organised efficiently on a global scale in terms of acquisition, cataloguing, archiving and distribution then monitoring using them becomes a realisable goal. The applicability of the IGBP data set to tropical forest monitoring is clear in the light of the TREES I data acquisition activities reported in Technical Note No. 1. This was also recognised by the ISY World Forest Watch conference (Rasool, 1992).

3.2 FAO Forest Resources Assessment

A quite different data acquisition and management activity, but one aimed specifically at tropical forests is the FAO Forest Resources Assessment (FRA) project. The first project was undertaken in 1980 and was largely an effort to collect and collate statistics on forest cover from national sources. Many of the statistics were gained from non-remote sensing sources. Two mapping units were used, namely forest and woodland, the definition being closed woody canopy versus tree cover ≤40%.

The 1990 project has relied more heavily on remote sensing techniques with a survey using Landsat 4/5 scenes for a sample of 10% of the forest area. The 1990 survey has recently been completed using eco-floristic zones produced in the 1980s in cooperation with the French Institute for the International Vegetation Map (FAO, 1993). It is not yet clear how these zones relate to the 1980 mapping units (FAO, 1992). Data acquisition is simple compared to AVHRR given the repeat period of 10 years and the 10% area coverage, in fact 117 scenes were interpreted by selected national forest agencies. Landsat is of course prone to the same cloud coverage problem as AVHRR necessitating the checking of many scenes before cloud free images can be found. Quicklooks are available from commercial vendors which enables cloud free scene selection to be made relatively easily.

The FRA project has also suggested an annual monitoring exercise based on the 10% sample which would necessitate a somewhat larger acquisition exercise. A different 10% is sampled each year resulting in full coverage every 10 years. This programme for continuous assessment of tropical forest resources using high resolution satellite data is currently seeking funds. The work would be decentralised and done in close collaboration with individual countries. The results would be collected by FAO who would compile global statistics. The results from both the 1980 and 1990 FRA exercises are controversial. The table below gives tropical moist forest areas and deforestation rates for the preceding years (for full details see Grainger, 1993, Tables 2, 3, 5 and 6). These estimates suffer from several of the problems noted below and should be viewed very cautiously.

Source	*Date*	*Area (million hectares)*	*Deforestation (mha/annum)*
Persson‡	1974	979	n/a
Sommer	1976	935	11-15 (for FAO)
FAO	1980	1201	7.3 (closed inc moist forest)
Myers‡	1980	972	7.5-20
Grainger	1983	1081	6.1
Myers	1989	800	14.2
FAO	1992	1282	12.2 (preliminary)

‡ derived by Grainger (1984)

Grainger (1993) also made a number of points about the accuracy of figures which apply to FAO and other inventory work:

- Who made the estimate? There are only two primary estimates of deforestation rates at a global level; that of the FAO and that from Myers. Most other estimates are secondary; i.e. derived from these primary estimates.

- To what type of change in forest cover does the estimate refer? Grainger defines deforestation as the 'temporary or permanent clearance of forest for agriculture or other purposes' which should be distinct from degradation caused by selective logging. FAO also make this distinction. The implications for inventory where definitions are not consistently applied are clear.

- What type of tropical forest is referred to in the estimate? This relates to the question of classification (see Section 4.2). Estimates for closed forest, open forest, moist forest etc., obviously cannot be compared either between nations or through time for different classifications.

- Was the estimate based on specified measurements or on the subjective judgement of an expert? If a measurement system was used then a reliability estimate should be available.

- If measurements were made, what remote sensing technique was employed?

- If measurements were made, was the whole forest area surveyed or just part?

- What were the dates of the measurements?

- Were estimates on which deforestation rates were based, both derived from the same source?

- Does the change refer to an historic or a projected change? It appears that projections have sometimes been taken as historic fact.

The FAO is aware of these problems; their 1980 figure of 7.3 is for forest clearance only. Further figures relate to undisturbed closed forests logged, but not cleared (4.4 million ha) and clearance of open trees formations (3.8 million ha). Adding both closed forest figures gives a figure closer to Myers' figure which are less explicit in definition.

Whitmore and Sayers (1992) indicate similar difficulties caused by problems in varying definitions of deforestation and classification criterion in their review of specific countries. Estimates of tropical closed forest area in Asia shows some countries with large decreases, while others such as Laos show increases. Deforestation rates show general increases at a national level which, despite definition problems, supports the general conclusions that rates have increased during the 1980s.

Final figures given by the 1990 FAO FRA report (FAO, 1993) estimate annual deforestation 1980-1990 at 15.4 million ha. This figure includes a wide range of forest types broken down into lowland formations (rainforest, moist deciduous, dry and very dry), upland formations and non-forest zone (< 0.5% contribution). The main division between forest and non-forest

is at 10% crown cover with deforestation defined as any land use change causing depletion of cover to below this figure. Degradation is not reflected in the FAO figures.

It is clear that FAO have made a significant contribution to information on tropical forests. However, many problems remain to be solved.

3.3 NASA Pathfinder

The Pathfinder activity is closely related to the IGBP-DIS initiative reported in Section 3.1. The NASA research group based at Goddard Space Flight Center has worked extensively with GAC (Global Area Coverage) to study vegetation in general. The advantage of GAC is that it is recorded globally and downlinked at one point making acquisition a simple task.

The Pathfinder (GIMMS) group is currently engaged in two data acquisition and management activities linked to tropical forestry.

The first activity is involved with the reprocessing of GAC data from 1981 to 1991. Channels 1 and 2 (visible) are being recalibrated and new NDVI are being output for fortnightly intervals for the 10 year period (Townshend, et al, in press).

Secondly, the group is using Landsat data to compile multi-date pan-tropical (wall-to-wall) inventory of tropical forests using manual interpretation techniques. In comparison with the FAO FRA effort, the acquisition of pan-tropical (i.e. covering the tropics) Landsat scenes is large (500 minimum). The results, known as the Humid Tropics Forest Inventory (HTFI), will produce complete forest cover maps of selected regions of S.E.Asia, central Africa and Amazonia for the mid-1970s, mid 1980s and mid 1990s. The objective is to monitor changes in cover.

There are several other acquisition and management problems faced by the NASA group (Justice, 1992):

- The availability of scenes from the tropics. After the commercialisation of the supply, the number of requests for tropical areas dropped considerably which means that the historical record is sparse.

- Local receiving stations in the tropics do provide coverage missing from the central archive, but the metadata from and contact points at these stations is often uncertain.

- The quality of and access to MSS data from the 1970s is problematic since much of the data is in photographic format and there are dropouts and detector banding in the scenes.

3.4 United Nations Environment Programme

The United Nations Environment Programme (UNEP) coordinates the Global Environment Monitoring System (GEMS) as an element of the United Nations Earthwatch programme.

The Global Resource Information Database (GRID) is part of the GEMS. Its mandate is to collect, store and disseminate geo-referenced data of all types. In relation to tropical forests, GRID aims to collect and disseminate AVHRR data for tropical regions and assist the FRA (see Section 3.2).

3.5 Radar Data Initiatives

Radar covers both airborne and spaceborne (Synthetic Aperture Radar – SAR) technology. There is a relatively long history of forest research and attempts at inventory using radar in both forms.

Early work using Side Looking Airborne Radars (SLARs) in the 1950s and 1960s quickly became commercial in the RAMP (Radar Mapping of Panama) project. This led to a number of similar projects in south and central America such as the Brazilian RADAM project. The scale of the RADAM mosaics was 1:250,000 and covered an area of 8.5 million square kilometres. The SLAR images were interpreted visually to provide thematic maps geared towards terrain analysis for oil and mining sites evaluation. In addition, the images provided information on broad forest type, land use for agriculture, soil type etc. (Churchill and Sieber, 1991 and van der Sanden, 1990).

Current work by a Dutch group under the Netherlands Remote Sensing Board consisting of various workers from ITC and the Wageningen Agricultural University (van de Burg, 1992) focuses on the investigation of airborne radar backscatter. The research uses local sites in Columbia and Guyana for which substantial amounts of local survey work has been done (including optical remotely sensed data). Correlating backscatter with known forest types enables radar signatures to be characterised. This should allow spaceborne SAR to be utilised in forest inventory; in particular it is hoped that the ERS-1 SAR can be utilised. Similar work is being undertaken as part of the 'South American Radar Experiment' (SAREX-92) and planned for the CEC-ESA EARSEC project.

For this recent work the key data acquisition effort is in synchronising local field and airborne survey with spaceborne (i.e. ERS-1) overpasses such that SAR images can be obtained. This is more difficult than for NOAA-AVHRR and Landsat since the ERS-1 SAR is only able to acquire data for 10% of any orbit. In addition, only a limited quantity of acquired data can be produced at the required product level in the ground segment due to the very heavy processing requirements. Thus, a precise request for the location of the required image must be submitted to ESA in advance of the appropriate orbit.

In space, the first SAR to be flown was on Seasat in 1978. This was an L-band instrument as were the two Shuttle Imaging Radars (SIR-A/B) flown in the early 1980s. Currently the ERS-1 mission provides C-band coverage. This is to be followed by ERS-2 and then Radarsat, all C-band. The recently launched JERS-1 has an L-band instrument. There are several problems which limit potential use of spaceborne SAR by tropical users:

- the very high data production rate requiring sophisticated ground receiving equipment
- the heavy processing requirement requiring extensive computing facilities.

In the context of the TREES project, acquisition of such data is planned to be an important

input for local validation and calibration of globally acquired data (such as AVHRR) or in giving detail to areas of active deforestation indicated by global scale monitoring. The ability of radar to provide global or regional scale information in itself will depend on the scale of airborne missions and on the representativeness of the relatively very small areas covered by SAR.

Further discussion of the use of both space and airborne instruments in found in Section 4.3.1.

3.6 Conclusions

The issues in the acquisition and management of data for tropical forest monitoring from current remote sensing instruments are many, both technical and institutional/political and include:

- instrument acquisition modes are not optimised for tropical areas
- data volumes are large
- data holdings are neither centralised nor standardised.

Section 4 of this report gives more detail about the subsequent analysis of these data and highlights further issues.

4.

Data Analysis and Classification

4.1 Introduction

In order to map and monitor tropical forests, a classification system is required. This classification must answer the following questions:

- what is the appropriate spatial scale of measurement for tropical forest monitoring?
- what temporal scale is required for monitoring (i.e. to identify seasonal effects)?
- what temporal scale is required for change detection?
- what classes should be extracted from the data?
- what classes can be extracted from the data?
- should the classification be based on established (non-remote sensing) scheme?
- should the same classes be extracted globally, or should the emphasis be on classification appropriate to local conditions?
- what classification procedure best identifies the classes of interest?
- is there a set of classes which can be extracted operationally, even though these may not represent the full potential of the data?
- how should the results be validated?

Section 4 considers current work with the exception of the TREES work itself which is considered in Technical Note No. 1 and attempts to establish how far these questions are being addressed. Section 4.2 outlines some issues in vegetation classification in general and in relation to remotely sensed data and Section 4.3 outlines the information potentially available from satellite data, describes current methods used for information extraction and considers validation methods.

4.2 Vegetation Classification Systems

Despite a long history of attempts stretching back over a century, there is currently no one agreed system for classifying the world's vegetation. This is sometimes a problem in fields associated with agriculture and the environment where information about the distribution and condition of vegetation communities is required. There have been a number of attempts to produce schemes; and these are three types (Adams, 1992):

- **Structural-physiognomic**
  These classifications are based on the visible features of structure (i.e. height), cover and physionomy; for example leaf form, deciduousness and spininess. Broad-scale schemes such as those of Kuchler (1967), Kuchler and Zonnerveld (1988) and UNESCO (1973) fall into this category. For tropical forests, the

scheme widely used in India and Malesia (Champion, van Steenis and Whitmore) and for Africa (White) also fall into this catagory. Matthews (1983) used the UNESCO system to produce a 1° raster grid for the world containing 32 classes such as temperate/subpolar evergreen forest, cold-deciduous forest without evergreens and tropical/sub-tropical evergreen drought-deciduous forest. There are in addition a large number of smaller schemes relating to regional, national and sub-national levels.

- **Floristic**
  Key plant types characterise the particular class. The plant is seen as typifying class character and ecological relationships. Takhtajan's (1973) world biogeographical provinces is one example while at a regional level, Braun-Blanquet's (1965) classification of Europe is well known.

- **Bioclimatic**
  Such classifications use climatic criteria such as rainfall, temperature and frost occurrence to classify vegetation regions. Holdridge (1967), Koppen (1936) and Walter (1973) are major examples. The Holdridge classification contains 39 classes such as: boreal moist forest, warm temperate dry forest and subtropical wet forest.

With this range of systems, the spatial extent of different types of vegetation can become a point of dispute; partly because of variations in the meaning of classes between systems and partly as a result of different measurement techniques even where classes do coincide (Townshend, et al, 1991).

Adams (1992) examined the various criteria used for classification systems and attempted to achieve the best compromise solution for each:

Criteria	*'Solution'*
structure, floristics or climate	structural / climatic
definition of limits	quantitative
field mapping factors	use existing classes as far as possible
number of categories	20
transitions	use existing methods but narrow options for divisions
anthropogenic influence	use time limited disturbance criteria

The resulting forest categories are for example: tropical broadleaved woodland, tropical deciduous broadleaved forest and cool woodland. The major discriminants at the highest level are the coverage of woody vegetation of certain heights (e.g. >6m, <0.6m); the broadleaved coverage and the average temperature of the warmest/coldest month. This leads to the production of 22 classes divided into natural/intensively cultivated and non-inundated/wetland groups. For spatial resolution, 1 km squares are recommended. Adams floated this idea in 1992 and is looking for response and discussion to try and move towards consensus.

Adams' classification attempts to meet the needs of a wide range of researchers, planners and developers. It attempts to take into account various requirements and reconcile them in a single system. The system is not systematic in terms of language or quantitative criteria neither is it novel, but is grounded in the real experience of workers in the field. Such an

attempt is therefore very valuable in giving an insight into requirements to be met by remote sensing. It is not as yet an accepted system, but represents an important viewpoint and one endorsed by WCMC.

The key discussion point raised by Adams is that of the need to use classification factors which are "easy to map from field vegetation" (Adams, 1992, P. 6). The challenge is to reconcile classes realisable from remotely sensed data to the classes defined by "real information which a vegetation category must carry in terms of its character as a habitat for animals, a fuel wood resource of whatever" (Adams, 1992, P. 6). Obvious parameters quoted by Adams (and which form a vital part of his proposed scheme) are canopy cover in relation to vegetation height. These can be directly related to biological realities which then enable management activities to be undertaken.

Taking Adams' proposed classification as a statement of requirement, the question arises as to whether remote sensing can supply some or all parameters necessary to define the classes. The obvious first answer is that no single spaceborne system can currently supply values for all of his parameters. However, some can be supplied and the following discussion outlines what they are.

4.3 Classification of Tropical Forests Using Remotely Sensed Data

The goal of the data analysis is to produce a classification of tropical forests which is useful for assessment of forested areas and for subsequent monitoring. Therefore for remotely sensed data to be used in forest classification there must exist a relationship between the parameters measurable from the image data and the required classes. This procedure can be data-driven, i.e. researchers can attempt to discover what classes could be extracted from the data. Alternatively it can be user-driven, i.e. given a set of required classes (e.g. Adams') a method must be established to extract these from the satellite data.

Section 4.3.1 describes the parameters extractable from the data. Section 4.3.2 describes methods which have been employed to use these parameters to produce a classification scheme.

4.3.1 Data Discriminants

This section outlines the parameters available from remotely sensed data which can be used to discriminate between tropical evergreen forest and other land cover categories.

Data Discriminants for Optical/Thermal Sensors

Spectral

Spectral discrimination between vegetation classes in remotely sensed data depends upon varying responses in the red, near infra-red and thermal portions of the spectrum. As a broad rule photosynthetically active vegetation produces a low spectral response in the red channel and a high spectral response in the near infra-red. This has led to the extensive use of various ratios between these bands in studies of vegetation, the most widely used of which is the normalised difference vegetation index (NDVI) where the index is derived from the ratio of near infra-red minus red to red plus near infra-red (Townshend and Justice, 1986). This index can be produced from Landsat, SPOT and AVHRR data. However,

despite the production of a Global Vegetation Index (GVI) data set from AVHRR data on a routine basis, the index has been found to be unsatisfactory for tropical forest monitoring (Malingreau, et al, 1989). This may be because of the poor quality of the red channel data (AVHRR Channel 1) which is greatly influenced by haze, smoke and other atmospheric effects, and exhibits an overall low contrast. Also, AVHRR Channel 2 includes a major water absorption band, and variations in water vapour can cause changes in the appearance of NDVI values unrelated to any change in ground conditions (Townshend, et al, in press).

However, the thermal infra-red channel of AVHRR can on its own provide discrimination between tropical forest and other vegetation types, since there is a clear drop in signal over closed forest canopies (Malingreau, et al, 1989). Thermal contrasts between forest and non-forest are at their greatest at the end of the dry season and the thermal Channel 3 of AVHRR has been successfully used for forest:non-forest discrimination (Gastellu-Etchegorry, et al, 1991). Some forests of course have no dry season. Channel 4 and Channel 5 can also be used satisfactorily.

Temporal

The use of time-series of remotely sensed data to discriminate between various forms of 'seasonal' forest has not been fully exploited. It is known from analysis of GVI and GAC data that the periodicity in the photosynthetic activity of the tropical forests can be traced. It is also known that as the seasonal character of the vegetation increases so does the amplitude of the NDVI; this appears to be related to rainfall patterns (Malingreau, 1991). In order to exploit this variation it would be necessary to have sufficient seasonal data available at a resolution at which the seasonal variations can be identified. This represents a major problem, since the high resolution data such as Landsat TM or SPOT may not be available sufficiently frequently, and would require in any case immense amounts of data processing, while the more readily available GAC data may not be of sufficient resolution to be suitable for spectral discrimination of seasonal change.

The use of time series of data for monitoring tropical forests has also not so far received much attention, due in large part to the absence of suitable long term data sets. A further problem in interpretation lies in the necessity to atmospherically correct the data so that any spatial or temporal changes may be attributed to real differences rather than to changes in radiometric calibration of the sensor, or atmospheric or illumination differences (Ahern, et al, 1987, Singh, 1988). The utility of both GAC and GVI data is limited by the absence of on-board calibration of Channels 1 and 2 and the effects of instrument degradation over time (Holben, et al, 1990). Inter-annual comparisons must therefore be made with care (Townshend, et al, in press). Accurate registration is also a problem when analysing such data sets (see also Section 4.3.3). Additionally, the problem of cloud cover can limit the availability of suitable data.

Circumstantial Evidence

The major circumstantial indicators that deforestation may be occurring are the presence of fires, roads, burn scars and smoke (Malingreau, 1991).

Active burning can be detected using thermal data, for example Channel 3 of AVHRR. Although the actual area of fire cannot be measured, the total number of fires can be used as an indicator of activity. There is however a problem in detection, since the times of peak burning do not necessarily coincide with the times of a satellite overpass. Also, AVHRR Channel 3 can saturate quickly, leading to confusion between fire and merely hot ground. Additionally, the undersampling of AVHRR GAC and GVI data is such that potential fire

pixels may be completely missing from the data (Belward and Lambin, 1990). High resolution 1 km data are therefore necessary for adequate detection of fires. However, burn scars from recent fires can be detected with AVHRR (Malingreau and Belward, 1992), (Langaas and Kane, 1991).

Road building can also be a major indicator of active deforestation (Fearnside, 1985) and has been used in monitoring studies in the Amazon Basin (Malingreau and Tucker, 1988). However, roads may not always be identifiable at the scale of the satellite data, particularly AVHRR LAC and GAC, and logging roads may not always be open to the sky, for example in Guyana (Whitmore, pers. comm.). The potential of road indicators for global monitoring is therefore limited.

Radar Data Discriminants

Cloud cover is a major limitation in the use of the optical portion of the electromagnetic spectrum, and the problem is particularly severe in the humid tropics where cloud cover can be an almost permanent feature. This is a major reason for the interest in the use of radar for tropical forest monitoring. The image derived from radar is a measure of the backscatter of energy from each element or pixel of that image. Backscatter varies according to a number of parameters (van der Sanden, 1990):

- radar system configuration in terms of frequency/wavelength, polarisation, incidence angle and viewing geometry
- terrain and surface cover properties including soil moisture.

System Configuration

Radar wavelengths/frequencies are traditionally one of several lettered bands ranging from Ka-band at around 8 mm (~36 GHz) to P-band at around 1 m (~420 MHz). Longer wavelengths penetrate the forest canopy to a greater extent and thus provide information on parameters such as stem volume (including the volume of branches enhanced by coniferous needles from which long wavelengths give a strong backscatter). On the other hand, shorter wavelengths are scattered by the canopy, especially if the canopy is of deciduous leaves. This means that the band chosen can help to distinguish forest type (coniferous and deciduous). In addition, the longer wavelengths can discriminate between primary and secondary forest due to the differences in woody biomass and surface clutter. In terms of workable applications, Werle (1986) lists discriminants which could be extracted from X- and C-band:

- deciduous/coniferous forest
- age/height differences
- forest boundary.

Polarisation is usually H(orizontal) or V(ertical) both for transmission and reception; i.e. HH, HV, VH or VV. Cross polarised (HV or VH) images tend to emphasise volume scattering (i.e. from canopies) in either mode. Whereas, like polarisation (HH and VV) produce differing results depending on the mode due to the interaction with the orientation of branches (Sieber, 1985). Sader (1987) lists the discriminants which may be discernible:

- canopy characteristics
- species composition/structure
- wet soil exposure.

Incidence angle can have a significant effect on backscatter. A number of studies show how angles ranging from 20° to 60° are related to ability to distinguish forest parameters. An optimum angle of about 30-40° is agreed by several since at this angle, differentiation between forest classes is maximised.

The relationship between the sensor and object orientation affects backscatter directly; notably the enhanced backscatter at forest edges.

Terrain and Surface Cover Properties
Topography has well known effects on radar images in terms of relief displacement (foreshortening and layover) and shadow. The removal of such effects is the subject of much work with DEMs and precise geocoding.

Within the forest, there are no simple relationships between backscatter and forest structure parameters; except perhaps for biomass and backscatter although response tends to saturate early with rising biomass. Using multiple regression techniques improves relationships by combining parameters. Both soil and canopy moisture plays a part in affecting backscatter. Soil effects in particular have been quantified. As an example, although a non-tropical one, of the ability of SAR to provide quantitative soil moisture data; Dobson, et al, (1992) worked on a recently acquired ERS-1 scene from the U.S. Canadian border area. They found that "backscattering from forested area is dominated by properties of the crown layer consisting of foliage and branches. Furthermore, ERS-1 SAR is sensitive to near-surface soil moisture from grass covered soil and soil moisture retrievals are possible" (P. 210).

Models
In order to answer the many questions raised by the experimental field work, attempts have been made to build models. These models attempt to include known physical properties which contribute to backscatter and to be configured in such a way as :

- to assess backscatter sensitivity to parameter changes
- to allow the identification of target parameters
- to allow for extrapolation of results.

A generally applicable model has yet to be developed due to the complexities of the subject.

4.3.2 Classification Methods

The data discriminants described in the preceding section must be mapped into a set of forest and non-forest land cover classes, i.e. a procedure must be found which maps a pixel with spectral/temporal characteristics X to a class C. Some references are made here to forest surveys outside the tropical regions where these are considered relevant to the tropical monitoring problem.

Visual Interpretation
Despite the availability of remotely sensed data in digital form and the development of many classification procedures for remotely sensed data (see next section) many of the surveys carried out to date have employed visual interpretation of photographic products, for example, (Kummer, 1992, Tardin and da Cunha, 1992). In fact, the vegetation monitoring study of the Landsat Pathfinder programme (see Section 3) uses visual interpretation as a major input (Townshend, pers. comm.). The procedure developed by

INPE and NASA for production of deforestation statistics relies on visual interpretation of imagery, digitisation of the boundaries, and entry of the results into a GIS (Justice, 1992). The advantages are that it is a relatively cheap procedure which can be conducted by people with local knowledge. Results may be more accurate than those obtained from computer-based methods, but this has not been proven. Kummer (1992) pointed to the failure of five different surveys of deforestation in the Philippines, four of which were visual interpretations of Landsat or SPOT data. He concluded that visual interpretations of photo-mosaics were more accurate with respect to forest cover than the computer-assisted classifications, however there were considerable local discrepancies. In particular there were differences in categorisation of different forest types such that the classification schemes were not strictly comparable.

Much of the work done to date using radar data has used visual interpretation as the major tool for analysis. This is a response to the complexity of computer-based classification work and the power of the human eye to discriminate textural classes.

Computer Based Classifications

Thresholding

The application of a simple threshold to the digital data, either to a single channel, or to some composite of channels such as the NDVI is widely used in studies of tropical forest cover, e.g. (Stone and Woodwell, 1988, Malingreau, et al, 1989, and Malingreau, 1991). This approach is relatively simple to apply, since it consists of establishing a threshold level with all digital values above the threshold assigned to, say, forest, and all those below to, say, non-forest (Malingreau and Tucker, 1990, Sawada, et al, 1991). The disadvantage of the method when using the AVHRR thermal channel is that it can only be applied locally because of spatial variability of surface thermal patterns, and that the same thresholds cannot be used from day-to-day because of intervening meteorological events (Malingreau, 1991). The same restrictions would also apply to other spectral bands, and the problems of sensor calibration and atmospheric effects outlined in Section 4.3.1 make temporal comparisons problematic.

Supervised Classification

Supervised classifications rely on the identification of 'training areas' of known cover type. Pixels are then assigned to the training class to which they most closely correspond using a set of statistical rules, for example Bayes maximum-likelihood (e.g. Gastellu-Etchegorry, et al, 1991). Recently, there has been a trend towards using a contextual component in this sort of classification in that the classes of the surrounding pixels are also considered (Gastellu-Etchegorry, et al, 1991, Tomppo 1989, Jaakkola, et al, 1988). The advantages of using these procedures are that they are replicable and statistically robust. The disadvantage is that they require considerable effort and local knowledge in selection of suitable training sites. Also, it is often necessary to establish training sites for classes which may not be of particular interest, but which, since they are present in the data, would have to be differentiated from the forest classes. Supervised methods are useful where the user knows exactly which classes are required, i.e. in a user-driven as opposed to a data-driven scheme (see Section 4.1).

Unsupervised Classification

An unsupervised classification procedure will segment the image into areas with similar spectral/temporal properties producing either a pre-determined number of classes, or a

data-determined number depending upon the exact type of procedure used. In all cases a statistical rule is used to establish the boundaries between classes in feature space. Once the classification has been made, it is necessary to assign labels to the classes produced. This requires considerable user-intervention and local knowledge, analogous to the selection of training sites described in the description of supervised classification above. It is possible to obtain classes for which no corresponding land cover type can be identified. If the procedure is restricted to producing a set number of classes, statistical anomalies can result in very inaccurate results. Despite its wide use in other applications of remote sensing (e.g. Belward, et al, 1990) this method has not been widely used for tropical forest applications outside of the TREES project (see Technical Note No. 1), although Sawada (1991) provides an example.

The unsupervised method is basically data-driven in that the 'intrinsic' classes in the data are determined, and then these must be assigned to 'actual' classes which may or may not be of interest to the user.

Mixture Modelling and the Problem of Scale

The problem of scale is inherent in any remote sensing classification. As described above and in preceding sections the basic assumption of a classification is that a spectral/temporal property can be uniquely related to a land cover class. In practice a pixel represents a sum of spectral responses from a variety of land cover types present in the pixel area. As spatial resolution increases the variation and complexity of this sum will increase. This implies that as resolution increases it will be increasingly difficult to make a unique assignment of a pixel to a land cover class.

Ormsby, et al, (1987), simulated AVHRR pixels from composites of MSS pixels in an attempt to model the internal variability of vegetation in an AVHRR pixel. Settle and Drake (in press) derived a scheme to model the potential mixture of cover classes within a pixel. Townshend and Justice (1990) have examined the effect of variations in scale on vegetation monitoring. The only research that has looked at mixture modelling, specifically for tropical forests, is Cross, et al (1991).

Classification of Radar Images

Relatively little work has been done on the classification of radar images in comparison with the work on backscatter response. Radar images are different from optical images in one important respect; the existence of speckle. Speckle means that per pixel classifiers used in optical/thermal images cannot be used to define regions of similar response. Instead, various techniques based around segmentation have been devised. While per pixel grouping usually relies on aggregating individual pixels with similar values in a bottom up sense; segmentation starts at a higher level (note however that optical images can also be segmented). For example, Nooren, et al, (1985) took the whole image as the starting point breaking it into a number of squares. Using a 'split-and-merge' algorithm the mean and variance of each square is calculated and a decision taken whether to merge the squares. If the square is not merged, then it is subjected to splitting and a further test. A comparable technique was used by Conway, et al, (1991) in applying a clustering algorithm. This algorithm operates by analysing clusters of pixels based around points in the image and iteratively minimises variances within clusters.

Once segments have been defined in the radar image, the second stage in the classification requires that they are labelled. This differs little in principle to the optical unsupervised case; i.e. the classes produced are compared to ground survey data in some way. However,

Conway, et al, (1991) use a labelling system which relies on comparing model-based cluster characteristics with those from the segmented image. The model is of backscatter from the land type, in this case arable crops, and is produced by modelling crop growth and predicting backscatter from the crop. The predicted backscatter from various crops is then compared to the backscatter of the segments.

Ancillary Data

The incorporation of ancillary information into segmentation schemes is becoming increasingly important (Gastellu-Etchegorry, et al, 1991, Tomppo, 1989, Itten, et al, 1991). For example, Gastellu-Etchegorry, et al include digitised elevation data as part of their iterative contextual classification of Sumatran forests and conclude significant improvements are obtained. Senoo, et al (1990) combine DEM data with SPOT data to improve classification of forests in Japan. Sawada, et al (1991) incorporate data on temperature and evapo-transpiration into their classification of Malaysian forests. Topographic data is also important in the analysis of radar images due to the relief effect.

Ancillary data is naturally incorporated into many visual analyses, since the human interpreter does not classify on a per-pixel basis, but will naturally group the data into regions and can take account of local variations in the data, while also including contextual knowledge.

4.3.3 Validation of Classifications

In order to be useful, a classification of tropical forests should have some indication of its accuracy. This requires a combination of field survey and comparison with other data sources, for example with satellite data at a higher resolution.

Itten, et al. (1991) compared the classified AVHRR data for Swiss forests with digitised map data and obtain 80.6% correct classification. Gastellu-Etchegorry, et al. (1991) used digitised vegetation maps in combination with local regional knowledge in validation of their Sumatran tropical forest classification using GAC data. Contingency tables of 'ground truth' versus satellite-based classification were produced. They found that extrapolation of their results was difficult, especially where there was extensive cloud cover. Tomppo (1989) uses a similar procedure to analyse the accuracy of classifications of Finnish forests. Kummer (1992) compares the results of a computer-based classification of tropical forest cover in the Philippines with four other visually based classifications and found considerable discrepancies between the results. (see also Section 4.3.2).

One problem with most validation schemes is that they require comparison of data classified at one scale with that classified at another (Kummer, 1992). Different sensors produce different sets of spectral/temporal measures, and different mixtures in each pixel at different spatial resolutions which leads to problems in class assignments. Additionally, if comparison is to be done accurately the data sets must be perfectly registered so that any changes between them are due to mis-classification rather than mis-registration. Work by Townshend, et al. (1993) has shown that even discrepancies of less than one pixel can lead to severe potential mis-interpretation of the data. Atmospheric effects, if not adequately corrected, can also lead to problems in comparison between results from different dates and different sensors (Ahern, et al, 1987). Accuracy figures must therefore be interpreted with this in mind. Further, comparison between, for example, AVHRR GAC, LAC and GVI data has been shown by Malingreau and Belward (1992) and Townshend and Justice (1986) to be problematic because the pixels used to obtain the data are not necessarily congruent.

4.4 Conclusions

Consideration of the analytical methods outlined in the preceding sections suggest that the answers to the questions posed in Section 4.1 are being data-driven; the emphasis has been on 'how much information can be extracted from such and such a data set?' as opposed to an analysis of the monitoring requirements which might then lead to an identification of appropriate classification parameters (e.g. as required by Adams 1992). This is in large part due to the fact that most work is at the research rather than an operational level, so that the emphasis has not been on establishing operational criteria. Also, there has been a considerable research emphasis on the use of satellite data for vegetation monitoring in general, not just on the classification of tropical forests. The use of NDVI to identify areas of high green leaf biomass has different requirements from the classification of forest types which relate to the criteria described in Section 4.2.

Spatial and temporal scales of analysis
In considering global monitoring of tropical forests it is important to determine an appropriate temporal and spatial scale for such monitoring. Townshend and Justice (1988) identified the major factors controlling change detection to be:

- spatial properties (registration and resolution)
- radiometric properties (radiometric resolution, bandwidth, and calibration)
- temporal properties (imaging frequency and repeat coverage).

The thrust of their work is the identification of a globally applicable spatial resolution. Further work remains to be carried out on the temporal requirements.

Empirical studies using different spatial scales have varied from the use of SPOT data (Kummer, 1992, Senoo, et al. 1990) with high resolution but relatively infrequent coverage through to the use of GAC (Gastellu-Etchegorry, 1991) with low resolution but relatively frequent coverage. The consensus seems to be that AVHRR LAC data provide a reasonable compromise between spatial and temporal resolution, and these data have been most widely used in tropical forest studies. However, there is also considerable use of Landsat TM data (e.g. in the NASA Pathfinder studies, see Section 3) and an apparent feeling in certain sections of the research community that it may be necessary to use data at this resolution to obtain sufficiently accurate results (Townshend, et al, in press, Justice, 1992).

Little empirical work appears to have been done on routine monitoring of the same area using data sets obtained over an extended period, so that the requirements of a system of change detection have not been fully identified.

Classification
A major problem is to establish which classes are of interest, for example, whether the data are to be divided into forest:non-forest, or whether a further sub-division of the forest into different types such as degraded forest, seasonal forest etc., is needed. The result must be integratable into classifications carried out using ground based methods (see Section 4.2).

In considering work done on global, or even regional, monitoring of tropical forest cover it is surprising how little systematic work has been done. Very few actual classifications of the tropical forests have been carried out using automated techniques over more than a very localised area. There seems to be no broad consensus as to which classes are appropriate even within a region.

There is general agreement that thermal and near infra-red images provide the best spectral discrimination of forest cover, but there is no agreement as to the optimum classification method. Visual interpretation is probably used most widely, but this seems to be for pragmatic rather than scientific reasons. Classifications using a supervised method and employing ancillary data such as elevation seem to meet with the greatest success (e.g. Gastellu-Etchegorry, et al, 1991). Classifications produced by this method should be able to correspond to non-remote sensing schemes which incorporate climatic data (e.g. Adams, 1992, and the bioclimatic classification schemes described in Section 4.2).

Validation
Determination of the levels of classification accuracy attainable has received little attention, either in determining the accuracy attainable at a given spatial scale, or in considering methods for detecting levels of change in forest coverage over time. Problems of data registration with respect to monitoring accuracy have also received scant attention. It is not clear how the scale differences in classifications from different resolutions should be reconciled in accuracy determination.

Radar Potential
Radar can be seen to have significant potential in forest resource management. The ability of radar to distinguish forest structure, forest type etc., has been demonstrated. However, the conclusion of most workers, at this time, is that considerably more research work needs to be done if radar is to become an operational tool. This is because of inadequate understanding of factors influencing variation of backscatter responses. A shortage of image data is one major reason why this has occurred.

In comparison with optical/thermal systems, a great deal of research has gone into investigating the physical relationship between measured backscatter and the surface object. This is because the relationship is based not only on the immediate surface characteristics of the surface object, but also on the underlying structure of, for example, the crop canopy, which radar has the ability to penetrate. In addition, radar resolution, being generally greater than other sensors leads to the investigation of small scale individual phenomena such as tree trunks. AVHRR by contrast gives a response aggregated from a 1 km square.

In conclusion, radar would appear to have great potential and may ultimately prove more powerful than optical systems for forest monitoring Unfortunately, the complexity and relatively poor data availability (at least at present) means that operational use in the near future, other than by using local scale airborne sensors, is unlikely.

One initiative which should be mentioned here is that of Raney and Specter (1991), who proposed a system consisting of a space segment (i.e. a SAR instrument) optimised for tropical forest use and a ground segment optimised for the user. The characteristics of the proposed system (TREIS - Tropical Radar Environmental Information System) are:

- a P-band SAR (long wavelength)
- a low bit rate telemetry stream based around 25 kbits (as AVHRR)
- on-board processing to reduce bit rate
- 50 m resolution, 20 km swath width, continuous operation
- twice yearly repeat of tropical areas
- minimal processing requirements
- PC class hardware distributed to many regional centres.

These characteristics constitute a response to many of the difficulties encountered with radar to date. The proposal has received support from the remote sensing community but has yet to be realised.

Operationalisation
A major attraction of monitoring with satellites is the potential application of automated operational procedures. However, although much research has been carried out on interpreting satellite data in tropical forest areas, this has not generally been with a view to producing an operational monitoring system for forests.

In Section 4.1 a set of questions was posed covering the requirements of a classification of tropical forests for monitoring purposes. An attempt is made below to answer these questions in the light of the research work described in the preceding section.

- *What is the appropriate spatial scale of measurement for tropical forest monitoring?*
  The generally accepted compromise between detail and coverage is 1 km^2. Adams (1992 P. 21) believes that this scale 'avoids the problems of becoming distracted by small scale heterogeneity'. AVHRR LAC provides such coverage.

- *What temporal scale is required for monitoring (i.e. to identify seasonal effects)?*
  Depends on the requirement and the forest type being monitored. For example, images from both wet and dry seasons each year are required to enable effects caused by deciduousness, soil moisture etc., to be accounted for. However, cloud cover problems mean that, in practice, all available data are used to form cloud free composites. GAC data are sufficient in quantity to provide relatively frequent composites, but work using GAC has to date been with NDVI only. LAC data have not yet been collected in sufficient quantities to enable frequent composites to be formed.

- *What temporal scale is required for change detection?*
  No single answer is possible. FAO are aiming at 10 yearly inventory. Given the known rate of change in certain areas, more frequent coverage would be preferable. An ideal would be yearly with account taken of seasonal changes; but in practise, the frequency will be determined by data availability and technical considerations.

- *What classes should be extracted from the data?*
  This depends on the purpose of the analysis. Since there is no agreement concerning vegetation classification in general, still less for tropical forests; remote sensing work cannot be expected to follow any one scheme; even if this was possible. The requirements are for useful classes which can be extracted automatically and consistently across images and through time. It is not clear what these should be.

- *What classes can be extracted from the data?*
  Unknown. The classes are currently data- driven (i.e. what can be extracted from the image); and there is no clear agreement as to what classes can be extracted from either AVHRR LAC, GAC or Landsat images.

- *Should the classification be based on established (non-remote sensing) schemes?*
  Yes. Ideally, an established (if not universally agreed) system should be used. Adams' scheme takes some account of remote sensing capability.

- *Should the same classes be extracted globally, or should the emphasis be on classification appropriate to local conditions?*
  Depends on requirements. For a global monitoring scheme returning aggregated statistics, classes must be consistent across the globe. However, for alternate (or additional) requirements where, for example, national concerns are paramount, then a regional (e.g. S.E. Asian) classification, tailored to particular surface conditions or data availability may prove more appropriate.

- *What classification procedure best identifies the classes of interest?*
  All work to date has been data-driven. The best of the results comes from supervised classifications using ancillary data (especially DEMs) or visual interpretation.

- *Is there a set of classes which can be extracted operationally, even though these may not represent the full potential of the data?*
  From work to date, the minimum classification which might serve operationally is forest:non-forest.

- *How should the results be validated?*
  Validation and ground survey for classification purposes are easily confused. Schemes for validation in the sense of 'after the event' checking of classification results are established, but issues are outstanding (e.g. the effects of mis-registration, inadequate atmospheric correction and comparison of classifications at different scales). The validation for operational monitoring systems is undeveloped.

5.

Summary and Conclusions

5.1 Summary

There is a considerable body of literature relating to the use of remotely sensed data for vegetation mapping and monitoring. There is relatively much less concerning tropical forestry in particular.

There have been several major initiatives for acquiring and managing data either indirectly (IGBP) or directly (FAO) for tropical forests. The use of AVHRR LAC/HRPT data is demanding in terms of management and the problem is far from solved, although recent work on catalogue interoperability and the establishment and consolidation of HRPT ground stations in tropical areas gives cause for hope. Due to the spatial and temporal resolution of LAC, AVHRR is seen by many workers as a viable mapping and monitoring source. However, other groups espouse the use of Landsat images for mapping (GIMMS group, FAO) and possibly for monitoring (FAO sample strategy). There is therefore no consensus on the optimum data source.

Radar work has been ongoing and apparently somewhat separate from work with other sensors. This is partly because of the local scale of results and partly as a result of the different techniques required for information extraction (e.g. segmentation). Given the potential of radar, and the need for merging of data sources, this is unfortunate.

Discriminants of parameters and classification of AVHRR and Landsat data is well established for vegetation in general in the form of the NDVI (GVI) data product. For tropical forests, the identification of discriminants is less well developed and the subsequent classification is almost totally undeveloped with only a handful of papers in the literature.

5.2 Current Initiatives in Relation to TREES

The stated objectives of TREES I are to produce a wall-to-wall map, the detection and monitoring of active deforestation areas and thirdly modelling of forest dynamics. The review in this document shows that these are ambitious objectives. In particular, the wall-to-wall map cannot easily be created from techniques and technology existing in early 1993. In particular AVHRR data in a consistent processed state are not readily available for all tropical areas; and discriminants of tropical forest parameters some of the many data sources which have been discussed are known and documented. However, classification on an operational basis (which implies the ability systematically to extract the same classes across time and space) is in its infancy. This is a major technical problem.

The TREES I project has therefore had to break a considerable amount of new ground and can be seen to be addressing a significant gap in capabilities.

6.

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Technical Note No. 3

Analysis of Users and Requirements

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1.

Introduction

Deforestation is a major global issue of concern, recognised by the general public, business community, scientists, policy makers and politicians throughout the world. Tropical deforestation has received the most attention over the past two decades with concern spreading more recently to problems of deforestation in temperate and boreal regions. The degradation and loss of tropical forests remains a particularly critical issue in biodiversity conservation and of foremost importance in the global change debate.

Despite the attention received by tropical forests, understanding of the effects of tropical deforestation have often been superficial. The research and information base on tropical forests remains generally weak, particularly at an international level. The extent and rate of loss of the tropical forest resource have not yet been effectively measured at a global coverage, with a particular weakness being the lack of spatial registration of statistical data. There are as many estimates as there are reports about the subject. The most comprehensive study so far is the FAO Tropical Forest Resources Assessment Project (1980 and 1990 baselines), compiled at the national level.

Despite the fundamental information gaps, a wide range of organisations are mandated to reverse the trend of tropical deforestation, using currently available information to guide their policies. A review of the objectives and policies of organisations using tropical forest information is essential to guide future information collection, retrieval priorities and decision-making.

The analysis of users and their requirements carried out for the TREES II Pre-feasibility Study has drawn on a knowledge of organisations involved in tropical forest issues and their data needs as understood by WCMC and the results of a questionnaire, which was specifically designed for the study. The questionnaire focused on the use of satellite-derived data and its integration in geographic information systems (GIS), with various forms of ancillary data. Computerised mapping and monitoring systems that once were expensive and controlled mainly by government agencies are now being more widely used by the private sector, non-governmental organisations (NGOs) and individuals. The primary objectives of the questionnaire were to gauge the level of interest in TREES, assess potential users' requirements and applications of such systems in monitoring tropical deforestation, and to enable potential users to input their suggestions into further development of TREES.

Names and addresses of users of forest information are stored in a contacts database maintained by WCMC. For the purposes of the questionnaire survey users have been divided into nine broad categories as follows:

- global change community (30)
- government agencies of tropical forest countries (229)
  (forest departments, protected area agencies and some research organisations)

- United Nations agencies (18)
- intergovernmental agencies and programmes (59)
- international non-governmental organisations (22)
- governments of non-tropical forest countries (13)
- national non-governmental agencies (180)
- forest research organisations (92)
- timber traders (12)

Total (655)

The figures in brackets show the number of users who received questionnaires in each category. As can be seen the number of questionnaires sent to different user groups varies considerably, and for example, relatively few commercial organisations (such as timber traders) were contacted. In some cases more than one individual was contacted in a particular organisation, or a range of regional offices of an organisation may have been contacted. In total 655 potential users have been identified and contacted for the current survey. The responses to the questionnaire are stored in a FoxPro database and an analysis of the results is presented in Section 3.

The objectives and activities of some of the major forest information users, all of which were contacted in the questionnaire survey, are described in Section 2. Because of the European basis to the TREES Project, this brief review of the main users concentrates to a certain extent on the European perspective on tropical deforestation by looking, for example, at initiatives of the Commission of the European Communities (CEC). The inter-linkages between European governments and other governments in tropical forest initiatives are considered through the work of UN agencies and membership of international conventions and agreements. The policies and bilateral aid programmes of selected donor countries are briefly summarised and the information needs of tropical forest countries are considered in relation to the enhancement of their data sources by international means. The policies and information requirements of the broad spectrum of NGOs involved in tropical forest issues are also analysed together with the needs of the forest research and global change communities.

2.

The User Community

The user community of tropical forest information is large and diverse and it would be extremely difficult to cover all users in this report. However, the following section outlines the forest activities and profiles of selected users and presents a useful summary of some of the organisations and programmes concerned with the conservation of tropical forests.

2.1 Intergovernmental Organisations

The intergovernmental organisations and programmes involved in tropical forest conservation and land use issues have in general developed their own information systems or have contractual arrangements with other environmental agencies such as IUCN, WCMC and national NGOs or environmental consultancies. In addition certain international organisations and programmes have arrangements to receive forest information from national members on a regular basis, e.g. ITTO.

2.1.1 Commission of the European Communities

The role of the European Economic Community in tropical forest conservation is set out in the communication 'The Conservation of Tropical Forests: the role of the Community' (Anon, 1989). Five main elements are specified for a community tropical forest conservation strategy:

- development aid and cooperation
- actions relating to the trade in timber
- development of additional resources
- 'debt for conservation' strategies
- research and development.

Information needs in relation to developing and implementing the strategy are not specified in the original document. The importance of satellite monitoring is however stressed as a means of assessing deforestation. The remote sensing techniques utilised by JRC are stated to be: 'a useful tool for research into deforestation and, therefore, they can be utilised for the control of the tropical forestry situation'.

Coordination with other international initiatives was envisaged as central to the strategy, particularly in the implementation of elements 1 and 2 above through the Tropical Forestry Action Programme (TFAP) and International Tropical Timber Organisation (ITTO). The strategy set out in the communication was only adopted in part by the Council, who developed their response largely in the context of TFAP and ITTO. The Council Resolution, 'Tropical forests: Development aspects' was adopted by the Council of Ministers for Development

Cooperation in May 1990. The information requirements necessary for implementation of TFAP and ITTO are discussed below.

The current Lomé Convention gives considerable emphasis to the importance of tropical forests, both in the general provisions, and in articles on environment, agricultural cooperation and food security, drought and desertification control, energy development, and regional cooperation.

The Council resolution, together with the Lomé Convention and other cooperation agreements provide a broad outline of CEC policy relating to tropical forest conservation. The Directorate-Generals (DGs) of the Commission which have remits covering tropical forest activities are shown in Table 1.

The provision of financial assistance is one of the main ways by which the Commission assists forest conservation and development in tropical countries. Over the past ten years more than 250 projects have been funded, in 61 countries, principally in Africa. A major project underway at present with support from the Commission is the, 'Pilot Programme to conserve the Brazilian rain forest', co-funded by the World Bank.

The main sources of CEC funds for forestry conservation and development were, until 1992, those in the context of the Lomé Convention and financial and technical assistance to Latin America and Asia. A supplementary budget line was opened in 1992: 'Actions in favour of tropical forests' resulting from an initiative of the European Parliament. The overall strategy for funding, under this budget line, based on the 1989 Communication, is to promote tropical forest conservation by '*i) implementing - and verifying - protection and sustainable management measures for significant areas of forest; and ii) developing, diffusing and monitoring the impact of technologies and systems for increasing living standards of the populations of forest regions through sustainable resource use*'.

Applied research and monitoring are also considered important aimed both at increasing knowledge of the overall trend of deforestation and how it relates to policy factors and actions in the field, and at identifying at a micro level the impacts of EC cooperation in the fields of sustainable development and protected areas. Remote sensing and geographic information systems are two areas of interest.

In March 1993, the Commission published a, 'Proposal for a Council Regulation (EEC) on operations to promote tropical forests'. This sets out the criteria and procedures for Community support to conservation and sustainable management of tropical forests. Under the Regulation the Commission is required to submit an annual report to the Council and to the European Parliament, specifying the actions that have been financed and summarising their progress and conclusions so that monitoring of activities can take place.

The Commission is integrating environmental considerations into the appraisal process for all aid programmes and projects. Evaluations based on monetary estimation of environmental impacts are planned.

Table 1: Responsibilities for Tropical Forest Activities within the CEC

DG		
I	External Relations	Development and aid in Asian and Latin American countries Amazonian rainforest protection programme UNCED
VI	Agriculture	Relationship with FAO
VIII	Overseas Development	Aid to ACP countries under the Lomé Convention ITTO
XI	Environment	Global change CITES
XII	Research and Development	Consultative Group on International Agricultural Research (CGIAR) European Tropical Forest Research Network
XVI	Regional Policy	EC's Regional Fund (ERDF) - supporting work in Guyane Français

2.1.2 The World Bank

The World Bank's environmental activities involve policy dialogue, lending, technical assistance, and research and aid coordination. They are designed to:

- assist member countries in setting priorities, building institutions, and implementing programmes for sound environmental stewardship
- ensure that potential adverse environmental impacts from Bank-financed projects are addressed
- assist member countries in developing linkages between poverty reduction and environmental protection
- address global environmental challenges through participation in the Global Environment Facility (GEF).

In its Forest Policy Paper adopted on 18 July 1991, the World Bank stated that it will not fund commercial logging in tropical moist forests. Full Environmental Impact Assessments (EIAs) are required for all infrastructure projects, for example roads, dams and mines, that may affect tropical moist forests or other primary forest. The Bank will continue to emphasise programmes that involve institutional development, forest protection measures and non forest income-generating projects, the primary objective of which are the preservation of tropical moist forest.

2.1.3 Global Environment Facility

The Global Environment Facility (GEF) is a three year pilot facility created to address four global environmental issues: conservation of biodiversity; limitation of greenhouse gas emissions; reduction of pollution in international waterways; and protection of the ozone layer. The GEF is jointly managed by the World Bank, UNEP and UNDP and is housed in the World Bank. Overall funding for the GEF is estimated to be about $1.3 billion over three years. Funding has been pledged by 24 countries, including nine from the developing world. Most of the biodiversity projects under the GEF are concerned with creating protected areas or building

park management capacity.

2.1.4 Regional Development Banks

The African Development Bank (AfDB) produced an Environment Policy Paper in June 1990. This provides guidelines for environmental impact assessment of both project and non-project loans and includes a brief on biodiversity. More recently AfDB has developed a draft forestry policy paper. The Bank proposes not to fund logging in primary forests; not to engage in developments affecting forest dwellers without their consent; and to routinely carry out environmental impact assessments for projects in forested areas.

The Asian Development Bank (AsDB) has developed guidelines for incorporating EIAs into the Bank's project cycle and has incorporated biodiversity conservation into its Forest Sector Policy Paper. AsDB is very interested in remote sensing and related capabilities and has compiled several papers on the subject. The Bank has an Office of the Environment.

The Inter-American Development Bank (IDB) has an Environmental Protection Division created in 1990 to ensure that IDB operations comply with member country legislation and the guidelines on EIA developed by the Bank. EIAs are required for IDB projects that have minor or major environmental impacts.

Table 2: Global Environment Facility (GEF) biodiversity projects

GEF investment projects

COUNTRY	PROJECT	TARGET	ASSOCIATED PROJECT	FUNDING US$millions
Congo	Congo Tropical Forest Preservation	Lowland rain forest	Free-standing	10.00
Kenya	Lower Tana River Primates	Riverine forest	IBRD US$30m	6.20
Uganda	Gorilla Reserve Bwindi Forest	Lowland and montane forest	Free-standing	4.00
Bhutan	Trust Fund for Environment Conservation	Lowland, temperate and alpine forests	Free-standing	10.00
Laos	Wildlife and Protected Areas Management	Lowland and montane forest	IBRD US$10m	5.50
Philippines	Conservation of Priority Protected Areas	10 high priority protected areas	IBRD US$158m	20.00
Brazil	National Conservation Units	25 conservation units	IBRD US$117m	30.00
Mexico	Biodiversity Conservation	20 protected areas	IBRD US$30m	30.00
			Subtotal	**140.70**

GEF technical assistance projects

COUNTRY	PROJECT DESCRIPTION	FUNDING $millions
East Africa	Support for training, research, equipment and institutional development of government, university, and NGOs working in protected area management	10.00
West/Central Africa	Establish a regional TRAFFIC office in Zaire and develop capacity to monitor both legal and illegal trade in wildlife	1.00
Viet Nam	Training/institutional development to prepare a plan for protected areas	3.00
South Pacific	Establish and manage 20 conservation areas with threatened biodiversity	8.20
Colombia	Assess diversity of the Choco Region through capacity-building research with a view to developing plans for protection and sustainable use	9.00
Guyana	Protect a large tract of rain forest, study the impact of local management	3.00
Amazon	Institutional strengthening within the eight members of the Treaty for Amazonian Cooperation	4.50
	Subtotal	**38.70**
Total GEF biodiversity funding		**179.40**

Source: World Conservation Monitoring Centre, 1992

2.1.5 International Tropical Timber Organisation (ITTO)

ITTO was created in 1985 under the auspices of UNCTAD. Since its establishment, ITTO has increasingly been called upon to promote and instigate tropical forest conservation, although this is only one of the eight original objectives of the International Tropical Timber Agreement (ITTA). The CEC, in its tropical forest conservation strategy, and European governments, such as Denmark, the Netherlands and UK cite membership of ITTO and support for its conservation initiatives, as a major element in their contribution to tropical forest conservation.

ITTO's stated objective in relation to conservation is:

> *'to encourage the development of national policies aimed at the sustainable utilisation and conservation of tropical forests and their genetic resources and at maintaining the ecological balance in the regions concerned'.*

The means by which ITTO is implementing this objective are through:

- projects relating, for example, to sustainable timber production and the development of extractive reserves in Brazil and Bolivia
- the production of guidelines for sustainable management and guidelines for conserving biological diversity in production forests
- *Target 2000.*

In 1990 the 46 member governments of ITTO agreed to ensure that all tropical timber marketed internationally should, by the year 2000, come from forests that are managed sustainably. Implementation of sustainable management for timber production requires information on resource extent, size and condition, management intention and quality of execution. Mechanisms for reaching ITTO's ambitious target of transforming forest management have not been fully formulated. One procedure that has been introduced, however, is regular reporting by members to the International Tropical Timber Council (ITTC) on progress towards reaching *Target 2000which will.*

The ITTO Forest Resource Accounting Activity is designed to supply a framework, first for accurate and comprehensive international reporting and secondly for regular national assessment and quality control of forest management. The Forest Resource Accounting system is being designed for ITTO by IIED and WCMC to provide a system whereby countries make progress towards reaching *Target 2000.* This will be achieved by assessing and monitoring the location, legal status, area, vegetation type, condition and management status of all forest lands in a country and by specifying targets for each of these measures. The system can be used by each country as a tool for monitoring the progress of its policies, designed in such a way that more information that is relevant to management can be added where desired. There are three levels of information to be recorded:

- site details (management area/concession area level)
- country statistics compiled by the national Forest Authority from all information about sites within the country
- global statistics compiled by ITTO from country statistics from all ITTO member countries.

The ITTA is now being renegotiated and its future direction is unclear. Many producer organisations feel that the agreement should cover all timbers, both temperate and tropical, and that the mandate of ITTO should be more focused on trade-related policies that have an impact on limiting deforestation.

2.2 United Nations Agencies

The General Assembly of the United Nations and its component bodies provide the main focus for intergovernmental discussion and action on global change issues.
These are amongst the major users and distributors of global forest information.

2.2.1 UN Food and Agriculture Organisation (FAO)

The mandate of FAO is to support development efforts in fisheries, forests and agriculture. The Forestry Department of FAO has responsibility for the promotion of national and international action for the effective management and use of forest and related resources as an integral part of sustainable land use. There are three main areas of activity:

- the collection, analysis and dissemination of data on all aspects of forestry to assist member countries in the formulation of policies and the planning of forestry investment
- assistance with the development and adaptation of appropriate systems for integrating resource management with industrial processing to ensure socio-economic development needs are met equitably
- promotion of the systematic development of the forestry profession so as to maximise the contribution of the forestry sector to sustainable development.

FAO through its professional staff at the headquarters in Rome, regional offices, and field projects, is involved in a wide range of forest conservation initiatives. The conservation-related initiative which has provided a focus for political support and which has received most public attention is the international Tropical Forestry Action Programme (TFAP).

FAO has been the primary agency involved in the collection of global information on rates of tropical deforestation. Forest Resources Assessments have been carried out to 1980 (FAO, 1981) and 1990 (not yet published) baselines. These global figures have been generated from the national level and are based on national assessments of the extent of forest cover.

FAO together with the Netherlands National Aerospace Laboratory (NLR), Wageningen Agricultural University (WAU) and the International Institute for Aerospace Surveys and Earth Sciences (ITC) have also initiated a feasibility study on a global operational forest cover monitoring network using satellite remote sensing data within the framework of TFAP (Looyen *et al.*, 1993). The development of a Forest Assessment and Monitoring Environment (FAME) is proposed. Firstly, the establishment of a pilot project (PFAME) is suggested which will include: 1) selection of pilot countries; 2) making demonstration products available for the pilot countries for local to national use; 3) evaluating the products with the local users; 4) refining

products to cover the requirements of the end user, and 5) assessing the remote sensing products and developing a prototype Remote Sensing Preprocessing and Archiving System (RESPAS). Execution of this pilot project will lead to the development of a full scale FAME.

2.2.2 United Nations Environment Programme (UNEP)

UNEP was established in 1973 and charged with working with governments, other UN organisations and NGOs around the world to coordinate and catalyse action on the global environment.

UNEP coordinates the Global Environment Monitoring System (GEMS) and the Global Resource Information Database (GRID), elements of the United Nations Earthwatch programme. GEMS is a collective international programme to acquire, through global monitoring and assessment, the data that are needed for the rational management of the environment. GRID provides an environmental data management service throughout the United Nations. Data from satellites, aircraft and ground survey are incorporated into the system. WCMC is currently negotiating formal status as the biodiversity node of GEMS.

UNEP Harmonization of Environmental Measurement office (UNEP-HEM) as part of GEMS is involved in a number of catalytic and coordinating activities aimed at improving the compatibility of environmental data on a global coverage. UNEP-HEM has recognised the importance of developing an improved, practical and widely-acceptable global classification scheme for vegetation classification. It has been considering various approaches to this problem in close cooperation with WCMC and also the International Geosphere Biosphere Programme core project Global Change and Terrestrial Ecosystems (IGBP-GCTE). The role of IGBP-GCTE is considered below.

UNEP was the coordinating body for the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, June 1992. The principal outputs of UNCED, in relation to forest conservation are:

- **Convention on Climate Change.** This was negotiated prior to Rio and signed at the Rio meeting by 153 States.

- **Convention on Biological Diversity.** This was also negotiated prior to Rio and signed by 153 States, together with the European Community, during the meeting.

- **Forest Principles.** (Non-legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of all Types of Forests.) Element 1(c) of the Forest Principles states that, '*the provision of timely, reliable and accurate information on forests and forest ecosystems is essential for public understanding and informed decision-making and should be ensured*'.

- **The Rio Declaration on Environment and Development.** This is a set of 27 Principles intended to encapsulate the results of discussions at the Rio Conference.

- **Agenda 21.** This is a comprehensive action plan aimed at reversing the effects of environmental degradation and promoting environmentally sound and sustainable development in all countries. Chapter 11 deals with combatting deforestation and identifies the actions needed to achieve this. The stated objectives are to sustain the multiple roles and functions of all types of forests, to enhance their protection, to sustainably manage and conserve forests through rehabilitative means, to promote efficient utilisation of forest goods and services through full valuation of these resources, and to strengthen capacities for the planning, assessment and systematic observation of forests.

2.2.3 United Nations Development Programme (UNDP)

UNDP has developed Environmental Management Guidelines, as a means of incorporating principles of environmental management into its work. UNDP funds a wide range of environmental projects including those which encourage sustainable development and the improvement of the 'quality of human life'.

2.2.4 Unesco

Unesco has responsibility for the World Heritage Convention (The Convention concerning the protection of the World Cultural and Natural Heritage). This aims to protect natural and cultural areas of 'outstanding universal value' as World Heritage Sites. There are currently thirteen World Heritage tropical rain forest sites, as listed in Table 3 below.

The principal aim of listing sites of universal value, under the World Heritage Convention, is to foster international cooperation in safeguarding these important areas. Monitoring the integrity of sites is of major importance but, at present, there is no standard methodology in place to do this.

The conservation of tropical forests is an integral part of the Unesco Man and the Biosphere (MAB) Programme. A set of five interlinked types of tropical research activity is undertaken within the framework of the MAB Programme and related Unesco activities:

- biological diversity, traditional ecological knowledge, and integrated conservation in the humid tropics
- ecological and economic sustainability of tropical rain forest management
- forest regeneration and ecosystem rehabilitation in the humid tropics
- tropical soil fertility and its biological management
- savanna ecology and management; responding to stress and disturbance.

The overall objective of this work is to contribute to the development of sustainable land-use systems appropriate for the social, cultural and biological characteristics of the peoples and ecological systems of the humid and sub-humid tropics. Under the MAB Programme, internationally important areas are protected as Biosphere Reserves. These are selected and managed as natural or minimally-disturbed representative examples of the world's ecosystem types. They are also selected to demonstrate the relationship between conservation and development and may include buffer zones with varying levels

of human use and exploitation. Tropical moist forest Biosphere Reserves are listed in Table 4.

Table 3: World Heritage Tropical Rain Forest Sites

PROTECTED AREA	COUNTRY	SIZE (ha)
Dja Faunal Reserve	Cameroon	526,000
Mount Nimba Reserve	Guinea Cote d'Ivoire	5,000
Tai National Park	Cote d'Ivoire	350,000
Kahuzi-Biéga National Park	Zaire	600,000
Salonga National Park	Zaire	3,656,000
Virunga National Park	Zaire	780,000
Talamanca Range and La Amistad Reserves	Costa Rica	193,929
Rio Platano Biosphere Reserves	Honduras	350,000
Darien National Park	Panama	597,000
Manu National Park	Peru	1,532,806
Northeast wet tropics	Australia	?
Sundarbans National Park	India	?
Sinharaja Forest Reserve	Sri Lanka	7,648

In cooperation with various UN and other agencies, including IUCN and the U.S. Smithsonian Institution, MAB is engaged in a programme of inventorying and monitoring the vegetation in the biosphere reserves. A system of inventory is being created to make a global estimate of the extent to which biosphere reserves assist in the conservation of biodiversity. WCMC maintains for Unesco a structured database for both World Heritage sites and Biosphere reserves.

Table 4: Biosphere Reserves Containing Tropical Moist Forest

PROTECTED AREA	COUNTRY	SIZE (ha)
Pilon-Lajas	Bolivia	100,000
Reserve Forestiere et de Faune du Dja	Cameroon	500,000
Basse-Lobaye Forest	CAR	18,200
Dinghu Nature Reserve	China	1,200
Odzala National Park	Congo	111,000
Reserve Naturelle integralle d'Ipassa-Makokou	Gabon	15,000
Bia National Park	Ghana	7,700
Monts Nimba	Guinea	17,130
Ziama Massif	Guinea	116,170
Taï National Park	Cote d'Ivoire	330,000

Gunung Gede-Pangrango	Indonesia	14,000
Lore Lindu	Indonesia	231,000
Tanjung Puting	Indonesia	205,000
Gunung Leuser	Indonesia	946,000
Siberut	Indonesia	56,000
Montes Azules	Mexico	331,200
Omo Reserve	Nigeria	460
Parque Nacional Fronterizo Darien	Panama	597,000
Manu Reserve	Peru	1,881,200
Puerto Galera	Philippines	23,545
Sinharaja Forest Reserve	Sri Lanka	8,850
La Luki Forest Reserve	Zaire	33,000
Reserve Floristique de Yangambi	Zaire	250,000

2.2.5 EEC member state governments

Within the EEC, the Dutch Government is the only Government to have published a comprehensive policy document on tropical rain forests. Implementation of the policy is by means of nine basic strategies:

- active protection of surviving virgin rain forest
- in principle, no collaboration with projects and developments that are harmful or potentially harmful to the rainforest
- encouraging planned land use and land management along with sustainable agriculture and forestry
- the tropical timber trade: controlled harvesting; encouraging the formulation and implementation of long-term planned timber production
- national and international encouragement for afforestation and re-afforestation projects
- strengthening institutions and legislation; empowering local populations
- strengthening the political and social base in tropical nations
- improving economic relations and relieving the debt burden
- increasing scope for national and international tropical rain forest policy by strengthening research and institutions.

2.3 Governments of Non-tropical Countries

Governments of non-tropical countries have become increasingly involved in tropical forest conservation over the past fifteen years, in response to scientific and public concern. In some cases this has resulted in the formulation of national tropical forest policies. Governmental agencies within European and other bilateral aid donor countries require information to support tropical forest policies and funding mechanisms. These are usually contracted out to independent

research organisations.

In 1987 the German Government appointed the Enquete Kommission to carry out an extensive study on the protection of tropical forests (Deutscher Bundestag, Drucksache 11/7220, 24.5.90). Policy recommendations of the Enquete's report focus primarily on national initiatives with a programme of initiatives at EC level also suggested. These include the reform of agricultural policies, a ban on tropical timber imports from primary forests, reforms in aid policies and procedures and a substantial increase in community level funding for tropical forest protection.

The UK Government does not have a comprehensive stated policy on tropical forest conservation. In 1990, a House of Lords Select Committee reviewed the EC Communication 'The Conservation of Tropical Forests: the role of the Community' and its conclusions include the following:

- The primary aim of the Community's strategy should be to support improved management of tropical forests and the areas which surround them. It is essential to develop locally appropriate forms of natural forest management to ensure that the forests have a long term value as a source of income for local people.
- It is important to establish an adequate network of protected areas where biological conservation is the main priority. More intensive economic activities, such as agriculture, plantation crops, and processing facilities should be encouraged in land beyond the natural forest boundaries.
- Aid from the Community should be directed towards those activities which contribute to sustainable forest management. These are likely to include the rehabilitation of disused and degraded land, support for agricultural improvements on land adjoining forests and the selective establishment of plantations, as well as improved natural forest management and the creation of reserves.

The UK Government's Overseas Development Administration (ODA) takes a lead on international forest conservation matters, including ITTO and TFAP, and is responsible for bilateral and multilateral forestry aid provision. The main objectives of the ODA Forestry Initiative are to help:

- enable developing countries to maximise the economic and social benefits they enjoy from their forests in a sustainable way
- limit deforestation by tackling its causes and supporting forest departments and other institutions in developing countries charged with conservation and management
- promote reforestation of degraded land and agroforestry
- increase the productivity of forests through research
- conserve the planet's bank of plant and animal species, most of which are unique to tropical forests
- promote the more productive use of existing agricultural land and the identification of alternatives for people on the margins of forests to unsustainable exploitation of forest resources.

The UK supports around 200 forestry projects in developing countries. Over 180 are funded through ODA, some as part of TFAP, and the remainder are managed by the Commonwealth Development Corporation (CDC). A current project relating to the conservation and sustainable development of the forests of the Western Ghats in India will be the largest forestry project ever funded by the UK. Management will be based on five zones with the innermost zone designated for biodiversity conservation.

The USDA Forest Survey conducts forest research in tropical and subtropical forests of the US, including tropical areas ie Puerto Rico, Hawaii, Florida, and provides assistance overseas. USAID currently provides more than $60 million annually for biological diversity conservation. USAID programs in natural forest management, buffer zone management and forestry policy reform are aimed at stopping deforestation and protecting biodiversity while developing the economic potential of natural areas and their buffer zones for both timber and non-timber forest products. Other Agency activities focus on environmental education; efforts to strengthen legislation, policies and institutions relevant to conservation of biodiversity and tropical forests. US-MAB also supports work in tropical forests.

2.4 Governmental Agencies in Tropical Forest Countries

The governments of tropical forest countries have the primary responsibility for tropical forest utilisation and conservation through the formulation of national policies. In reality these are unlikely to be successful unless the needs of the full range of forest users within the countries are satisfied. Mechanisms to control unplanned deforestation at a national level are generally weak at present because of 1) limited financial and technical resources, 2) strong external and internal pressures which promote over-exploitation of forest resources and forest conversion to other land uses.

Some countries continue to promote deforestation through legislation which requires forest clearance as a means of establishing legal claim to unoccupied lands. In other cases deforestation is indirectly encouraged through fiscal incentives and subsidies for cattle ranching (Blockhus *et al.*, 1992).

Initiatives to control deforestation at a national level include the formulation of forest conservation policy, improved land use planning, the imposition of legal and fiscal controls on logging, the reduction of timber felling and other steps towards meeting the ITTO *Target 2000* and the extension of protected area systems. A few examples of national measures are:

- India introduced a new National Forestry Policy in 1988 with the achievement of ecological stability stated to be the primary objective of all forest management.
- The Philippines and Thailand have introduced logging bans in recent years in response to problems caused by deforestation.
- Indonesia has 18.7 million ha of totally protected areas and 30.3 million ha of protection forests, the primary function of which is to protect watersheds.

International factors clearly have a major influence on tropical deforestation but the extent to which international solutions can be found depends on the response of national governments. Obligations to the international community arise primarily from membership of international legal agreements.

In order to formulate forest policies and prevent unplanned deforestation access to all available data should be guaranteed. There has, in the past, been a tendency to accumulate information on forest resources and biodiversity in non-tropical countries and little of the information has been repatriated. Space-derived data on tropical forests has also largely been processed in a limited number of non-tropical centres of expertise and are not easily accessible.

The majority of forestry agencies in tropical forest countries will have access to detailed national forest information carried out by them or on their behalf. National departments very often have their own up-to-date, large scale (down to compartment level) paper maps and satellite imagery which they use for management and planning. Some national departments already provide their own statistics from satellite-derived imagery; e.g. INPE (National Institute for Space Research) in Brazil, or work in collaboration with FAO, which uses high resolution imagery to estimate forest extent from national level sampling. However, national users may wish to compare their own data with neighbouring countries and problem areas could be identified on the less detailed imagery which may be missed by less-frequently gathered Landsat or SPOT imagery. Certainly, AVHRR imagery would be extremely useful for tracking threats to the forest such as fires; often countries are not aware of where forest fires are burning because of inaccessibility. It may be useful to receive information on incursions into legally gazetted forest areas. National departments may also be pleased to acquire repatriated information, in digital or map format and may welcome prototype information to initiate or enhance existing in-country monitoring systems. It is often evident that important data exist outside a country but which are not available in-country.

The extent to which government agencies in tropical countries are already using data derived from remote-sensing for forest assessment varies considerably. The Royal Forest Department in Thailand, for example, has a highly developed information management system including remote sensing and a cartography department, whereas the Forestry Department of Cambodia is lacking in resources. The Directorate General of Forest Inventory and Land Use Planning, Indonesia has a National Forest Inventory Project which will be completed by 1996. The nationwide mapping using satellite data, mainly Landsat MSS (1986-91) has been completed in phase-I of the Forest Resource Monitoring activities, and, in phase-II, starting 1992, a Digital Image Analysis System has been implemented using Landsat TM. The Forestry Department of Sri Lanka prepared a national forest map at nominal 1:250,000 scale in late 1992 by interpretation of 1992 TM imagery. This preliminary map is available in digital (ARCINFO) form. A more detailed and field-checked map at nominal 1:50,000 scale is currently being prepared from the same imagery and will be complete by mid 1994. This will form a major input to a national forest GIS and will serve as a baseline against which to measure future change in forest area. The new map will also be available in ARCINFO format. The national forest map divides closed canopy forest into seven categories of natural forest, based on elevation, rainfall, and other characteristics (eg mangroves) and four species categories of forest plantations (W.R.M.S. Wickramasinghe, *in litt.* 1993)

2.5 International Non-governmental Organisations

There is a very wide range of NGOs involved in the conservation of tropical forests around the world. The policies, activities and related data needs of a selection of these are given below.

International environmental NGOs collect information on forest ecosystems at the project level as well as utilising global assessments from a variety of sources. Few currently have the capacity to effectively monitor forest extent nationally or internationally although they require these data for use in formulating and assessing proposals and strategies. Others, such as WCMC and IUCN, are already trying to address these deforestation issues and have established sophisticated geographic information systems.

2.5.1 International Union for Conservation of Nature and Natural Resources (IUCN)

IUCN - The World Conservation Union is unique amongst NGOs in that it brings together States, government agencies and NGOs in a world partnership. The work of IUCN is coordinated with the environmental responsibilities of FAO, Unesco and UNEP through the Ecosystem Conservation Group.

The forest conservation activities of IUCN are coordinated by the Forest Conservation Programme based at IUCN's headquarters in Gland, Switzerland. The Programme focuses on the conservation of species and ecological processes, and promotes forest uses which are compatible with the conservation of biological diversity. Special emphasis is given to the development of compatible uses for buffer zones around national parks and reserves.

The Forest Conservation Programme deals with global and local policy issues and undertakes field projects. The Central African Project for the conservation and sustained use of forest ecosystems, funded by the EC (DGVIII), is an example of an approach developed by IUCN to regional forest conservation. Over one hundred sites of critical importance for biodiversity conservation have been identified and measures proposed to ensure their conservation. A network of pilot projects has been designed to demonstrate different aspects of a community-based approach to forest resource management.

The Forest Conservation Programme works closely with WCMC, and utilises, for example, the Centre's spatial data on tropical forests maintained on a GIS, data on plant and animal species, and information on forest sites important for conservation. The Centre also acts as a repository for data gathered under IUCN auspices.

The WCMC database of tropical forest maps held on an ARC/INFO GIS called the *Biodiversity Map Library* (BML), based on the most recently available sources, provides the only currently available systematic global forest cover database in digital form. The data are available for dissemination to the user community in digital or paper format and form the basis for a three volume joint IUCN/WCMC publication *The Conservation Atlas of Tropical Forests* (Collins, N.M., Sayer, J.A. and Whitmore, T.C., 1991; Sayer, J.A., Harcourt, C.S. and Collins, N.M, 1992).

The Biodiversity Programme of IUCN promotes the concept of biodiversity among IUCN members and partners. It provides a comprehensive overview for the wide range of IUCN activities which contribute to conserving biodiversity. The Programme provides a focus for requests for policy advice from governments, IUCN members and the IUCN Regional Offices. The Biodiversity Programme also advises GEF, UNEP and UNDP on biodiversity issues.

The IUCN Plant Conservation Programme has undertaken a project with collaboration from botanists around the world to identify the several hundred major Centres of Plant Diversity (CPD). These are defined as places particularly rich in plant life which would, if protected, safeguard the majority of wild plants in the world. A table showing the tropical forest sites for which data sheets have been prepared is given in Appendix D.

2.5.2 Birdlife International

Birdlife International is the new name for the International Council for Bird Preservation (ICBP). Birdlife International has identified priority areas for global conservation by analysis of information on bird distribution (Bibby *et al.*, 1992). Birds are good indicators because they occur in most land habitats throughout the world, and are sensitive to environmental change. Bird taxonomy and distribution are better known than for any other reasonably large group of animal or plant taxa.

In order to analyse patterns of bird distribution locality records were gathered for all bird species with breeding ranges below 50,000 sq km. In total, about 51,000 separate locality records of these birds have been computerised and mapped with the aid of GIS. Analysis shows that species of restricted range tend to occur together in places which are often islands or isolated patches of a particular habitat, especially montane and other tropical forests. Boundaries of these species groupings have been identified and defined as Endemic Bird Areas (EBAs). 221 EBAs have been identified, 76% of which are located in the tropics. Birdlife International works closely with WCMC and are currently adding mapped EBAs to the WCMC *Biodiversity Map Library*. By overlaying EBAs onto forest cover and protected areas information, the conservation status of these areas can be evaluated.

2.5.3 World Wide Fund for Nature (WWF) International

WWF is the world's largest private international conservation organisation with 28 Affiliate and Associate National Organisations around the world and over 4.7 million regular supporters. The international headquarters of WWF is in Switzerland.

The conservation and rehabilitation of forests and woodlands has been one of WWF's three primary goals for the five years 1987-1992, the other two major goals being preservation of global biodiversity and the conservation of wetlands and coasts. The WWF Forest Programme covers the conservation of both tropical and temperate forests. A WWF International Position Paper published in 1989 sets out the main areas of interest of WWF International in tropical forest conservation (WWF International, 1989). These are:

- establishment and management of protected areas
- sustainable forest management

- rights of indigenous forest-dwellers
- TFAP
- ITTO
- regulation of trade in tropical timbers
- macro-economic issues: debt, agricultural subsidies and policies, terms of trade, development aid agencies.

At present WWF does not have an integrated strategy for forest conservation work. The organisation has a series of policy activities, relating to the above issues, conducted mostly at international level and, over one hundred field projects, mostly concentrating on protected area management in the tropics.

The Forest Working Group of WWF has proposed that links between international policy objectives and the field programme should be improved by the preparation of country plans (Forest Working Group, 1992). These would be prepared nationally with targets for forest conservation listed and a strategy for how to achieve them. To measure progress towards the targets Country Data Sheets, containing such data as protected area coverage and deforestation rates would be prepared and updated annually as part of a monitoring and evaluation process. At an international level, the country plans would be taken together to assess progress towards achievement of global targets and to identify priority areas for further action.

2.5.4 World Resources Institute (WRI)

WRI, sited in Washington DC, is an independent research and policy institute founded in 1982 to help governments, environmental and development organisation and the private sector, address sustainable resource use and development issues. The work of WRI focuses on six broad areas: climate, energy and pollution; forests and biodiversity; economics; technology; resource and environmental information; and institutions.

2.5.5 The Nature Conservancy

Established in 1951, The Nature Conservancy is an international, non-profit environmental organisation, sited in the USA, which is committed to the protection of natural diversity. The Nature Conservancy works with local conservation organisations throughout Latin America, helping to build their conservation capacity. A current cooperative campaign involving more than 30 conservation organisations, is 'Parks in Peril'. This aims to improve management of 200 key protected sites in Latin America and the Caribbean by the end of the century.

The Nature Conservancy is involved in the establishment and operation of a network of Conservation Data Centres (CDCs), through the provision of technical, scientific and administrative support and training. The Conservancy also makes available the computer technology, data inventory and management methodology and procedure manuals on which the CDC network is based.

2.5.6 Friends of the Earth International (FoE)

FoE International is a network of member groups in over 50 countries, with an international

secretariat based in Amsterdam. Various national groups campaign on tropical forest issues with policy and research priorities decided at a national level.

In 1989, FoE commissioned a comprehensive survey carried out, firstly, to determine the current rates of tropical deforestation and, secondly, to appraise the consequences thereof for emissions of greenhouse gases, notably carbon dioxide (Myers, 1989).

2.5.7 Forest Stewardship Council

The goal of the Forest Stewardship Council (FSC) is to set a worldwide standard for good forest management by promoting widely recognised and respected Principles of Good Forest Management. It will act as a forum to provide consistency in forest certification schemes. The draft FSC Principles and Criteria for certification will complement existing national and international laws and forestry initiatives of ITTO, IUCN, TFAP, UNCED and the Forest People's Charter.

FSC is an initiative involving British NGOs and industry and acting in consultation with governments. An increasing number of influential NGOs and major companies are becoming involved. USAID, the EEC, GTZ and private corporations have expressed interest in funding the work of FSC.

2.6 National Non-governmental Agencies

There is a very wide range of environmental NGOs concerned with tropical forest conservation, with groups based in both tropical and non-tropical countries. These range from radical single-issue campaigning organisations through to long-established learned societies. The resources and expertise of national NGOs varies equally widely. Their role in tropical forest conservation is increasingly being recognised by governments and inter-governmental organisations. The International Tree Project Clearinghouse (ITPC), a programme of the UN Non-Governmental Liaison Service, exists to support the NGO and grass roots communities involved in forestry related activities. This support takes the form of information collection and dissemination.

As an example, the Malayan Nature Society, founded in 1940, is a non-government organisation dedicated to the study, conservation and enjoyment of the Malaysian natural heritage and the surrounding region. The Society has about 2800 members in 34 countries and is the oldest as well as biggest scientific organisation in Malaysia. From a relatively passive conservation body, the Society has become a more active campaigning organisation. It has, for example, lobbied against the logging of forests of Endau-Rompin and the building of a dam in Taman Negara.

2.7 The Forest Research Community

A large number of individuals and organisations are working in forestry research. This research may cover a wide range of topics and it is more difficult to pin-point specific user needs. These

may comprise international programmes and research organisations such as CIFOR (the new Centre for International Forestry Research), or universities, such as Wageningen in the Netherlands, and Reading in the UK, who are actively involved in remote sensing work. Other research organisations may be involved in plantation forestry or working at the forest species level to identify tree species for reforestation for instance, such as the Oxford Forestry Institute (OFI), Edinburgh, Bangor and Aberdeen universities in Britain.

2.7.1 International Union of Forestry Research Organisations (IUFRO)

IUFRO is currently preparing guidelines for international forest monitoring. The intention of the guidelines is to promote international uniformity between forest data collectors. Institutions and researchers conducting remote sensing studies or setting up permanent plots on forested lands, will be encouraged to follow the standards and definitions provided in the guidelines.

2.7.2 Centre for International Forestry Research (CIFOR)

Established in early 1993, CIFOR is one of 18 international agricultural research centres supported by the Consultative Group on International Agricultural Research (CGIAR), and is the focal point within CGIAR for strategic forestry research. CIFOR is a non-profit, autonomous, scientific research and training institute with headquarters at Bogor in Indonesia.

CIFOR has a global mandate, but will concentrate in the tropics during the next five years. Four research programmes are planned:

- social sciences, economics, policy analysis and development
- ecology, conservation, management of natural forests
- rehabilitation of degraded and depleted forest lands
- utilisation and marketing of forest goods and services.

In addition to these four research programmes, CIFOR will have one programme to provide generic support through database and library systems, together with dissemination of research results, education and training. CIFOR will be concentrating on tropical forests for the next five years and will require regular, accurate data on forest extent, condition, type, protection and deforestation.

2.7.3 European Tropical Forest Research Network (ETFRN)

ETFRN was established in 1991 in order to provide information and services to support research on tropical humid and dry forests. This includes all research areas related to the tropical forest environment. The aim of ETFRN is to increase the cooperation and consultation of research institutions, governments and industry of European and tropical countries through well targeted information management.

2.7.4 CIRAD-Forêt

CIRAD-Forêt (formerly known as CTFT) is one of the seven departments of CIRAD (Centre de coopération internationale en recherche agronomique pour le développement) a French state-

owned organisation. It is the agency responsible for tropical forestry and wood science. CIRAD-Forêt's main partners are FAO Forestry Department, Man and Biosphere Programme of Unesco, IUCN, ITTO and the International Council for Research in Agroforestry (ICRAF). One of the organisation's main areas of research is natural forest management in the humid tropics. Forest survey and mapping is an important aspect of this work, using remote sensing combined with ground checking.

2.7.5 The International Geosphere-Biosphere Programme (IGBP)

IGBP was established in 1986 by the International Council of Scientific Unions (ICSU). Over 50 countries have national IGBP Committees, including most EC member states with the exception of Luxembourg, Portugal and Spain. The aim of IGBP is:

> *To describe and understand the interactive physical, chemical and biological processes that regulate the total earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human activities.*

Six core projects are currently being undertaken within the IGBP framework. The one most relevant to tropical forest conservation issues is Global Change and Terrestrial Ecosystems (GCTE), which is described in Section 2.8.2 below.

Each core project of IGBP is involved in data analysis and model building. Synthesis of these activities is guided by the IGBP Task Force on Global Analysis, Interpretation and Modelling (GAIM). The aim of GAIM is 'to advance the development of comprehensive prognostic models of the global biogeochemical system, and to couple such models with those of the physical climate system'.

The IGBP Data and Information System (IGBP-DIS) addresses the generic issues of data processing and management for land, ocean and atmosphere systems, in close liaison with GAIM and IGBP core projects. IGBP-DIS has paid particular attention to the use of AVHRR data in the provision of information relevant to global change issues. IGBP-DIS provides the link between IGBP and the Committee on Earth Observation Satellites (CEOS), an international association of agencies with interests in the collection, validation and dissemination of space data relevant to global change. It is expected that IGBP will be involved with the five working groups set up by the Space Agency Forum on the International Space Year (SASIFY) including those on: global land cover change; the World Forest Watch; and the global satellite image mapping project.

2.7.6 The World Climate Research Programme (WCRP)

The WCRP is the research component of the World Climate Programme, jointly sponsored by ICSU; the World Meteorological Organisation (WMO) and the Intergovernmental Oceanographic Commission.

2.8 Global Change Community

One of many research activities within the global change community is to understand the effects of changes in climate, atmospheric composition and land use on terrestrial ecosystems and to determine feedback effects to the physical climate system. Forest conversion will have a local affect and may have a global affect on numerous physical processes. To predict affects on the natural ecosystem, using modelling techniques, this user group requires forest information at periodic intervals to evaluate changes in forest cover and the consequences of this loss at a global level.

2.8.1 The Intergovernmental Panel on Climate Change (IPCC)

IPCC was jointly established in 1988 by the World Meteorological Organisation (WMO) and UNEP. The Panel's charge was to:

- assess the scientific information that is related to the various components of the climate change issue, such as emissions of major greenhouse gases and modification of the Earth's radiation balance resulting there from, and that is needed to enable the environmental and socio-economic consequences of climate change to be evaluated; and
- formulate realistic response strategies for the management of the climate change issue.

The Panel has established three working groups to assess available scientific information on climate change; assess the environmental and socio-economic impacts of climate change; and formulate response strategies. The Panel has prepared its First Assessment Report which summarises the findings of the three working groups.

IPCC collects data from a wide variety of sources to support the work of its Working Groups.

2.8.2 Global Change and Terrestrial Ecosystems (GCTE)

The overall objective of GCTE is 'to develop a predictive understanding of the effects of changes in climate, atmospheric composition and land use on terrestrial ecosystems, and to determine feedback effects to the physical climate system'. A global vegetation map is urgently needed by IGBP-GCTE for model verification and development in predicting global change effects. IGBP-GCTE has therefore been working closely with UNEP-HEM and WCMC on the development of a global vegetation classification scheme (see above).

GCTE is currently developing the LEMA (Long-term Ecological Modelling Activity) network which should be operational by the end of 1993. LEMA will link together ecological modelling groups around the world to facilitate model development through exchange of data, models and model components (Steffen, *in litt.* 1993).

3.

Analysis of User Requirements

The results of the questionnaire survey conducted for this report indicate the high level of interest amongst a wide range of forest information users in the provision of information resulting from TREES. The response rate itself is indicative of the strong demand for an information system based on satellite-derived imagery. Despite the tight deadlines of this evaluation of user needs, by the end of May the overall response rate was 21% from a total of over 655 questionnaires sent out. In many of the organisations contacted the staff resources available to deal with forest conservation issues in general are very limited, particularly in the NGO sector. Furthermore travel to international meetings and involvement in field-based activities restricts the office time available to respond to enquiries. This became particularly apparent in following up questionnaire responses by telephone.

Indicative responses showing enthusiasm for the development of the TREES project are:

- *'It certainly appears that TREES will produce a most valuable set of data on tropical forests, one that will be very useful for GCTE modellers.'* - GCTE project of IGBP.

- *'UNEP-HEM is cooperating with WCMC and IGBP in a project to look at ways of developing a new system for vegetation classification, in particular for global mapping and monitoring. In this context we are very interested in the type of information available from the TREES project and ways of using it in the classification.'* - UNEP-HEM

- *'The Commission has recently started a special programme on tropical forests that will greatly benefit from the data collected and processed under the TFIS.'* - CEC-DGI/J, Directorate for Asia

- *'We realised that the TREES project is very useful and would like to congratulate the Commission of the European Communities and the European Space Agency (ESA) for their joint effort. FRIM will be looking forward to actively participating and contributing to the project.'* - FRIM (Forest Research Institute Malaysia)

- *'TREES is a very interesting and valuable project. WWF HK has been using GIS to establish an ecological database of Hong Kong for more than two years. We welcome any opportunity to participate in the TREES project and to integrate our database for the integrated forest information system which you have mentioned.'* - WWF-HK

- *'I look forward to working closely with WCMC and the TREES Project and agree that rapid access to an integrated forest information system will contribute immensely to conservation efforts in the future.'* - Olson, WWF-USA

- *'The information you can send to us will be of great use to the work that Fundacion Natura carries out. This information will be shared out through the Latin American forest network which our institute coordinates.'* - Fundacion Natura

The response rate to the questionnaire by different user groups is shown in Table 5 below. It is important to take care when comparing percentage responses from different user groups. Information given about user group G (national NGOs) represents 40 respondents (22% of the total sent to that group) while information about group I (timber traders) represents only one respondent (8% of the total sent to that group) and therefore cannot be taken as representative. It is also important to note that the overall size and resources of different user groups varies considerably, and the numbers of questionnaires sent to these user groups varies accordingly. However, no attempt has been made in this evaluation to compile a definitive list of potential users.

Table 5: User response to questionnaire survey

USERS	Response - end of May		
	Sent	Received	%
A Global change community	30	11	37
B National forestry departments etc	229	31	14
C UN agencies	18	5	28
D Intergovernmental agencies	59	10	17
E International NGOs	22	8	36
F National governmental agencies	13	3	23
G National NGOs	180	40	22
H Forest research community	92	31	34
I Timber traders	12	1	8
Total	**655**	**140**	**21**

The response rate varies between the different user groups. Group B (national agencies and research organisations in tropical forested countries) have responded (14%) below the mean % response (24%), whereas group A (global change community), group E (international non-governmental organisations) and group H (forest research) have all responded with enthusiasm. However, out of those in group B who have responded, the need for TFIS is very apparent and individuals concerned are keen to be kept up to date with TREES progress. Indeed, a few organisations have stressed their interest in becoming involved with TREES; e.g. *FRIM will be looking forward to actively participating and contributing to the project* (Hamzah, *in litt*, 1993).

This difference in response rate may also be attributable to slower and less reliable communication links in Southern countries.

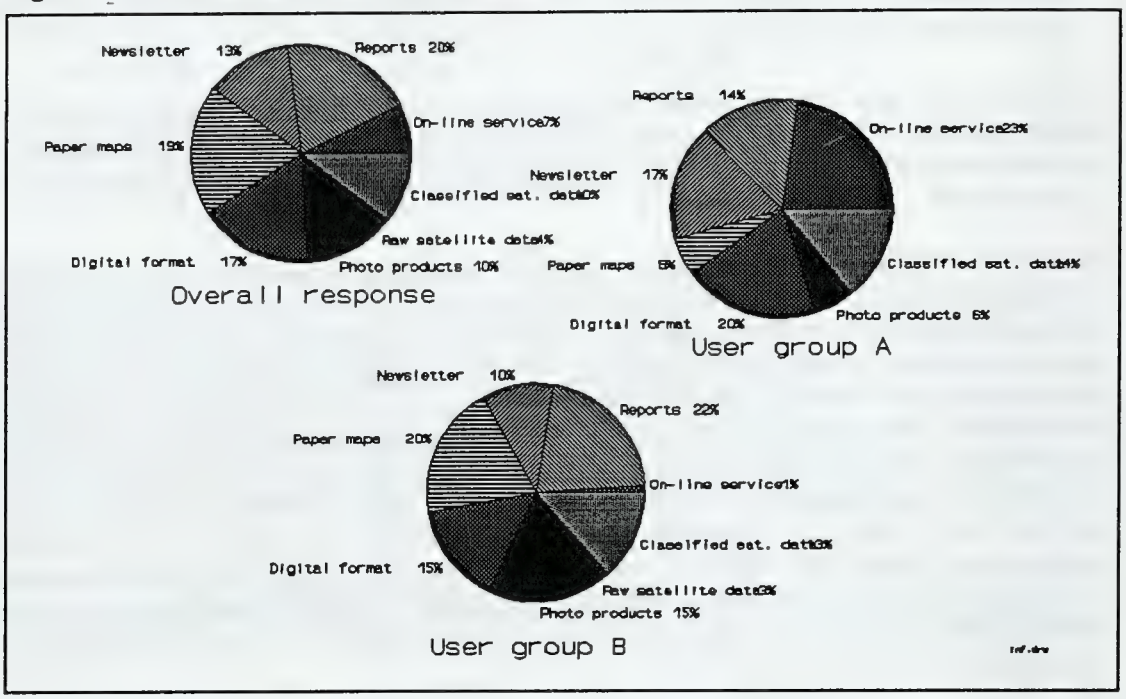
Only one respondent from the **timber traders** has answered and therefore no deductions can be drawn for this user groups. This may be because the timber traders are not interested in the service being offered by TREES or because only a small number (10) were sent the questionnaire.

Appendix D lists all those who have responded within the targeted user groups and their comments on the usefulness of TREES to them and some of their own activities. These comments are an extremely valuable addition to the yes/no type answers which the questionnaire mostly comprises and should be taken fully into account. Specific comments are incorporated into the discussion below. Appendix E contains a list of potential users' current sources of forest information. The specific sources of forest survey data most frequently cited by respondents of the survey are FAO followed by WCMC/IUCN, but this varies from user group to user group. Government agencies in tropical forest countries cited data from a variety of national sources and in very few instances mentioned international organisations as a source of supplementary data. High resolution satellite data, aerial photographs and ground surveys are currently of great importance to the national organisations. Of the organisations currently using satellite data, Landsat TM is the most frequently cited source, followed by SPOT XS and Landsat MSS.

The format in which respondents required data is shown in Figure 1.

Only 4% requested raw satellite data, the preferred options being paper maps 19%, reports 20%, digital format 17%. There is clearly a need for centralised processing of satellite-derived forest data and its provision in appropriate formats. There appears to be a higher incidence in use of GIS in the global change (73%) and forest research communities (77%) compared with other user groups (51% total). It is interesting to note that compared to the national organisations in tropical forested countries with an average occurrence of GIS, are not particularly interested in an on-line service (group B, Figure 2), whereas the global change community preferred this as a method of data delivery (group A, Figure 2). However, interestingly, for GIS occurrence, group B (52%) fair better than intergovernmental agencies (30%) and international non-governmental agencies (13%). The detection of vegetation type and vegetation condition from satellite data are cited most frequently as applications of processed data being considered.

Figure 1 Information format requirements



The questionnaire survey has highlighted major requirements of the satellite-derived data and these are indicated below. Each database record represents one targeted potential user who has responded. (The list of contacts for forest information are maintained in a contacts database, ordered by user group.) Simple statistics and counts have been derived from the database and are examined below. Unfortunately, potential users were given no more than 6 weeks to respond, but an overall response rate of 21% is sufficient to draw conclusions. Users replying after the end of May have not been included in this evaluation.

3.1 Resolution of Information

Demand for information at high and medium resolutions is much higher than demand for low resolution information. The questionnaire results are summarised in Table 6 and Figures 2 and 3, while more detailed results are given in Table 7 and Figure 4.

Figure 2 shows the number of respondents requesting each level of resolution while Figure 3 shows the mean percentage response. To derive this latter figure, the percentage response of each user group was calculated and an average of all nine figures was calculated. This figure adjusts for distortion in the results caused by the varying number of responses from each user group. For example, Figure 2 shows that a larger number of respondents requested high resolution information compared to medium resolution. Table 7 shows that the greatest demand

for high resolution data comes from the national forestry departments, of whom 74% requested this information. However, there were 31 respondents in this group (22% of all respondents) compared with, for example, only three in group F (national NGOs). Their requirements, therefore, make a much greater contribution to the overall results than those of lower-responding groups. However, until further responses are received even the mean percentage response should be treated with caution since, by giving equal weight to user groups rather than to respondents, it assumes that user group results are always representative. This certainly cannot be assumed for groups C, F and I where only five, three and one responses respectively have been received to date.

Table 6: Resolution of data requested by respondents

	% respondents requesting data	% information requests
high <1:100,000	62	47
medium	55	41
low >1:1,500,000	19	12

All user groups require some information at all resolutions, with the exception of the timber traders where only one response has been received to date.

Figure 2 Resolution - number of responses

Figure 3- Resolution - mean % response

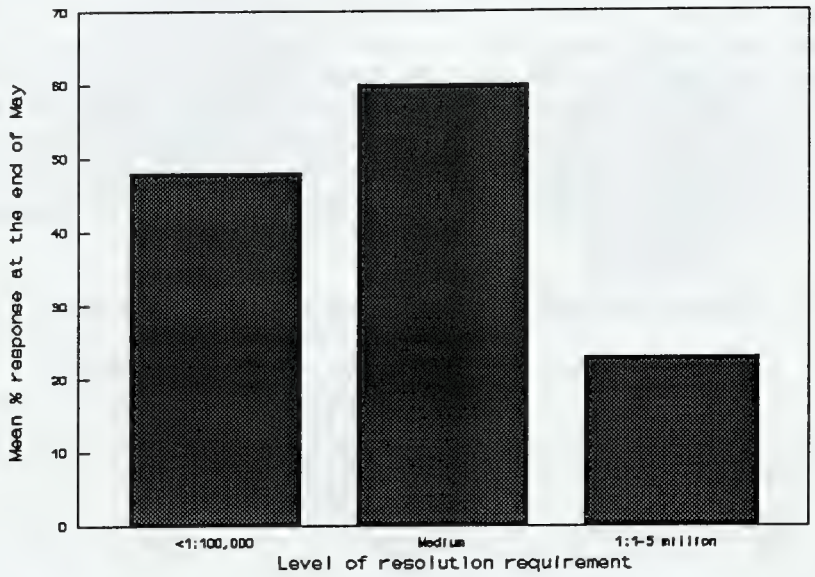
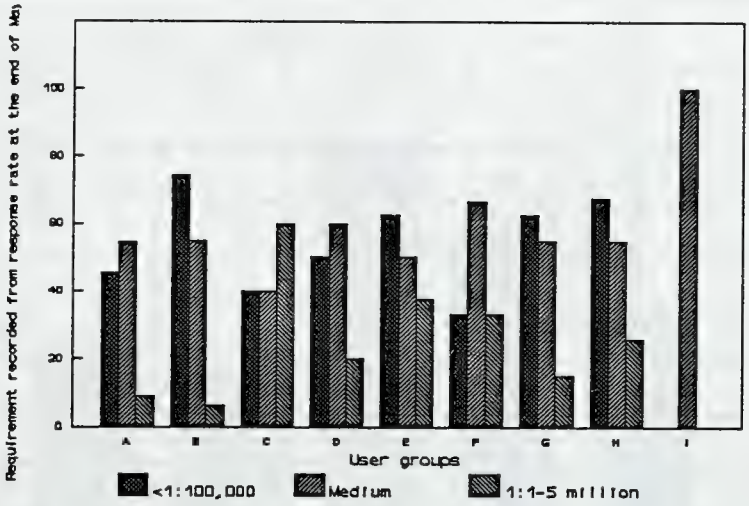


Table 7: Information requirements - resolution of data

Users	Level of resolution requirement					
	<1:100,000		Medium		1:1-5 million	
	n=	%	n=	%	n=	%
A	5	45	6	55	1	9
B	23	74	17	55	2	6
C	2	40	2	40	3	60
D	5	50	6	60	2	20
E	5	63	4	50	3	38
F	1	33	2	67	1	33
G	25	63	22	55	6	15
H	21	68	17	55	8	26
I	0	0	1	100	0	0
Total	87	62	77	55	26	19
Mean % response		48		60		23

Figure 4 Resolution requirement per user group



Key:

A	=	Global change community
B	=	National forestry departments, protected areas agencies and research organisations in tropical forested countries
C	=	UN agencies
D	=	Intergovernmental agencies and programmes
E	=	International non-governmental agencies
F	=	National governmental agencies
G	=	National non-governmental agencies
H	=	Forest research community
I	=	Timber traders

3.2 Coverage of Information

Respondents' requests for information at coverages from local to global are given in Table 8 and Figures 5, 6 and 7. Most respondents requested national information, but more respondents required local information than global information. The order of requests was as follows:

national	104	respondents
local	77	
regional	73	
subnational	67	
global	59	

Table 8: Information requirements - coverage

Users	Coverage of information requirement as recorded									
	Local		Subnational		National		Regional		Global	
	n=	%	n=	%	n=	%	n=	%	n=	%
A	4	36	5	45	6	55	7	64	8	73
B	16	52	12	39	22	71	12	39	9	29
C	2	40	3	60	2	40	3	60	4	80
D	6	60	5	50	8	80	5	50	6	60
E	5	63	3	38	8	100	7	88	6	75
F	0	0	0	0	2	67	1	33	1	33
G	21	53	20	50	33	83	20	50	12	30
H	23	74	19	61	22	71	17	55	13	42
I	0	0	0	0	1	100	1	100	0	0
Total	77	55	67	48	104	74	73	52	59	42
Mean % response		42		38		74		60		47

Figure 5 Scale of information - number of respondents

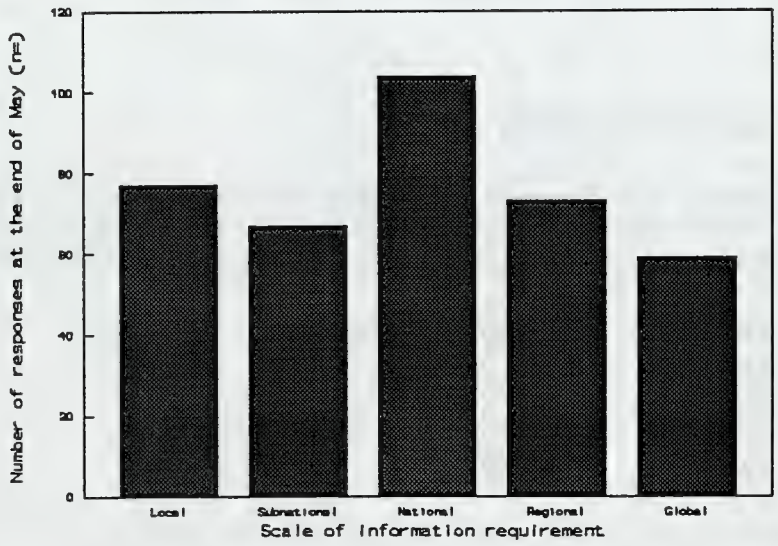


Figure 6 Scale of information - mean % response

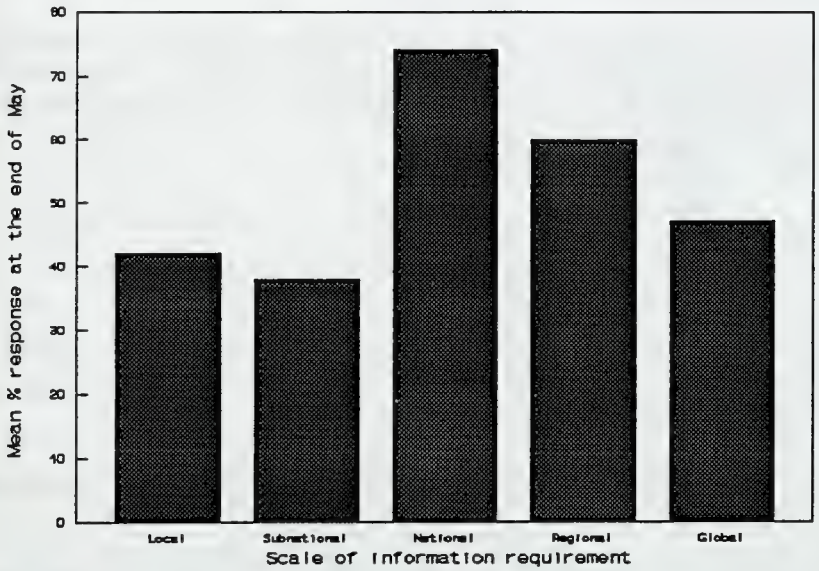
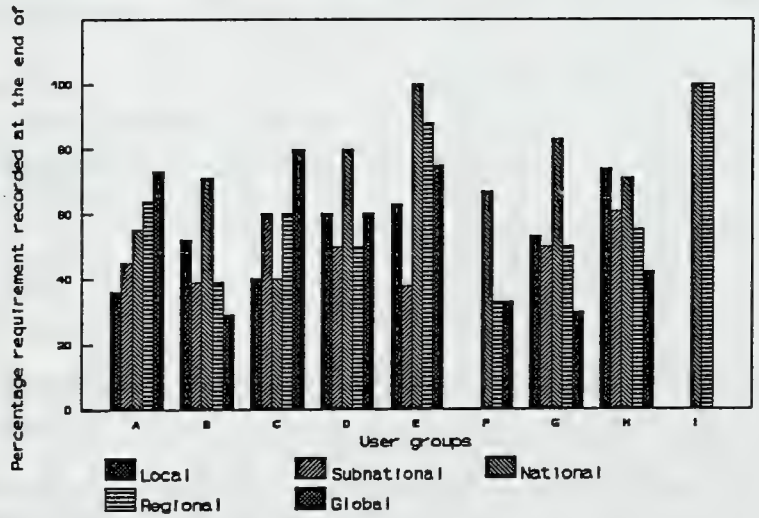


Figure 7 Scale of information by user group



Seven of the nine user groups, representing 97% of respondents, requested information at all five levels. The scope of the user groups, not surprisingly, reflected the scope of their requirements. So, for example, the global change community and UN agencies requested information with more or less increasing frequency as the coverage moved from local to global. International NGOs, national forestry departments etc., intergovernmental agencies and national NGOs showed greatest need for national information with demand decreasing at both higher and

lower resolutions. The forest research community showed a preference for information at more detailed (local, sub-national and national) levels.

3.3 Information Frequency

All information types were requested yearly more frequently than at any other interval. There was little preference shown between 3- and 5-year intervals. There were few requests for information at 10-year intervals, but slightly more requests for information to be received once only. Overall responses were as follows:

	% of respondents	% of total requests
yearly	56	40.0
3-yearly	40	23.5
5-yearly	36	22.5
10-yearly	12	4.5
once only	17	7.5

The full results are presented in Table 9.

Table 9: Information requirements - frequency

	Frequency requirement									
Users	Yearly		3-yearly		5-yearly		10-yearly		Once only	
	n=	%	n=	%	n=	%	n=	%	n=	%
A	3	27	1	9	7	64	2	18	3	27
B	17	55	15	48	11	35	4	13	8	26
C	1	20	2	40	4	80	1	20	0	0
D	5	50	4	40	4	40	2	20	1	10
E	7	88	4	50	1	13	0	0	0	0
F	1	33	1	33	3	100	1	33	0	0
G	29	73	16	40	8	20	4	10	6	15
H	15	48	13	42	12	39	3	10	6	19
I	1	100	0	0	0	0	0	0	0	0
Total	79	56	56	40	50	36	17	12	24	17
Mean %		55		34		43		14		11

3.4 Information Categories

Number of requests for information in each of the eight categories (forest boundaries, fires, roads etc) are shown in Table 10.

Table 10: Information requirements - categories

Users	Type of information required															
	CFB		FF		R		PA/FR		B		FT		TV		BIO	
	n=	%	n=	%	n=	%	n=	%	n=	%	n=	%	n=	%	n=	%
A	8	73	5	45	5	45	6	55	8	73	8	73	4	36	8	73
B	26	84	14	45	14	45	23	74	14	45	24	77	16	52	24	77
C	5	100	2	40	4	80	5	100	3	60	5	100	3	60	5	100
D	8	80	6	60	6	60	8	80	5	50	8	80	6	60	9	90
E	6	75	4	50	6	75	8	100	2	25	6	75	4	50	5	63
F	2	67	0	0	0	0	0	0	2	67	2	67	0	0	2	67
G	32	80	21	53	24	60	34	85	16	40	36	90	17	43	29	73
H	25	81	13	42	15	48	27	87	15	48	26	84	15	48	27	87
I	1	100	0	0	0	0	0	0	0	0	1	100	1	100	0	0
Total	113	81	65	46	74	53	111	79	65	46	116	83	66	47	109	78
Mean %		82		37		52		65		45		83		50		70

More respondents requested information on changes in forest boundaries, protected areas/forest reserves, forest types and areas of high biodiversity (varying from 78% to 83% of respondents - see below). Requests for information on forest fires, roads, biomass and timber volume were much lower, at between 46 and 53% of respondents.

forest types (FT)	83%
changes in forest boundaries (CFB)	81%
protected areas/forest reserves (PA/FR)	79%
areas of high biodiversity (BIO)	78%
roads (R)	53%
timber volume (TV)	47%
forest fires (FF)	46%
biomass (B)	46%

In general, responses for each group followed the patterns presented by total responses. There were a few exceptions:

- 73% of respondents from the global change community requested information on biomass, compared with 46% of all respondents;
- only 55% of respondents from the global change community requested information on protected areas/forest reserves, compared with 79% of all respondents;
- 75% of international NGOs requested information on roads, compared with 53% of all respondents.

Requests for information categories in relation to resolution, coverage and frequency are shown in Figures 8, 9 and 10. For most categories of information, more respondents requested

information at national coverage than any other coverage. Exceptions were timber volume and roads where local information was more important. A similar pattern of frequency requirement was shown for all information types, except biomass and areas of high biodiversity where the preference for annual information was less marked.

Figure 8 Resolution required by information type

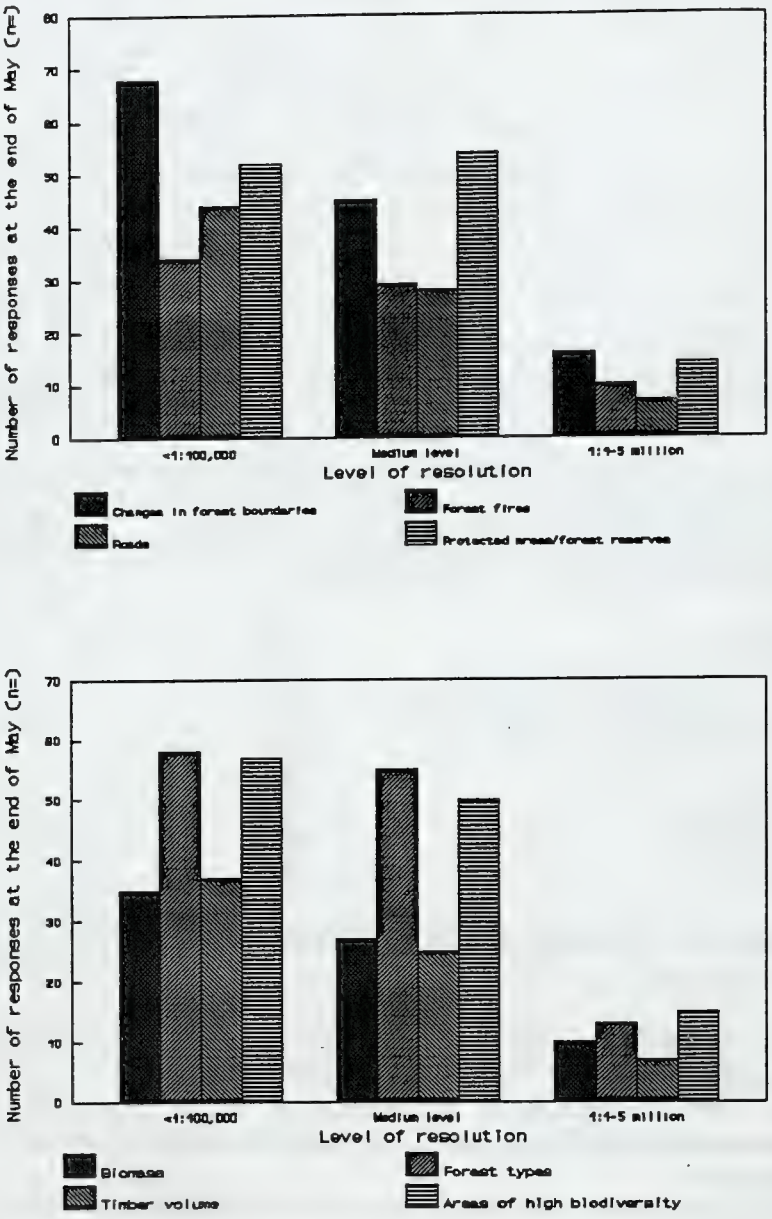
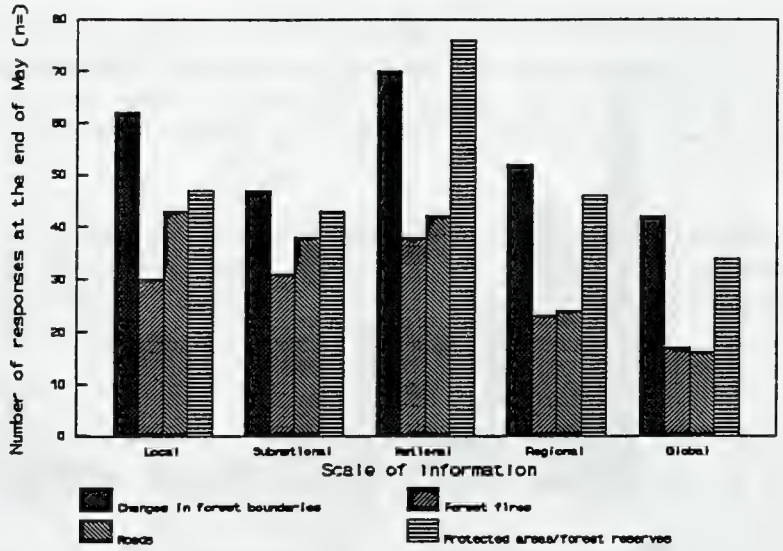


Figure 9 Scale required by information type



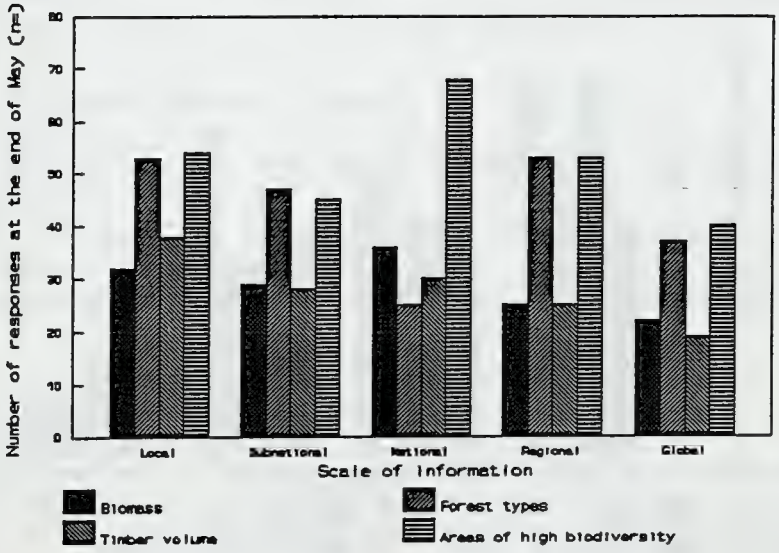
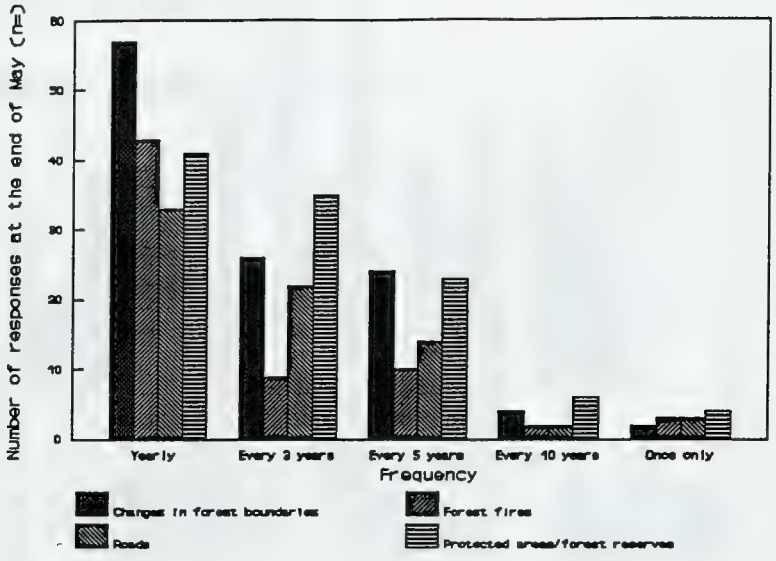
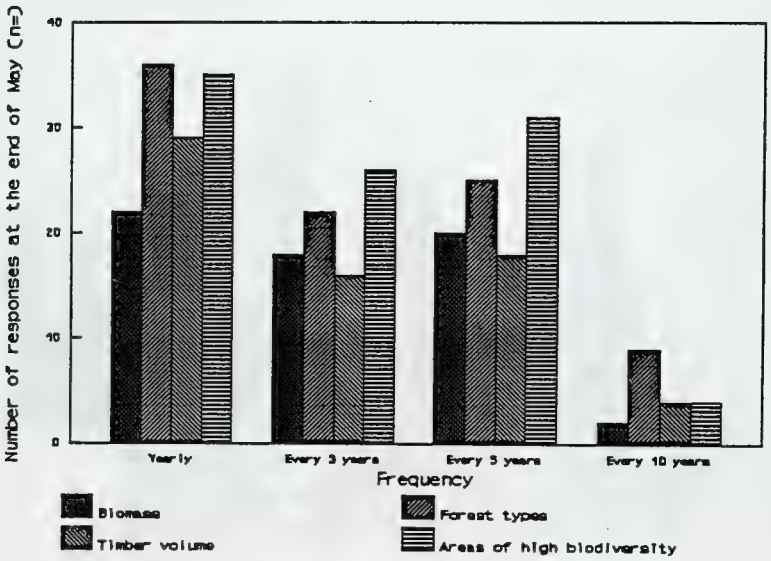


Figure 10 Frequency required by information type





3.5 Requirement Priorities

Most of the information relating to user requirements was collected in the large matrix on page two of the questionnaire. The numbers of requests for each category of information in this matrix are given in the tables in Appendix F. The first table gives the number of requests while in the second table these numbers are expressed as a percentage of the total number of respondents.

To assess the importance to the user of the various information requirements, the average number of cell entries per requirement type (coverage, frequency, response speed and resolution) was calculated (as total number of cell entries divided by the number of cells). The results were as follows:

coverage	41
resolution	35
response speed	27
frequency	15

From Appendix F it can be seen that the most frequently requested information types were:

- national level information on changes in forest boundaries, protected areas/forest reserves, forest types and areas of high biodiversity
- information on changes in forest boundaries, roads, protected areas/forest reserves and forest types within one month of request
- annual changes in forest boundaries at national and regional level within one month of request and at resolutions less than 1:100,000.

Other frequently requested information included:

- forest types at all levels from local to regional, and at high and medium resolution
- areas of high biodiversity at local and regional levels and at high and medium resolutions
- roads, protected areas and forest reserves at high and medium resolution.

3.6 User Group Requirements

There were some variations in the requirements of individual user groups compared with requirements of respondents as a whole. The **global change community** expressed a higher demand for information on biomass and a lower demand for information on protected areas and forest reserves. In general, they required information less frequently than other users:

frequency	global change community (%)	total (%)
yearly	27	56
3-yearly	9	40

5-yearly	64	36
10-yearly	18	12
once only	27	17

They also required more global information than other users:

coverage	global change community (%)	total (%)
local	36	55
sub-national	45	48
national	55	74
regional	64	52
global	73	42

National forestry departments, protected areas agencies and research organisations in tropical countries had a lower requirement for regional and global information and requested more accurate information than other users:

resolution	national forestry departments etc (%)	total (%)
local	52	55
sub-national	39	48
national	71	74
regional	39	52
global	29	42

resolution	national forestry departments etc (%)	total (%)
high	74	62
medium	55	55
low	6	19

United Nations agencies expressed a higher demand for information at longer intervals:

frequency	UN agencies (%)	total (%)
yearly	20	56
3-yearly	40	40
5-yearly	80	36
10-yearly	20	12
once only	0	17

They also expressed a higher demand for global data and for low resolution data:

coverage	UN agencies (%)	total (%)
local	40	55
sub-national	60	48
national	40	74
regional	60	52
global	80	42

coverage	UN agencies (%)	total (%)
high	40	62
medium	40	55
low	60	19

International NGOs have a higher requirement for regional, global and low resolution data:

coverage	international NGOs (%)	total (%)
local	63	55
sub-national	38	48
national	100	74
regional	88	52
global	75	42

resolution	international NGOs (%)	total (%)
high	63	62
medium	50	55
low	38	19

Their need for information on roads is higher than average (75% compared to 53% of all respondents), as is their need for frequent information:

frequency	international NGOs (%)	total (%)
yearly	88	56
3-yearly	50	40
5-yearly	13	36
10-yearly	0	12
once only	0	17

The responses of **intergovernmental agencies, national NGOs** and of the **forest research community** tended to reflect average patterns of all respondents, although the **forest research community** requires slightly more local and subnational data:

coverage	forest research community (%)	total (%)
local	74	55
sub-national	61	48
national	71	74
regional	55	52
global	42	42

The results of the questionnaire survey will clearly be useful in planning the future development of the TREES project and an integrated forest information system. It is also important to note certain reservations expressed by the respondents. These mainly relate to: actual and potential overlap with other programmes; limitations imposed by cost; availability of technical resources and expertise to access and utilise data.

In relation to overlap of satellite monitoring activities, Rodenburg (WRI) points out that TREES is duplicative with at least two other programmes, the work of EROS and at Woods Hole. Lund (USDA Forest Service) stresses the need for coordination between TREES, RESPAS and NASA Pathfinder activities, pointing out that whilst there is unnecessary duplication of work, not much progress is being made in making satellite data available to the countries which need it. Furthermore he suggests that the key groups should be urged to define their areas of responsibility and work together to provide information for resource inventory management and monitoring. Eden (CEDAR) points out that collaboration will allow effective comparison of the divergent results, and thus real appraisal of the various methodologies.

Others recognised the complementary objectives of TREES and their own organisation's activities and requested collaboration; e.g. K.D. Singh (*in litt*, 1993) of the FAO Forest Resources Assessment project, suggests that his work and TREES *'seem to serve a complementary purpose and it would be most desirable if the two activities could be*

integrated in the framework of a combined or complementary FAO/EC Programme.'

Cost was cited most frequently as a problem by current users of satellite-derived data, being indicated in 40 responses. Various NGOs commented that they would not utilise a forest information system based on TREES unless it was inexpensive.

A considerable number of respondents commented that they would like to be updated on progress in the work, and receive, when available, more specific information on the proposed forest information service. In the absence of detailed specifications, several respondents indicated a general interest in any available information from TREES. Halpin, for example, pointed out that the Global Systems Analysis Program at the University of Virginia is potentially interested in the development/acquisition of most types of forest inventory data suggested in the questionnaire. *'It is difficult for me to objectively prioritize our potential data requirements and our possible contributions to the TREES system when our focus is so variable between individual research projects. So the bottom line is that at some point in time we may be sincerely interested in most anything you may produce under the program. This is obviously not very helpful in establishing your priorities, but I am certain that this would not be an uncommon observation from many academic institutions.'*

3.7 Conclusions

The following list is a summary of preferred user requirements:

A: Global change community
- A.1 The global change community has requirements for information on: changes in forest boundaries, areas of high biodiversity, forest types and biomass.
- A.2 Requirements for this information are satisfied by a frequency of years.
- A.3 Coverage required is regional and global.
- A.4 Medium resolution satisfies the majority of the community requirement.

B: National forestry departments and protected areas agencies
- B.1 National forestry departments require information on: changes in forest boundaries, protected areas/forest reserves, forest types and areas of high biodiversity.
- B.2 Required frequencies for information delivery are yearly, and every three years.
- B.3 Information is required at local and national coverage.
- B.4 Information is required at high and medium resolutions.

C: United Nations agencies
- C.1 UN agencies require information on: changes in forest boundaries, protected areas/forest reserves, forest types and areas of high biodiversity.

C.2 Information is required every five years.
C.3 Information is required with global coverage.
C.4 Information is required at low resolution.

D: Intergovernmental agencies and programmes
D.1 Intergovernmental agencies and programmes require information on: changes in forest boundaries, protected areas/forest reserves, forest types, forest fires and areas of high biodiversity.
D.2 Information is required annually, and at three year intervals.
D.3 National coverage is required.
D.4 Information is required at medium resolution.

E: International non-governmental agencies
E.1 International non-governmental agencies require information on: changes in forest boundaries, roads, protected areas/forest reserves and forest types.
E.2 Information is required annually.
E.3 National and regional coverage is required.
E.4 High and medium resolution is required.

F: National government agencies
F.1 National government agencies require information on: changes in forest boundaries, forest types and areas of high biodiversity.
F.2 Information is required every five years.
F.3 National coverage is required.
F.4 Information is required at medium resolution.

G: National non-government agencies
G.1 National non-government agencies require information on: changes in forest boundaries, protected areas/forest reserves and forest types.
G.2 National coverage is required.
G.3 Information is required at high and medium resolutions.

H: Forest research community
H.1 The forest research community requires information on: changes in forest boundaries, protected areas/forest reserves, forest type and areas of high biodiversity.
H.2 Information is required annually.
H.3 Local and national coverage is required.
H.4 High resolution information is required.

Other requirements:
I.1 The majority of potential users require high level information products, not semi-processed data.
I.2 Most users prefer deliver of information in paper and digital form, with the exception of the global change community who prefer an on-line

delivery.

I.3 Several users stressed the desire to see cooperation between TREES and other similar activities worldwide.

I.4 Uncertainty regarding potential costs of information were cited as an area for concern by many respondents.

I.5 Many users requested that they be kept updated on the progress of the TREES programme.

4.

Translating Information into Action Programmes

It is generally acknowledged that there is an urgent need for regular and reliable information concerning tropical forest cover and deforestation.

- Effective management of forest resources requires suitable, up-to-date information on the state, extent and distribution of forest.
- Remotely sensed data, supported by other important ancillary data can assist in providing this information.
- These data should be in a format that is easily accessible and simply assimilated into decision making programmes and environmental modelling.
- These data are not currently freely available. Spatial and statistical data that are not 'restricted' must be made freely available and must be open to scrutiny by all users.
- Collaboration between TREES and the user is vital if the data are to be accepted and used wisely to truly assess the status of the world's tropical forests.
- Several potential users have expressed their interest in collaborating with TREES and this should be considered carefully.

At present there appears to be a fundamental lack of mechanisms for translating space data derived from earth observation systems into practical forest management and conservation programmes. It has been pointed out that the international forest research community needs to address the requirements of a global satellite monitoring programme from the forest management perspective. Methods and procedures need to be developed to link satellite-based forest monitoring with forest management and regional planning, with IUFRO a suggested forum for discussion (Justice, 1992).

Certain general priority uses for satellite-derived forest data can already be suggested. These include:

- modelling biomass levels
- monitoring areas protected for forest conservation under international agreements or internationally agreed programmes:
  - World Heritage Sites
  - Biosphere Reserves
- monitoring priority areas potentially in need of international conservation assistance:
  - Centres of biodiversity
  - Deforestation zones
  - Centres of Plant Diversity
  - Endemic Bird Areas

- inclusion in Forest Resource Accounting - monitoring progress towards ITTO's *Target 2000*
- prioritising activities under regional and country programmes which requires a knowledge of extent of tropical forest cover and relative and absolute deforestation rates.

Specific uses mentioned in the questionnaire survey include the placing of forest management areas in a regional context (Programme for Belize); use of data in university teaching and research (University of Brunei Darussalam); use of data to monitor logging and encroachment into sensitive areas (Responsible Forestry Programme [FSC]); use of data to suggest changes in forest policy (Asociacion Ecologista Panameña); use of independent satellite derived data to verify official forest survey information (WWF India).

The use of satellite derived data in forest conservation, management and research programmes is greatly enhanced when it is used in conjunction with other forms of data. Integration in GIS offers a mechanism to overlay the specific datasets required by the wide range of organisations and individuals involved in forest conservation. Additional datasets which could usefully be integrated into the TFIS system relate to:

Environmental factors:	forest extent
	forest types
	forest condition
	forest boundaries
	forest biomass
	seasonality
	hydrology
	topography (e.g. slope)
	soil erodibility/erosion
Forest management:	protected areas
	forest reserves
	forest concessions
	local rights
Forest policy:	land use planning
	forest legislation and policy
	colonisation policies
Threats:	fires
	logging
	roads
	railways
	population movements/growth
	industry (mining etc.)
	major projects (dams etc.)
	other natural phenomena

It is clear that the development of an integrated forest information system based on TREES should build on existing programmes and networks. This will facilitate the collection of datasets itemised above and will increase the accessibility of the system to the user community. As has already been pointed out the development of TREES and the FAO Forest Resources Assessment 1990 Follow-up Project using multi-date high resolution data on a sampling basis would seem to be complementary. A considerable number of respondents indicated that their organisation is in a position to be involved in verification and data exchange.

Most users are interested in a value-added service and are less interested in obtaining raw (unprocessed) satellite data. This is probably an indication that most users do not have the money or technical capability of dealing with these unprocessed data. Therefore, maintenance of a system, acquisition of data and distribution of data are of paramount importance to TREES and the potential user and also supports the notion of an integrated forest information system. Contacts, networking and collaboration are important aspects for efficient dissemination of data. Precise knowledge of user requirements, at a prototype level, may be necessary to ensure that these methodologies are put in place. It is also important to note that until a potential user is exposed to the TREES data, precise needs cannot be fully assessed, or stated requirements may change. WCMC, an organisation which already has a well established network of contacts in forest conservation and management, may well have a key role to play in the provision and dissemination of data.

4.1 Key Considerations in the Development of TFIS

The following list summarises the salient points which have been deduced from this users survey. These key considerations should be taken into account in the future development of an integrated tropical forest information system.

- There is a clear demand for an integrated forest information system based on satellite-derived forest cover data and potential applications which suggest that this will contribute to forest conservation.
- The demand is wide-ranging with national government agencies, intergovernmental agencies, and NGOs all expressing strong interest.
- It is important to consider the requirements of different user groups in identifying the potential users of TFIS, and to design the system accordingly. High priority should be given to user groups who have shown a particular interest in the service.
- Requirements may change once the user starts to employ data provided by TREES and therefore products should be sufficiently flexible to account for these possible refinements in requirements.
- AVHRR satellite data appear to be relatively infrequently used by tropical forest conservation and management organisations and is considered to have limited applications in forest monitoring.
- Data with a sufficiently high resolution to be used for national forest monitoring is the primary requirement.
- The most frequently requested information is national level information on changes in forest boundaries, protected areas and forest reserves, to be received within one month

of request.

- Global level information on forest extent and deforestation rates is of more interest to the Global Change Community for modelling purposes.
- Close liaison should be maintained with similar global forest monitoring programmes - EROS, RESPAS, NASA Pathfinder.
- TFIS should be developed in collaboration with the organisations which are currently the main sources of international data on forest cover and deforestation notably FAO and WCMC.
- Regular updates on the development of TFIS should be provided to the potential user community.
- Forest research organisations such as IUFRO and CIFOR should be involved in coordinating TFIS and the forest research community. CIFOR can for example help to extend the forest map library (GIS) of WCMC for integration into TFIS.
- Financial support from CEC, UNDP or other appropriate bodies should be considered for the provision of GIS systems to national government agencies and national NGOs to encourage collaboration and guarantee the effectiveness of TFIS.
- National agencies have expressed their interest in ground-truthing satellite derived data and this should be taken into account in planning TFIS, with a view to developing collaborative ventures.
- The use of GIS is becoming much more common and TFIS should be designed to cope with conversion between the wide variety of software packages used.
- A regular standard reporting system should be designed for all users. This could for example be in the form of a published twice yearly report available at low cost or free of charge. Most users prefer paper maps, reports and newsletters for data acquisition although on-line service should not be ignored.

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Appendix A

Letter Introducing TREES

Dear Colleague

THE FUTURE DEVELOPMENT OF THE *TREES* PROJECT

Objective data on the extent and condition of tropical forests are urgently needed for planning forest conservation and management into the next century. There is a global demand for such data as expressed at the Rio Earth Summit and recognised in the *Statement of Forest Principles*.

The TREES (Tropical Ecosystem Environment Observations by Satellites) project, a joint initiative of the Commission of the European Communities and the European Space Agency (ESA), sets out to meet some of these data needs, using the latest technology to provide pan-tropical forest information.

WCMC and EOS (Earth Observation Sciences Ltd) are currently advising on the future of the TREES project. We will be looking at the objectives and targets, the extent to which these meet the needs of the user community and the ways forward for the development of the project. This will include an integrated forest information system.

WCMC is seeking the views of a wide range of users of forest information, and we would greatly value your involvement. Please spare the time to read the brief account of the TREES project which is enclosed and to fill in the questionnaire. We need to know if an integrated tropical forest information system based on the work of TREES could meet your information requirements, and if so how the development of the project could best meet your specific needs. We will take into account the broad range of technological capabilities.

We will ensure that all organisations that respond to the survey are informed of the developments relating to the proposed tropical forest information system. It would be greatly appreciated if you could return the questionnaire to WCMC by 20 May 1993. Thank you for your help.

Yours sincerely,

N M Collins, Ph.D.
Director of Programme

Appendix B

TREES - Provision of Tropical Forest Information

'The provision of timely, reliable and accurate information on forests and forest ecosystems is essential for public understanding and informed decision-making and should be ensured.' (*Non-legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of all Types of Forests*, UNCED, 1992)

The Tropical Ecosystem Environment Observations by Satellite (TREES) project is a joint initiative of the Commission of the European Communities (CEC) and the European Space Agency (ESA). Over the past two years a research team has been designing and implementing a system to assess the world's tropical forest cover using satellite-derived data and ancillary data from numerous other sources. Implementation of the TREES project involves close collaboration with those countries in which tropical forests are located and cooperation with other relevant initiatives around the world. The TREES project, which is being undertaken by the Institute for Remote Sensing Applications of the CEC Joint Research Centre at Ispra in northern Italy, is currently acquiring spatial information derived from satellite receiving stations, to compile a pan-tropical baseline map showing forest extent and forest type - the first such map based on satellite-derived data. A method is being set in place to classify the satellite data automatically and make regular updates, concentrating on those areas of rapid deforestation. These data are being augmented with important ancillary information, such as vegetation maps from national and regional sources, land-use information, biodiversity attributes, management data and other ecological information. Data will be maintained in a geographic information system (GIS) to facilitate data manageability, analysis, access and distribution. When the system has been designed and tested, a procedure will be implemented and data will be made available to a wide range of users through an integrated Tropical Forest Information System (TFIS).

What are the data sources?

The main type of satellite imagery used by the TREES project is from the AVHRR (Advanced Very High Resolution Radiometer) on-board the NOAA satellites. AVHRR images have 1km resolution and are being collected for the project from receiving stations in Africa, Latin America and Southeast Asia. As procedures improve, there may also be the possibility of using ERS-1 satellite radar coverage. The forest categories currently being investigated for identification are: closed canopy tropical rain forest; degraded tropical rain forest, where regional forest cover is $<70\%$; secondary forest; seasonal moist forests, and areas of active deforestation, identified using indicators of change (roads, fires, boundary changes, appearance of forest canopy). AVHRR data are supplemented by higher resolution SPOT and Landsat TM images. Analysis of the seasonality of the vegetation is being undertaken using GAC (Global

Area Coverage) data. Fieldwork and other methods of verification also form an important part of the validation and information gathering process. As well as the satellite-derived data, other relevant information from many sources is being incorporated into the system and managed within the TFIS. These ancillary data will help provide a more holistic picture of the world's tropical forests.

How will TREES develop?

The TREES project was established in 1990, and the first phase of the project (TREES I), which concentrated on methodological aspects, data gathering and mapping, is nearing completion. Phase two of TREES (TREES II) is now being planned to build on this work, to develop TFIS and provide a continual forest monitoring service. EOS (Earth Observation Sciences Ltd.) and the WCMC (World Conservation Monitoring Centre) are helping in this process by objectively assessing TREES goals and achievements over the past two years, by looking at modifications which may be necessary as a result of changing views on tropical deforestation, by assessing the actual and potential needs of the user community and, as a result, by proposing ways forward. EOS and WCMC will be analysing the requirements for operational forest monitoring and making recommendations for the orientation of further research under the umbrella of TREES II. From the outset of the TREES project it was agreed that, "unless the data are put to use in an effort to control deforestation then the TREES work will have been wasted". It is essential that TREES is designed and maintained to the required standards and needs of the user community - the organisations and individuals who manage, study and conserve the world's tropical forests.

Appendix C

Questionnaire

USER PROFILE AND USER NEEDS

Questionnaire

USER PROFILE AND USER NEEDS

In order to plan the next phase of the TREES project the Commission of the European Communities has asked WCMC to contact users of tropical forest information to find out their data needs. Your views will help to determine the development of an integrated tropical forest information system incorporating satellite-derived data. Please fill in text or tick box(es) where appropriate, make any additional comments, and return your views to Clare Billington, WCMC, 219 Huntingdon Road, Cambridge, CB3 ODL, UK. Tel: 44.223 277314 and Fax: 44.223 277136. THANK YOU

1. Major Activities

A. ***Your organisation's full name:***
Contact person (capitals please):

Address:

Tel: Fax: Telex: email:

B. ***Please indicate which of the following activities your organisation undertakes:***

B1. Forest resource surveys ☐
B2. Forest management for production ☐
B3. Forest management for nature conservation ☐
B4. Forest management for recreation ☐
B5. Forest policy making ☐
B6. Forest research ☐
B7. Land use evaluation and planning ☐
B8. Global change research ☐
B9. Vegetation classification/mapping ☐
B10. Protected area systems planning ☐
B11. Provision of information service ☐
B12. Raising of public awareness ☐
B13. Provision of forest goods ☐
B14. Provision of consultancy services ☐
B15. Provision of development aid ☐
B16. Other, please state what

C. ***Does your organisation use forest survey information? If yes, what activity are these data used for:***

C1. Resource management ☐
C2. Global change research ☐
C3. Biodiversity conservation ☐
C4. Other research, please state what
C5. Other, please state what

If yes, what are your current sources of supply?

Please elaborate:

2. Information Requirements

D. The TREES project is currently developing a prototype forest information system incorporating satellite-derived data and important ancillary information. Would you be interested in receiving forest information from such a system?

D1. Yes ☐

D2. No ☐

Where appropriate, please tick boxes to answer the following tabulated questions:

Information requirements	Changes in forest boundaries	Forest fires	Roads	Protected areas/forest reserves	Biomass	Forest types	Timber volume	Areas of high biodiv-ersity
E. Which types of information would you seek from an integrated forest information system?								
F. At what scale would you require this information?								
Local level								
Sub-national level								
National level								
Regional level								
Global level								
G. How frequently would you require this information?								
Yearly								
Every 3 years								
Every 5 years								
Every 10 years								
Once only								
Other								
H. Would you need a response to your information request:								
Immediately								
Within a month								
Other								
I. At which level of accuracy would you require this information?								
High level< 1:100,000								
Medium level								
Low level 1:1-1.5 million								

J. How would you wish to receive this information/data?

J1. On-line service ☐
J2. Reports ☐
J3. Newsletter ☐
J4. Paper maps ☐
J5. Digital format files (e.g. ARC/INFO, ERDAS, IDRISI) ☐
J6. Photographic products ☐
J7. Raw satellite data ☐
J8. Computer classified satellite imagery ☐
J9. Other, please state how

3. Information Analysis and Supply

K. Does your organisation maintain a geographic information system?

K1. Yes ☐
K2. No ☐

If yes what type of software do you employ?

K1.1. ARC/INFO ☐
K1.2. ERDAS ☐
K1.3. IDRISI ☐
K1.4. SPANS ☐
K1.5. ILWIS ☐
K1.6. Other, please state what

L. The verification of satellite data and supply of other data using local knowledge is essential. Is your organisation in a position to be involved in verification and data exchange?

L1. Yes ☐
L2. No ☐

M. Do you distribute forest survey information?

M1. Yes ☐
M2. No ☐

If yes, in what form are these data distributed:

M1.1. Paper reports ☐
M1.2. Computer database tables and text ☐
M1.3. Paper maps ☐
M1.4. Digital maps ☐
M1.5. Others, please state how

4. Forest Monitoring

N. Does your organisation monitor forests?

N1. Yes ☐
N2. No ☐

If you answered 'no' then there is no need to carry on with the questionnaire. Please note, however, that there is a section at the end of the questionnaire for you to make further comment

if you wish. Many thanks

If you answered yes please tick a box(es) to indicate at which level the forest surveying is being undertaken and by which method:

	Global	Regional	National	Sub-national	Local
Ground survey					
Aerial survey					
Satellite imagery					

O. If your organisation uses satellite imagery which satellite data do you use?

O1. Landsat TM ☐
O2. Landsat MSS ☐
O3. SPOT XS ☐
O4. SPOT P ☐
O5. AVHRR (local area coverage) ☐
O6. AVHRR (global area coverage) ☐
O7. Other, please state what

P. If you have used satellite-derived data to assess forest cover, what, if any, are the problems you have experienced?

P1. Data availability ☐
P2. Data access ☐
P3. Cost ☐
P4. Distribution ☐
P5. Interpretation ☐
P6. Data processing ☐
P7. Hardware/software ☐
P8. Available data content not suitable ☐
P9. Other, please state what

Q. If your organisation is considering the use of satellite data for forest monitoring, what classes would you need to detect?

Q1. Vegetation type ☐
Q2. Vegetation condition ☐
Q3. Timber volume ☐
Q4. Biomass ☐
Q5. Other, please state what

R. For your purposes do you require:

R1. Low resolution satellite derived data (1km resolution) at regular intervals ☐
R2. Higher resolution satellite derived data (30m resolution) at less frequent intervals ☐

Additional comments:

Appendix D

List of Respondents and Summary of Comments

This appendix represents the list of users who responded to the questionnaire by the end of May 1993.

Global change community

Agren
Department Ecology and Environmental Research, Swedish Univ Agric. Sci

Steffen
Global Change and Terrestrial Ecosystems Core Project of the IGBP
Thank you for your questionnaire on the TREES project. I have completed it on behalf of GCTE, as the ongoing data that will arise from TREES will be very useful to our modelling groups. You will note that I have listed the GCTE Core Project Office as the contact. This is an interim arrangement, as we hope to have our LEMA (Long-term Ecological Modelling Activity) network established and operational by the end of the year. LEMA will link together ecological modelling groups around the world to facilitate model development through exchange of data, models and model components. LEMA will be coordinated by a small secretariat, to be established at the University of Virginia with Prof Hank Shugart's group. When the LEMA Secretariat is established, it will be the point of contact for data exchange between GCTE and other groups, such as TREES. It certainly appears that TREES will produce a most valuable set of data on tropical forests, one that will be very useful for GCTE modellers. Best of luck in the next phase of the project!

Jorgensen
DFH Institut A, Environment. Chemistry, Int. Society of Eco. Modelling

Congalton
Department of Natural Resources, University of New Hampshire

Brown
Department of Forestry, University of Illinois

Glantz
National Center for Atmospheric Research

Windhorst
Ecosystem Research Project Centre
Though we are not a forest research institution from our origin, our interest in the TREES

project results out of the following: 1) as an institution devoted to ecosystem research we are also involved in forest research. This includes also activities to develop an integrated ecological information system, which will allow a question oriented access to the elaborated knowledge stored in models, in a relational data-base (ORACLE) and in the GIS (ARC/INFO). Just now we are discussing the structural scheme for the system and the layout for the documentation schemes in order to meet our needs for integrated ecological interpretations. The creation of transparent interfaces to other information-systems is therefore still possible. A more detailed knowledge about the TREES approach would possibly enhance the necessary harmonization process in this field; 2) together with our Danish partner Prof. S.E. Jorgensen we started an activity to install an International Centre of Ecological Modelling (ICEM). The success of this activity and the benefit for the participants of the courses will increase with the availability of information elaborated and documented in the TREES project. Thus we would be glad to receive more information about your work and the conclusions you draw out of the returned questionnaires.

Spence
Global Climate Observing System

Halpin
Global Systems Analysis Program, Department of Environmental Sciences,
The Global Systems Analysis Program at the University of Virginia conducts forest ecosystem studies which range in spatial scale from full global coverage to regional and site specific case studies of ecosystem dynamics depending on the current mix of research projects undertaken at a given time. For example at this time we have projects ranging from the analysis of global climate change on world forest systems conducted at extremely coarse spatial resolutions, while at the same time have projects dealing with individual nature reserves using data at 30m spatial scales. Because of the broad range of projects we conduct under this program, we could be potentially interested in the development/acquisition of most types of forest inventory data suggested in the questionnaire depending on the type of research activity currently underway. This necessarily generalist position is reflected in the many "all of the above" responses to most of the questions posed in the survey. It is difficult for me to objectively prioritize our potential data requirements and our possible contributions to the TREES system when our focus is so variable between individual research projects. So the bottom line is that at some point in time we may be sincerely interested in most anything you may produce under the program. This is obviously not very helpful for establishing your priorities, but I am certain that this would not be an uncommon observation from many academic institutions. With that said, I have a personal interest in seeing the development of global coverage (1km) vegetation index and monthly NDVI phenology mapping (similar to the work Loveland (PE&RS 1992) use for the US) to replace the coarse GVI data sets now in use. I am extremely interested in the development and dissemination of data bases for this type of research and appreciate being informed about future developments. I also want to state that I am very willing to offer assistance where possible and have always valued my contacts with WCMC. Thanks for keeping me in mind and please stay in touch.

Dale
Environmental Sciences Division, Oak Ridge National Laboratory

Leemans
National Inst. for Public Health & Env Protection, Global Change Dept
I believe this could be a very important initiative, but from the documentation it is not clear to me how this initiative fits in with some other research activities in research programmes like IGBP-DIS. I hope that all these activities will be well directed, so that a minimum of overlap occurs and some products of good quality are developed. Currently my research has changed from climate impact research to land cover modelling. We have assembled a group of c.15 researchers to further develop the IMAGE model. This model included sub-models for energy-use, ocean-atmosphere interactions, the terrestrial biosphere and all their linkages. It is now one of the first global change models which is aimed at developing and evaluating policy scenarios. I am responsible for the terrestrial biosphere models and an explicit simulation of land cover change, such as deforestation and agricultural intensification. The preliminary results are very promising. I envision that the approach taken can also be useful for evaluating sustainable development, conservation and biodiversity issues.

National forestry departments, protected areas agencies and national research organisations (mainly in tropical forested countries)

Hamzah
Forest Research Institute Malaysia
We realised that the TREES project is very useful and would like to congratulate the Commission of the European Communities and the European Space Agency (EDA) for their joint effort. FRIM will be looking forward to actively participating and contribute to the project.

Jonkers
Tropenbos-Cameroon Programme
Our research project in Cameroon is just starting. Inventories etc. will commence in the second half of 1993. We do not maintain a GIS at present but will use ILWIS or ARC/INFO soon.

Johns
Makerere University Biological Field Station, Uganda

Abdel Nour
Forests National Corporation, Sudan
Trying to obtain a GIS

Marguba
Nigeria National Parks

Senekane
Lesotho Ministry of Agriculture, Co-operatives and Marketing
Please note: Lesotho is not in the tropics but sub/tropics. It has 8% of its land area dominated by tree and predominantly shrub species, generally knee high to head high, which are an important source of local household fuel and help protect steep slopes. The country is classed as virtually treeless. The main forestry activity by Government and local people

is firewood plantation development in areas from 0.1 ha to 400 ha. The average size of Government plantations is c. 15 ha and of private plantations c. 0.15 ha. Government plantations total 450 and are all actual or proposed forest reserves. Private plantations have not yet been surveyed, assessed or even counted but will exceed 3,000.

Pomeroy
Makerere University, Institute of Environment and Natural Resources, Uganda
The National Biodiversity Data Bank (NBDB) is a unit within MUIENR and is involved in all aspects of Uganda's biodiversity. The use of remote sensing and GIS are likely within the next 2 years or so.

Hoeft
Wau Ecology Institute, Papua New Guinea
Wau Ecology Institute is presently starting to set up GIS for land use and conservation planning on a regional scale. We are working on soil and vegetation classification and attempt to come up with thematic maps including land-use and conservation suggestion. For this goal we have used aerial photographs up to now. However, prints were of rather poor quality and only part of our area was covered. Delineation of different forest types from these photographs was impossible at our scale of interest. I have recently seen satellite images composed from a mixture of infrared and far red which impressed me by showing clear differences between "primary" and "secondary" forest. For our Institute being a non-profit oriented place of research and education relying almost entirely on outside funds price is a major impediment to purchasing and using those data. Up to now, we have therefore worked primarily on the ground truth survey. We are looking forward to getting further information from you.

Wickramasinghe
Forest Inventory and Management, Forest Department, Sri Lanka
A national forest map at nominal 1:250,000 scale was prepared in late 1992 by interpretation of 1992 TM imagery. This preliminary map is available in digital (ARCINFO) form. A more detailed and field-checked map at nominal 1:50,000 scale is currently being prepared from the same imagery and will be complete by mid 1994. This will form a major input to a national forest GIS and will serve as a baseline against which to measure future change in forest area. The new map will also be available in ARCINFO format. Updating is planned every five years. The national forest map divides closed canopy forest into seven categories of natural forest, based on elevation, rainfall and other characteristics (e.g. mangroves) and four species categories of forest plantations.

James
Forestry and Wildlife Division, Dominica

Deravariere
British Virgin Islands National Parks Trust
My organisation is responsible for the management of terrestrial parks in the British Virgin Islands. In this regard some of the forested areas, which are national parks, come under its jurisdiction. Information that is available in these parks may need to be updated.

Preston
Department of Forestry, Queensland, Australia

Leduc
Direction de l'Agriculture et de la Foret, French Guiana

Teo
National Parks Board, Singapore Botanical Gardens

Kumar
Department of Agriculture, British Virgin Islands

Eaton
University of Brunei Darussalam
Certain aspects of the TREES project are obvious value to our university carrying out teaching and research in a tropical rain forest area. My own particular interests are in protected areas and resource management. We are not involved in forest monitoring although have used LANDSAT imagery identifying forest boundary changes, especially in relation to protected areas. We do not have a GIS but one is being developed in association with the Kuala Belalong Rainforest Research Project.

Director General
Tanzania National Parks
Tanzania National Parks is mainly concerned with management and conservation of the protected areas or national parks. The use of wildlife or the biotic natural resources is strictly on non consumptive use, i.e. tourism and scientific research which is mainly in the form of ecological monitoring to provide information for management decision making. Other research projects are normally specific solution seeking or knowledge. They are long term and short term. The long term projects normally even if they were not meant to answer specific management problems become very useful. The major management objective is to answer biodiversity in our protected areas by preventing human activities such as poaching and their related fires during illegal hunting, honey gathering and cattle raiding across parks. The other thing we do is to develop roads and hotels in a well planned way so as not to jeopardise the conservation goals.

Somma
Adiministracion de Parques Nacionales, Argentina

Lopez
CIDDEBENI, Trinidad
Our institution is beginning to work with GIS. We believe that within a shortish time, 3-6 months, we will be able to exchange information on digital maps.

Liang for Sastrosemito
Directorate General of Forest Inventory & Land Use Planning, Ministry of Forestry, Indonesia
The points you raised in your letter related to global demand for the objective data on the extent and condition of tropical forests has also become the Government of Indonesia

concern. The first National Forest Inventory Project is undergoing and will be completed by 1996. The wall to wall mapping using satellite data mainly Landsat MSS (1986-91) has been completed in phase-I of the Forest Resource Monitoring activities, hence in phase-II starting 1992 a Digital Image Analysis System has been implemented using Landsat TM.

Siddiqui for Nazir
Ministry of Food and Agriculture, Government of Pakistan
The Pakistan Forest Institute, Peshawar is responsible for conducting research and education in forestry and allied disciplines. Apart from research the Economics Branch of the Institute compiles forestry statistics of the county and publishes it annually. This information is collected from the provincial/regional forest departments as well as field surveys. In near future the Institute would develop GIS facilities and would conduct training and survey for forest inventory in the country.

Dias for Barbosa
National Institute for Space Research - INPE, Brazil

Pinso
Rakyat Berjaya Sdn Bhd, Sabah, Malaysia

Playfair
Suriname Forest Service, Planning Division
We are applying for an ILWIS GIS. We need to detect vegetation type and condition for mixed tropical high forest.

Incer
IRENA - Instituto Nicaraguense de Recursos Naturales y del Ambiente, Nicaragua

Compadre
Ministere de l'Environnement et du Tourisme, Burkina Faso

Granja
Conselho Estadual do Meio Ambiente (CONSEMA), Brazil
We are sending a folder that tells about our Monitoring Sistem by Satellites, named "Olho Verde" (Green Eye).

Gwyan
Forestry Development Authority, Liberia

Soundele
SODEFOR (Societe de Developpement des Plantations Forestieres)

Appiah
Forestry Service, Government of Mauritius

Timber traders

Franco

Asociacion Ecujtoriana de Industriales de Madera, Franco

UN agencies

Olesen
UNEP-GRID
GRID cooperates with TREES, FAO, GEMS and WCMC already.

Srestha
UNEP/GRID Bangkok
GRID-Bangkok mandate is to supply geo-referenced environmental information for the user community. A digital spatial database will be developed very soon through collaborations in Asia. The database combines tables and geographic information systems data related to the main physical features and some socio-economic variables. The scoop is the sub-national level or the 1:1,000,000 scale. TREES II could be one of the contributors to this Asia database for the land cover/vegetation information. GRID-Bangkok plans also to use NOAA data to update the existing information as we do now for a few countries (Cambodia, Thailand) already.

Klune
UNEP-HEM (Harmonisation of Environmental Measurement)
UNEP-HEM is cooperating with WCMC and IGBP in a project to look at ways of developing a new system for vegetation classification, in particular for global mapping and monitoring. In this context, we are very interested in the type of information available from the TREES project, and ways of using it in the classification. A major part of HEM's task is concerned with collection and dissemination of information about who is doing what, where, how and why in the field of environmental measurement. This is our general interest in the TREES programme.

Bangoura
UNEP-GEMS National, Guinea
Our organisation was created under UNEP-GEMS/PAC as an Environmental Monitoring and Assessment Centre; however, lack of funds means that the Centre is not yet operational, but we do what we can. The Centre's work programme was to comprise: the use of aerial point sampling (APS): GIS for data collection and integration; and finally data distribution and training. Since the Centre is not functional, our Service faces serious problems as Guinea is covered in wet tropical and shade forest. The long-term objectives of the Centre have become a focal point for networks such as UNEP-GRID, AFRINEM, PAEMN, FAO ARTEMIS/DIANA, CILSS and AGRIMET. The Centre should continue to assess, develop and apply methods of monitoring resources all over Africa, and assist in the adoption of such methods in similar situations. We request all institutions, organisation etc. to assist us to bring our efforts to fruition and to see the Centre in operation.

Singh
FAO, Forest Resources Assessment
EEC TREES-2 (Follow-up Project) using NOAA and FAO Forest Resources Assessment 1990 Follow-up Project using multi-date high resolution data on a sampling basis seem to serve a complementary purpose and it would be most desirable if the two activities could be integrated in the framework of a combined or complementary FAO/EEC Programme.

Intergovernmental agencies and programmes

Kerr
Commonwealth Secretariat, UK
This organisation is interested in national level statistics for forest cover in all fifty Commonwealth countries. A baseline data set with an update every three years and some early warning system for major changes by use of a Newsletter would be very welcome. We are not in a position to feed data into the system.

Fottland
NORAD - The Catchment Forestry Project, Norway/Tanzania
The Catchment Forestry Project is working with management of forest resources, mostly protected in parks of Tanzania. We have thus interest in and will assemble any knowledge, relevant to the management of forest. [It is usually so in Western countries that forest knowledge and management starts on the ground and information have successively been collected from further away i.e space at present. The problem about satellites is that you do not avoid the necessity of ground truth, being the most important part, and which Western countries have had for a long time. I do unfortunately see limited use of satellites as long as the ground truth is lacking.

Kotari
JICA, Japan
We, as the bilateral technical cooperation implementation Agency of Japan, are very much interested in receiving an integrated tropical forest information by our project.

Wagner
World Bank
It is difficult to fill this in accurately for the whole World Bank! Obviously, we have projects in many countries, which often use data such as you supply in design, monitoring etc. Any improvement on the paucity of reliable, high quality data now available would be good. Projects are designed in conjunction with client countries, consultants, FAO etc; they all use different sources of data. The Bank would probably only use TREES type data "second hand" as it were, through these initial sources.

Beese
Commission of the European Communities, DGXII B-4

Anz (for Pinto)
CEC - DG for Agriculture - UNIT VI FII 2
As you probably know, DG VI and in particular my Directorate, is not directly concerned by tropical forestry matters, as these are among the competencies of DG VIII (cooperation and development) and DG I (external affairs). In the forestry sector, the competencies of DG VI are limited to matters concerning the Community's forests and, in particular, to the implementation of EC legislation relating to forestry. Particular aspects of DG VI activities which may interest you are those relating to the Community's action for the protection of forests against atmospheric pollution and fires, where important monitoring and information collecting activities have been developed. For your information, I join in the annex the last Commission report on the condition of forests in Europe. The answers given to your questionnaire by my department are relating only to the Community's forests (European). As

I already said above, we have no direct information needs concerning tropical forests.

Busca and Corda (for Fossati)
CEC - DGI/J, Directorate for Asia
As you probably know, the Commission has recently started a special programme on Tropical Forests that will greatly benefit from the data collected and processed under the TFIS. Please do not hesitate to get in touch with my collaborators for further information and exchange of views.

Fraser
Overseas Development Administration (ODA), UK

Persson
SIDA
FAO is after all trying to develop a system for continuously following changes in forest resources. What can you add to this? Global information is of rather limited importance. What's the difference if we know that deforestation is 12.16 or 20 million ha per year. No meaningful global action will be taken I fear (whatever the figures say). I hardly know which actions can be taken at the national level. TREES data will be of limited value to control deforestation! Data is needed at the national level! It is at the national level that something can be done about deforestation. I doubt if NOAA satellites can give information of value at the national level. In summary I don't think this information in practice will be of great value to SIDA. In the countries we work, more detailed information ought to be available. For me as a professor in international forestry the information would of course be of value. Every year I try to tell my students about the global forestry situation. But that knowledge or those lectures doesn't change the world. In summary once more. Information is needed at the national level.

Lutz for Tuyll
Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ)

International non-governmental agencies

Smeraldi
Amazonia Program-Friends of the Earth
We would like to stay updated about the development of your work and receive, upon availability, a more specific information on the service (terms, conditions, etc.).

?
Association Technique Internationale des Bois Tropicaux,

Spire
ATIBT - Association Technique Internationale des Bois Tropicaux, France

Renard
Caribbean Natural Resources Institute

Stattersfield
Birdlife International (ICBP)
We met with Jane D'Souza a few months ago and so heard about the project firsthand. We are keen to collaborate by providing our bird data (= "biodiversity attribute data") and in return would like to receive up-to-date forest boundaries/types for areas which we consider important. However, we were concerned with the accuracy of the maps which she showed us e.g. large areas of lowland forest shown in southern Thailand. To be of practical value the data must be more accurate! In addition, high resolution data is best, because we are often concerned about the conservation of relatively small areas of forest which can be vital for biodiversity conservation.

Herrera
Red Nacional de Informacion Forestal (REDINFOR), Peru

Anderson
Greenpeace International
We wouldn't use your material much, unless it was inexpensive. We have forest campaign staff working on the ground in Siberia, Vancouver, the Amazon, PNG, Finland, Karelia, Nth west USA, Guatemala for whom your maps could be very useful. Please let me know about rough costings for your materials. Thanks

Gilmour
IUCN Forest Conservation Programme

National governmental agencies

Hunter
Natural Resources Institute, UK

Lund
USDA Forest Service (for Puerto Rico, Hawaii, Florida)
The USDA Forest Service conducts forest inventories of the forested lands of the US and also provides assistance abroad. Hence, I completed two questionnaires; one reflecting our domestic work (we have tropical lands in Puerto Rico, Hawaii, Florida, and the territories in the S. Pacific) and one reflecting our international work. A general comment - there are many groups starting to monitor the world forests using satellite imagery.These include TREES, FAO, UNEP, NASA, Woodshole etc. The World Conservation Monitoring Centre can do us all a great service by urging that these groups define their areas of responsibility and work together toward providing the information we need to inventory, manage and monitor our resources.

Lund (2)
USDA Forest Service (International work)
There has to be coordination between TREES, RESPAS, NASA Pathfinder activities. We are unnecessarily duplicating each other work and not making much progress in making satellite data available to countries in need.

National non-governmental agencies

Burton
World Wide Land Conservation Trust, UK
I have completed this in order to ensure some input. However, I hope that copies can also be sent to Roger Wilson c/o Programme for Belize [done], Belize City and also to Dr Peter Furley, Department of Geography, Edinburgh [done]. Their comments, taken in conjunction with those of ODA/NRI should give an accurate assessment of the WWLCT/PFB activity in Belize. The WWLCT is also currently investigating Costa Rica and the Philippines and may become involved in other parts of the world.

Borner
WWF-Switzerland
Member of WWF International's Forest Advisory Group. Can get additional material from WWF International.

Williams
Sierra Club, USA
While the Sierra Club does not currently use satellites, we might in the future.

Muchoney
Remote Sensing, The Nature Conservancy
TNC require high resolution data at frequent intervals; frequency in receiving data depends on specific areas; for level of accuracy generally a scale of 1:100,000 is desirable, classification accuracy standards should be 80-85%.

Juniper/Rice
Friends of the Earth
Some of the answers given (such as distribution of forest survey information) are based on FoE's future work on Geographical Information Systems (which as far as the forest campaign is concerned, is currently being developed). Presently, we have no facility to 'directly' monitor forests (aside from on-the-ground inspection). This is something we may want to develop in the future (i.e. use of satellite imagery). All monitoring is 'indirectly' taken from other credible sources reporting on the issue.

Johnson
Tropical Agricultural Development, USA
Currently using WCMC to provide maps for Global Action Plan for Palm Conservation.

Verhagen
Friends of the Earth International

Kuhlmann
ARA - Arbeitgemeinschaft Regenwald und Artenschutz, Germany

Bogaert
WWF-Switzerland

Rodenburg
World Resources Institute
As you know, WRI is interested in both forests and the institutionalization of monitoring. Global monitoring of earth resources is what I want to see implemented. TREES is duplicative with at least two other programs I know of 1) Tom Loveland (?) at EROS, Sioux Falls, South Dakota is extending his 1 km land cover database of the USA to North America and then the entire world over the next five years. 2) George Woodwell of Woods Hole is going to map all tropical forests. Call a meeting as all of you involved in these global efforts can work together.

Wilson
Programme for Belize *The principal use to which TREES could be put would be to place PFD management areas in a regional context. At national and local level there is already adequate provision for monitoring and landuse purposes.*

Colchester
World Rainforest Movement
The World Rainforest Movement monitor policy and project impacts on forests. Also want mapped information on concession areas (mining, logging, oil prospecting, etc.) and tenure classification (PAs, PFE, Statelands, ejido, private property etc.).

Chaudhry
WWF-Pakistan

Jackson
Responsible Forestry Programme (FSC)
Our timber certification and labelling scheme involves inspections of concessions to determine that good management practices are being upheld. We are therefore interested in satellite information which can tell us things such as whether logging has encroached on demarcated areas (e.g. set-aside zones of biological importance, or indigenous lands), whether more timber is being extracted than desirable, whether logging is taking place too near watercourses, erosion along roads - and so on. Normally, this information will be obtained by inspectors visiting sites and making assessments using structured inspection forms. There is thus scope for ground-truthing some of your satellite data. Our interest is the satellite scheme depends in on how accurate the information is, and to what level of resolution, the level of expertise needed to interpret the data supplied, and of course, the cost.

de Freitas
Carmabi Foundation, Netherlands Antilles

Country representative
IUCN-Laos

Fox?
East-West Center, Hawaii

Godoy
IUCN-Guatemala
IUCN has a ARCINFO GIS in San Jose Costa Rica, which can be used to give a regional service. However, the IUCN representation in Guatemala has only restricted access to is because of costs. The Unit for Planning in Peten (UNEPET) has another ARCINFO GIS which functions at relatively low cost and which could cooperate with ourselves and WCMC.

Rios
CDC-Peru

Tang
WWF-Hong Kong
TREES is a very interesting and valuable project. WWF HK has been using GIS to establish an ecological database of Hong Kong for more than two years. We welcome any opportunity to participate in the TREES project and to integrate our database for the integrated forest information system which you have mentioned in the near future.

Pereira
Fundacao de Tecnologia do Estado do Acre, Brazil
Thank you for sending us information about the TREES Project. We believe it will be helpful and useful for all who work on tropical forests. About the question K, nowadays we are using a Brazilian software made by INPE (National Institute of Spatial Research) called SGI, but we have a project to work with ARC/INFO and PCI (Canadian software) probably at the end of this year (93).

Naim
IUCN-Pakistan

Gomez
Asociacion Ecologista Panamena, Panama
The information on tropical forests in Panama, which you can give us, will be useful to suggest changes in national forest policy. Furthermore, the data can be used for monitoring deforestation and how it affects global climate change.

Oliver
Forests Forever

Jean and Rodriguez
Instituto Nacional de Recursos Naturales Renovables, Panama

Castello
IUCN-Ecuador

Bass
International Institute for Environment and Development, UK
We would not want information annually, but whenever we receive information we would want it to be this years!

Campredon
IUCN Guinea-Bissau
Of course we are interested by information you can provide but note that we have very few people able to devote time to new activity, that the average technical level of people in Guinea-Bissau is very low, and also that we are dealing with a very patchy environment in a very small country. Anyway I'm pleased to look forward..

Galvarro
CEDOIN (Centro de Documentacion e Informacion, Bolivia

Acevedo
Centro de Datos para la Conservacion, Paraguay

Broekhoven
IUCN East Africa, Forest Conservation Programme
Would be able to verify satellite data in specific localities, where we have field projects.

Michel
IUCN-Burkina Faso

Leblanc
Environmental Defense Fund
I recently mailed to Dr Collins a copy of a paper entitled "Preserving Tropical Forests and Climate: The Role of Trees in Greenhouse Gas Emissions Trading," written by myself and Dan Dudek. This paper advocates the establishment of a forest monitoring system to implement the climate convention in a way that includes forests as sinks and that allows joint implementation forestry projects. Such a monitoring system would need to be implemented under the auspices of a scientific body set up by the Conference of the Parties. See pages 33-40 of this paper for a proposal including specification of data requirements for the monitoring system.

Olson
WWF-USA, Conservation Science Program
We are in the initial stages of developing a GIS program here at WWF-US and anticipate a wide variety of information needs in the future. We would like to have access to databases of regional and local forest cover, forest condition, and surrounding landuse. We have been currently working with forest coverages for some regions in Southeast Asia in order to develop effective methods for prioritizing habitat fragments for conservation action. The forest coverages have been most useful for testing a variety of spatial models and for integrating biotic inventories with landscape-scale analysis. If possible, we would like to be able to obtain similar coverages for other regions and receive updates on a regular basis. Temporal sequences in forest cover data would allow us to conduct a number of analyses that examine temporal patterns of isolation and to assess rates of deforestation for threat evaluation. The Conservation Science Program will also support WWF regional programs and field projects with GIS. Information on forest cover and condition for local regions or specific conservation areas around the World will likely be necessary in the future. Ideally, if a field project asks for current and past information on forest coverage and landuse for a particular area we would like to be able to obtain it for them in a timely fashion, both raw images and

processed or digitized data. We hope to develop GIS capabilities for all of the regional programs, but we will likely be responsible for obtaining the majority of databases. I can envision a wide variety of needs based on the diversity of activities conducted here. I look forward to working closely with WCMC and the TREES Project and agree that rapid access to an integrated forest information system will contribute immensely to conservation efforts in the future.

Kumar
WWF India
The unfortunate situation is that in India, capability does not exist in any NGO for an independent verification of the Forest Survey of India data. WWF-India too does not have a specialised forestry policy evaluation desk or person. Currently this task is assigned to Mr Ashok Kumar, Director, TRAFFIC-India. Visual observations (which are not comprehensive) and anecdotal accounts continue to point to degradation of forests, unauthorised removal and theft of timber, pressure of head loaders and graziers. In some states still having rich forest cover such as Arunachal and Andamans virtual plunder by corrupt officials is reported. In this situation, access to independent remote sensing data will enable us to verify the FSI data - to begin with as it relates to the Protected Area network or other sensitive forest rich states. We have reasons to believe that FSI may be under pressure to conceal reduction of forest cover. Ideally, we would like a full project for the evaluation of the FSI reports of 1989 and 1991 with independent ground truth verification in critical forest areas. There is a need to develop greater capability to monitor forest cover and forest policy in India but for the present, we are not able to create an independent desk owing to lack of funds.

Benitez
Fundacion Natura, Latino Americana de Bosques Tropicales, El Salvador
The information you can send to us will be of great use to our work in that Fundacion Natura carries out. This information will be shared out through the Latin American forest network which our institute coordinates.

Junkov
ORCA - IUCN Central America Office, Costa Rica
The frequency with which the information is required varies depending on the projects being carried out. In some cases information is needed annually, especially when you are dealing with projects on a local level. To determine changes on a regional scale the information may be gathered every three years. The precision level of the information also depends, in our case, on the scale of the project. It could be less than 1:100,000 for local projects or 1:100,000 for the whole of the Central American region. Both the studies with satellite imagery and those on a regional level will be initiated in the next few months in the GIS unit of IUCN. Generally the projects in which we participate have an initial planning period for the work to be carried out, for which, in the majority of cases, we require quite quickly lists of the information already available for the area of the project. The information itself would be required on a slightly longer time-scale, which could be about one month.

Skyum
The National Forest and Nature Agency, Denmark
The use of satellite data has for the present a low priority, but the Agency would be pleased to receive current information about the TREES-project.

Hulse
WWF-Vietnam
In our organisation we have done the following activities related to your subject: undertaking the national forest inventory and monitoring (five-year rotation). The forest map of this project is made from TM satellite images and stored in GIS system; establishing a map database at national and provincial level. Digitised map as follows: elevation map (1:100,000); administrative map by communes (1:50,000); forest map (1:250,000); road network map (1:100,000); soil map (1:100,000); land use map (1:100,000). For these activities we have developed one GIS system named FEWGIS (writing in C language) and one digitising section with about 40 staff.

Donovan
Rainforest Alliance, USA

Forest research community

Barnes
Department of Biology, University of California, USA

Jacobsen
Tropical Forest Foundation, USA

De Wulf
Laboratory of Remote Sensing and Forest Management, University of Gent, Belgium

Burley
Oxford Forestry Institute, UK

Eden
Centre for Developing Areas Research (CEDAR), Royal Holloway-Univ
1. Since other organisations than TREES (CEC/ESA) are monitoring tropical forests (eg. FAO) it is important that sufficient collaboration occurs between organisations to allow effective comparison of the no doubt divergent results, and thus real appraisal of the various methodologies. 2. Emphasis on monitoring deforestation is obviously important, but precise evaluation of replacement land covers also needs to be undertaken, i.e. agricultural land, pasture (+-weeds), woody regeneration etc. "Degraded tropical rainforests" is insufficient for land management or carbon budgeting purposes. 3. If the Brazilians can monitor deforestation annually on Landsat TM for Amazonia, would not an extrapolation of their methods to the tropics as a whole provide a sounder medium-term basis for TREES than automated AVHRR analysis? At this stage, I believe a low-tech approach is probably more reliable and useful.

Evers
Institute for Forestry and Nature Research in coop with TROPENBOS, The Netherlands
Timber volume is needed at individual tree level or multiple sites per ha.

Freiberg
European Tropical Forest Research Network (ETFRN)

ETFRN can possibly ground truth satellite derived data via the ETFRN network. From TREES I would expect that: a) derived from global satellite data (pre-stratified) it should be necessary to request these data on-line or CD-ROM/Floppy disk, to manage these data on the users desk (resolution of 1 x 1 km); b) further it should be possible, indicating e.g. the region or country, to obtain a more detailed data output (eg. 80 x 80 m, 30 x 30 m) from TREES (or another listed data supplier) to process/manage these data on their own PC(e.g./ local/regional management plans, landscape planning to make printouts on printer); c) for all R+D projects and commercial projects/activities this could be an interesting tool, if the user costs are reasonable!

Longh
Centre for Environmental Science, Leiden University, The Netherlands

Carver
Map and Imagery Laboratory Library, University of California, USA
As you can probably tell, I had a tough time filling this out, since its the users of the Map and Imagery Lab who build GIS and work with mapping of vegetation - and 25 years of experience as a university spatial-data librarian have taught me that there is no predicting exactly what users will need, beyond the obvious - eg. spatial data covering the state in which the library is located. UCSB's role is that of a research institution, with emphasis on graduate and faculty research, so at the same time, someone will probably work on just about any one of the research categories you have listed.

Poorter
Tropenbos Foundation, The Netherlands

Leakey
Institute of Terrestrial Ecology, Scotland, UK
It would be interesting to have information on changes in cloud cover with time.

Wijngaarden
International Institute for Aerospace Surveys and Earth Sciences, The Netherlands

ter Welle
Utrecht University, The Netherlands

Sayer
CIFOR - Center for International Forestry Research
CIFOR is still some way from defining precisely what its role, if any, might be in global monitoring efforts. We do, however, have a programme area dealing with "location and types of global forest resources to satisfy future demands for goods and services". At the meeting last week in Delhi of the incipient World Commission on Forestry and Sustainable Development, there was a good deal of enthusiasm amongst one or two participants for CIFOR to collaborate with the Commission on certain global monitoring issues. The Commission sees itself as having a role in helping to define methodologies and the respective roles of the different agencies involved in this sort of work. George Woodwell, in particular, was very keen on convening a meeting of all the major players during the coming months (at Woods Hole) to clarify responsibilities and seek enhanced collaboration. Underlying these

discussions was the idea that the Commission, possibly in collaboration with CIFOR, would promote the production of a bi-annual "state of the World's forests". This would be somewhat similar to the sorts of ideas that we discussed with Robin Pellew when we last met in Cambridge. The Commission was very well aware that a great deal is already being done to harmonize approaches and to integrate data derived from different sources. A question is whether any of these efforts are sufficiently resourced to really achieve an adequate global product. The other question is the respective roles of the principal UN agencies which have a mandate to do this sort of work. I suggest that there might be some collaborative work between WCMC and CIFOR in this area. CIFOR, subject to the Board's approval, may be able to help WCMC expand its forest map library work and to make it more readily available to CIFOR's partners. This might constitute a contribution toward the product that the Commission would be seeking.

Ricker
Yale University, School of Forestry and Environmental Studies, USA
Not being an expert on Geographic Information System's analysis, it would be useful to get information about what data and in which form can be provided by WCMC (and costs). Furthermore, it would be important to know the accuracy of data (in particular for deforestation data in a region it would be necessary to know the possible error range).

Evans
Forest Inventory and Analysis, Southern Forest Experiment Station
Please see enclosed reprints on examples of research interests.

Williams
School of Agricultural and Forest Sciences, Bangor University, UK

Tomppo
Finnish Forest Research Institute
Possibly, our institute produces similar information as TREES. Need satellite data to detect timber volume and growth by tree species, site fertility, mean age of trees, damages etc. i.e. all variables of National Forest Inventory - about 100 variables.

Doolittle
International Society of Tropical Foresters (ISTF), USA

Henry
World Forest Institute, World Forestry Center, USA

Marshall
Royal Society South-east Asian Rain Forest and Aberdeen University

Thompson
Division of Forest Science and Technology, CSIR, South Africa

Heden
Swedforest International, Sweden

Barborak
Wildlife Conservation Society
I highly recommend you contact CCAD - Central American Commission on Conservation and Development, based in Guatemala, via Juan Corlos Godoy of IUCN's office there. With help from NASA, CI and University of Florida, they are involved in regional data-base development on these themes in Central America. WCS is collaborating with the U. of Florida in developing an up to date map of the region's protected area network in relation to remaining forests, lands needing restoration, and potential forest corridors linking protected areas.

Condit
Center for Tropial Forest Science, Panama/USA

Smith
Seed Conservation Section, Jodrell Laboratory, Kew Botanical Gardens, UK
From my own standpoint, I would hope for a greater emphasis on dryland forests.

Gillman
Open University, UK
Our work focuses on forests in Central Guyana and Trinidad (northern range and southeast). Local biodiversity assessments in those areas are put into a regional context (Guianas, Venezuela, Caribbean). Any support for that work would be gratefully received.

Jack
Environmental Management Unit, Monash University, Australia
An email network newsgroup (e.g. "forestNet") might be useful - depends on attitudes to "teleresearch" and perhaps this is worth encouraging.

Rudel
Rutgers University, USA

Adam
CSIR, South Africa

Winser
Royal Geographical Society, UK
In consideration there are three things you should perhaps be aware of: 1)Geographical Observatories - the RGS has embarked on a programme to create a network of environmental field centres for long-term research. It is hoped to provide a ten-year commitment to such programmes. The Society is about to embark on a two-year period of consultation and a number of forest sites are being considered; 2) GTOS (Global Terrestrial Observing System) - following discussions with both UNEP and IGBP the RGS is looking at the possibility of including monitoring in its fieldwork programme, either at its permanent research centres at its sites that it has worked in the past; 3) Links with EOS - we have responded to Chris Justice's request for centres that can validate EOS data and this we have begun in Jordan and Tanzania. I hope they will be developed for any future forests programmes.

Appendix E

List of Current Sources of Supply

Global change community

- Swedish Forest Survey
- Various, as obtained by individual research groups contributing GCTE
- FAO, WCMC mainly
- UNFAO reports, surveys other NGO surveys
- Own measurements, cooperation with other scientists
- GCOS is currently in the planning stage
- Existing digital data bases; manually digitised vegetation maps; AVHRR-GVI,GAC,LAC; TM; SPOT; Aerial photo
- USDA Forest Service, FAO; published papers; in-house research and data storage (CDIAC)
- Data from national surveys World Bank, UNEP, WRI and FAO

Forest departments, protected area agencies and research organisations in tropical forested countries

- Information from National Forest Inventory and also from field survey
- Own surveys, reports on previous surveys
- Contracted aerial surveys, satellite info (GIS etc.)
- National 1:20,000 & 1:50,000 maps, ground survey, 13yr old aerial photo (b+w) 10yr col aerial photos
- There are good data on Uganda's forests from sources: Hamilton and Howard and various on-going projects
- Vegetation and soil analysis, interpretation of aerial photographs
- Mapping by R/S and ground surveys
- a) own research, b) short term consultancies, c) ordinance surveys: 1:26,000 b/w aerial photography
- Site data (plots), aerial photos, satellite imagery
- Saw mills, loggers and research organisations
- Aerial photographs (10,000 ft), field reconnaissance survey, topographic map (1:25,000)
- Own studies; publications from local institutions; FAO; CDC; Governmental organisations; IUCN
- Terrestrial surveys, remote sensing data interpretation (visual and digital)
- LANDSAT, SPOT and Brazilian environment agencies; eventually international environmental agencies like EOSAT, NASA, SPOTIMAGE etc.
- Aerial photos, transet inventories
- FAO, UICN, WWF
- Field work; satellite imagery (Landsat TM); bibliography
- Soil inventories; aerial photos (1:20,000); SPOT or TM images; aerial survey

UN agencies
- All currently available datasets in the public domain, or for which distribution agreements can be obtained
- Existing maps, National Survey Department, UN Agencies (FAO), national environmental statistics dept
- National organisations and institutions; members of Infoterra
- FAO is mandated by its member governments to collect and report periodically on global forest resource data

Intergovernmental agencies and programmes
- FAO estimates and material based on FAO figures
- From client countries' organisations FAO, or any other source, SPOT satellite information etc.
- EC Forest Health Inventory, national reports
- Relevant information is provided by consultants mainly during project preparation
- Own surveys, forest dept. surveys, forest concession holder's surveys; NOAA data for forest fires, forest cover change and land-use planning
- National sources
- Aerial photos; existing topographical maps; satellite images (Landsat and SPOT)

International non-governmental agencies
- INPE, Brazil
- FAO
- Donated and purchased materials; CD-Rom
- Field knowledge, literature, organisations like WCMC/FAO etc.

National non-governmental agencies
- Various university data houses, including Edinburgh. Manomet Bird Observatory, JPL etc.
- Biological and Conservation Database (BCD), TNC
- WCMC
- FAO national statistics
- Studies, books, scientific and fieldwork WWF/IUCN
- Self generated
- WRI, FAO, WCMC atlases
- Local fieldwork
- Forest inventory data from national department of forestry
- National and international reports Landsat and SPOT images
- PAFG-GUA, WCMC
- Secondary information produced by research centres, private researchers, NGOs etc; primary information produced by CDC (Conservation Data Centre)
- Local ecologists & scientists. Biodiversity conservation of local fauna, flora & habitats by assessing potential environmental impacts of developments & identifying conservation areas
- Our current sources of supply are ground survey and ancilliary data (research, books, papers, newsletters and others)
- Smithsonian Tropical Research Institute

- Survey data supplied by forestry depts. of timber producing countries, by FAO and ITTO. Timber trade data supplied by FAO, ITTO
- Members of IUCN, FAO, IUCN Forest Programme, various country data
- National and local surveys, international literature
- Ministry of the Environment, Direction Generale de la Recherche Scientifique et Technique; various scientific organisations
- Scientific and technical papers
- Publications, WCMC
- Reports of Forest Survey of India and observations of ground truth
- International and national libraries; meetings and workshops;
- Paper maps; photographic material; satellite images; GPS locations
- Usually country specific; The Nature Conservancy US

Forest research community

- Various sources e.g. FAO, WRI
- UNEP/GRID, information from bilateral partners
- National forest departments, IUCN
- National survey data e.g. INEP, Brazil
- SAREX-gz
- WCMC
- Resource monitoring/assessments, dissemination of data, remote sensing/GIS
- Federal and state inventories
- A variety of published information, both original research papers and books/atlases
- Ground surveys by scientists and collaborating organisations; air photo coverage; Landsat and SPOT data from Satellite Application Centre, South Africa
- Remote sensing; field inventories; reports; public databases
- Bibliographies, forest departments
- Individual researchers' arrangements
- Ground survey. Literature/personal communications
- Surveys, mapping, aerial photos; aerial/satellite data from Eros Data Center; sister organisations (Natural History Museum, Kew etc.)

Timber traders

- FAP; NNUU; UNCTAD/GATT

Appendix F

Requests for Information Summarised by Information Type

Information requirements	Changes in forest boundaries	Forest fires	Roads	Protected areas/forest reserves	Biomass	Forest types	Timber volume	Areas of high bio-diversity	TOTAL	% of total for inform-ation type
Which types of information would you seek from an integrated forest information system?										
At what scale would you require this information?										
Local level	62	30	43	47	32	53	38	54	359	22
Sub-national level	47	31	38	43	29	47	28	45	308	19
National level	70	38	42	76	36	75	35	68	440	27
Regional level	52	23	24	46	25	53	25	53	301	18.5
Global level	42	17	16	34	22	37	19	40	227	14
How frequently would you require this information?										
Yearly	57	43	33	41	22	36	29	35	296	40
Every 3 years	26	9	22	35	18	22	16	26	174	23.5
Every 5 years	24	10	14	23	20	25	18	31	165	22.5
Every 10 years	4	2	2	6	2	9	4	4	33	4.5
Once only	2	3	3	4	7	18	5	12	54	7.5
Other	2	2	2	3	0	3	0	1	13	2
Would you need a response to your information request:										
Immediately	7	7	6	6	3	7	6	4	46	7
Within a month	69	41	65	65	39	67	38	61	445	68
Other	21	12	24	24	15	25	14	26	161	24.5
At which level of accuracy would you require this information?										
High level < 1:100,000	68	34	52	52	35	58	37	57	393	47
Medium level	45	29	54	54	27	55	25	50	339	41
Low level 1:1-1.5 million	16	10	14	14	10	13	7	15	99	12
	614	341	454	573	342	603	344	582	3853	

Information requirements		Changes in forest boundaries	Forest fires	Roads	Protected areas/forest reserves	Biomass	Forest types	Timber volume	Areas of high biodiversity
Which types of information would you seek from an integrated forest information system?									
At what scale would you require this information?									
	Local level	44	21	31	34	23	38	27	39
	Sub-national level	34	22	27	31	21	34	20	32
	National level	50	27	30	54	26	54	25	49
	Regional level	37	16	17	33	18	38	18	38
	Global level	30	12	11	24	16	26	14	29
How frequently would you require this information?									
	Yearly	41	31	24	29	16	26	21	25
	Every 3 years	19	6	16	25	13	16	11	19
	Every 5 years	17	7	10	16	14	18	13	22
	Every 10 years	3	1	1	4	1	6	3	3
	Once only	1	2	2	3	5	13	4	9
	Other	1	1	1	2	0	2	0	1
Would you need a response to your information request:									
	Immediately	5	5	4	4	2	5	4	3
	Within a month	49	29	46	46	28	48	27	44
	Other	15	9	17	17	11	18	10	19
At which level of accuracy would you require this information?									
	High level < 1:100,000	49	24	37	37	25	41	26	41
	Medium level	32	21	39	39	19	39	18	36
	Low level 1:1-1.5 million	11	7	10	10	7	9	5	11

response > 45 % 50 response 36-45 % 40 response 26-35 % 30

List of Acronyms

ACP	African, Caribbean and Pacific
AVHRR	Advanced Very High Resolution Radiometer
CDC	Conservation Data Centre
CEC	Commission of the European Communities
CEO	Centre of Earth Observation
CEOS	Committee on Earth Observation Satellites
CGIAR	Consultative Group on International Agricultural Research
CIFOR	Centre for International Forestry Research
CIRAD	Centre de coopération internationale en recherche agronomique pour le developpément (formerly known as CTFT)
CPD	Centres of Plant Diversity
DIS	Data and Information System
EBA	Endemic Bird Area
EC	European Community
EOS	Earth Observation Sciences
EROT	European Communities' Regional Fund
ESA	European Space Agency
ETFRN	European Tropical Forest Research Network
FAO	United Nations Food and Agriculture Organisation
FoE	Friends of the Earth
FRA	Forest Resource Assessment
GAIM	Global Analysis, Interpretation and Modelling
GATT	General Agreement on Trade and Tariffs
GCTE	Global Change and Terrestrial Ecosystems
GEMS	Global Environment Monitoring System
GIS	Geographic Information System
GRID	Global Resources Information Database
HTFI	Humid Tropics Forest Inventory
ICBP	Birdlife International (formerly International Council for Bird Preservation)
ICSU	International Council of Scientific Unions
IGBP	International Geosphere - Biosphere Programme
IIED	International Institute for Environmental Development
IPCC	International Panel on Climate Change
ITTA	International Tropical Timber Agreement
ITTO	International Tropical Timber Organisation
ITTO	International Tropical Timber Organisation
IUCN	International Union for Conservation of Nature and Natural Resources
IUFRO	International Union of Forestry Research Organisations
JRC	Joint Research Centre
MAB	Unesco Man and the Biosphere Programme
NASA	National Aeronautic and Space Administration
NGO	Non-governmental Organisation
SASIFY	Space Agency Forum on the International Space Year
TFAP	Tropical Forestry Action Programme
TFIS	Tropical Forest Information System
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

UNEP/HEM	UNEP/Harmonisation of Environmental Measurement
Unesco	United Nations Educational Scientific and Cultural Organisation
WCMC	World Conservation Monitoring Centre
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation
WRI	World Resources Institute
WWF	World Wide Fund for Nature

Technical Note No. 4

Problems and Recommendations for Solutions

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1.

Introduction

The analysis of user requirements is reported in Technical Note No. 3. Specific user needs related to the monitoring of tropical forests were determined. The purpose of this technical note is to examine these user needs in relation to the TREES II programme and determine how they may best be met by TREES II. Problems in meeting the user requirements are identified and discussed, and potential solutions are suggested.

Global monitoring requirements can only realistically be met by using satellite-based data. It is therefore assumed throughout this Technical Note that satellite based data is to be used by TREES II.

In Section 2 the user requirements identified in Technical Note No. 3 are examined in relation to the possibility of their provision via satellite data with respect to the questions of whether the required information can be extracted from the data, whether it can be extracted at the required scale, and whether the data volumes are such that it can be extracted at the required frequency.

In Section 3 some non-technical issues are examined, in particular the political sensitivity of the TREES programme.

In Section 4 a number of 'products' and 'reports' are proposed which are designed to meet as many of the user requirements as possible within the constraints of the TREES programme. Each product and report is described in detail, and outstanding problems in their production are listed.

Section 5 summarises the findings of this technical note and leads in to the specific issues to be covered in Technical Note No. 5, the Work Plan for TREES II.

2.

Technical Requirements

2.1 Introduction

The user requirements analysed in Technical Note No. 3 are discussed below in relation to their potential provision via satellite-based data. In Section 2.2 the requirements specified in Technical Note No. 3 are considered. Each of the main areas on which users were questioned is treated separately and the most frequently requested data are considered to form a user requirement (cf Technical Note No. 3, Section 3). Each requirement so identified is then discussed in the following sections in relation to its potential provision via remote sensing and in particular within the constraints of the TREES project.

For each user requirement the following questions must be addressed:

- Is the required information potentially extractable from remotely sensed data?
- Can the information be presented at the required spatial scale?
- Can the information be extracted with the required frequency?

The first issue depends upon the spatial and radiometric properties of the data; the second depends on the spatial resolution of the data; the third depends upon the data volume in relation to the available manpower and hardware resources. The first two issues are therefore primarily technical in nature, whereas the third has both technical and managerial implications.

In Section 2.3 the information requirements are discussed in relation to their potential provision via satellite data. The issues involved in spatial scale are discussed in Section 2.4 and in frequency of provision in Section 2.5. In Section 2.6 the identified user requirements which could feasibly be met by a TREES II programme are identified, and the reasons for failing to meet user requirements are discussed. The requirements which can be met are then synthesised into a set of three related requirement groups.

2.2 User Requirements

Technical Note No. 3, Section 3.7 lists a number of requirements which are categorised by user group. In order to extract specific information requirements from this list the common information requirements from each group have been extracted. For example, both groups B (national forestry departments) and D (intergovernmental agencies) require forest boundary data annually at medium resolution (see Requirement 2 below). The following list of requirements is therefore categorised by information type. Numerical data supporting the requirements are derived from Technical Note No. 3, Appendix F.

Boundaries

81% of users requested boundary information, making it the most frequently requested information category after forest type. Fine scale[1], >1:100,000, data is most frequently requested (68)[2], but medium scale, 1:100,000 to 1:1,000,000, (45) and coarse scale, 1:1-1.5 million, (16) are also required. Most users require data annually (57); however, data every 3/5 years would be almost as popular as the annual data (54). Boundary data is requested by all the surveyed user groups, as shown below:

Requirement 1	Forest boundaries (113), annually (57) at fine scale (68) Requested by groups B, E, G and H[3].
Requirement 2	Forest boundaries (113), annually (57) at medium scale (45) Requested by groups B, D, E and G.
Requirement 3	Forest boundaries (113), every 3 years or more (54) at coarse scale (16) Requested by groups A and C.
Requirement 4	Forest boundaries (113) every 3 years or more (54) at medium scale (45) Requested by groups B, D and F.
Requirement 5	Forest boundaries (113), every 3 years or more (54) at fine scale (68) Requested by group B.

Forest Fires

Forest fire data are requested by 46% of users, with the most frequent requests coming from groups D, G and E. Data are requested annually at medium to fine scales.

Requirement 6	Forest fire data (65), annually (43), at medium scale (29)

[1] The terms 'fine' and 'coarse' are used throughout this report instead of the more usual 'large' and 'small' which can be confusing for the non-specialist.

'Fine' scale	1:100,000 or greater
'Medium' scale	1:100,000 to 1:1,000,000
'Coarse' scale	1:1,000,000 or less

[2] Numbers in brackets refer to the number of users requesting data.

[3] The codes for user groups are as follows:

- A global change community
- B national forestry departments
- C UN agencies
- D intergovernmental agencies
- E international NGOs
- F national governmental agencies
- G national NGOs
- H forest research community
- I timber traders

Roads
Road data are requested by 53% of users, with the most frequent requests coming from groups C and E. Data are mostly requested at annual frequency, but there are also users requiring less frequent data.

Requirement 7	Road data (74), annually (33) at medium scale (54)

Protected Areas
Protected area information is requested by 79% of users, with the most frequent requests coming from groups B, C, D, E, G and H. Data are required annually (41), or every 3 years or more (68). Users are almost evenly divided between fine (52) and medium (54) scale requirements.

Requirement 8	Protected area data (111), 3 yearly (68), fine scale (52)
Requirement 9	Protected area data (111), 3 yearly (68), medium scale (54)
Requirement 10	Protected area data (111), annually(41), fine scale (52)
Requirement 11	Protected area data (111), annually(41), medium scale (54)

Biomass
Biomass data are requested by 46% of users, with the most frequent requests coming from groups A and F. Data are required every 3 years or more (40) at both fine (35) scale and medium scale (27).

Requirement 12	Biomass (65), every 3 years or more (40), fine scale (35)
Requirement 13	Biomass (65), every 3 years or more (40), medium scale (27)
Requirement 14	Biomass (65), annually (22), fine scale (35)

Forest Types
Forest type information is the most frequently requested data type, required by 83% of users, and required by users from all groups. Data are required annually (36) and at 3 yearly or greater frequency (74), with users evenly divided between fine (58) and medium (55) scale products.

Requirement 15	Forest types (116), annually(36), fine scale (58)
Requirement 16	Forest types (116), annually (36), medium scale (55)
Requirement 17	Forest types (116), every 3 years or more (74), fine scale (58)
Requirement 18	Forest types (116), every 3 years or more (74), medium scale (55)

Timber Volume
Timber volume information is requested by 47% of users, mainly from groups C and D. Data are requested annually (29) or at intervals of 3 years or more (34) and at fine scale (37) and medium scale (25).

Requirement 19	Timber volume (66), every 3 years or more (34), fine scale (37)
Requirement 20	Timber volume (66), every 3 years or more (34), medium scale (25)
Requirement 21	Timber volume (66), annually (29), fine scale (37)
Requirement 22	Timber volume (66), annually(29), medium scale (25)

Biodiversity
Biodiversity data are requested by 78% of users, with the most frequent requests coming from groups B, C, D and H. Data are requested annually (35) and at 3 yearly or greater intervals (61). Scale requirements are evenly divided between fine (57) and medium (50) scales.

Requirement 23	Biodiversity (109), every 3 years or more (61), fine scale (57)
Requirement 24	Biodiversity (109), every 3 years or more (61), medium scale (50)

2.3 Problems in Meeting Information Requirements

In this section each topic on which users were questioned is discussed with respect to the ability of satellite data to provide the required information. Consideration is also given to the scale and frequency of provision as discussed later in Sections 2.4 and 2.5.

Boundaries
The boundary between forest and non-forest classes can be extracted from remotely sensed data by classifying each pixel as either 'forest' or 'non-forest'. This implies that there must be a radiometric separation between the two classes. Research described in Technical Note No. 2 has shown that this is the case for the major data sources i.e. TM, SPOT and AVHRR. However, discrimination is a combination of both the radiometric and the spatial properties of the data. Less success is to be expected at coarser resolutions largely because each pixel may contain a mixture of cover types, thus making the decision as to its class more complex.

The spatial resolution of the data also affects the ability to map the boundary at different spatial scales. Accurate recording of boundaries is most important for the detection of boundary changes. Using TM data with a resolution of 30 m registered to ±0.5 pixels would imply that a boundary change of 60 m could be represented accurately. At a scale of 1:1,000,000 this would be equivalent to a 0.06 mm line width. For 1 km AVHRR data a 2 km boundary change could be represented. At a scale of 1:1,000,000 this would be a line 2 mm wide. Boundary changes could only be represented using AVHRR GAC data, with 4km resolution, correct to 8 km.

The above discussion assumes that the user wishes to know the precise location of the boundary itself. For users requiring mapping at fine scales (e.g. 1:100,000) this is almost certainly the case. However for users requiring coarser scale data it can be assumed that their primary interest is in the actual amount of forest, and in its variation over time, as opposed to the precise location of the boundary. For these users provision of statistics indicating the percentage forest:non-forest cover at regional or national level may be adequate. This point is returned to later.

Fires

Information concerning biomass burning can be both an indication of active deforestation and supply important information for climate modelling. It is not clear in what form the users might require this information. However, the FIRE project at JRC is dealing explicitly with the provision of fire data. It would be unnecessary for TREES to duplicate this effort, but there should be some coordination in the dissemination of the data. If TREES were to focus on the provision of annual data in some form, then the FIRE data could be included in this.

Roads

Roads which are open to the sky and which have sufficient contrast with their background can certainly be detected with TM data using automated techniques even when they are relatively narrow (Gurney, 1983). In areas such as Rondonia where deforestation follows the road network closely roads can be clearly seen on AVHRR data (Malingreau *et al*, 1989). However, many logging roads in S.E. Asia are narrow and not open to the sky, so that detection with satellite data is problematic (T. Whitmore, pers. comm.). Therefore, it might not be possible to provide road data for all the tropical forest regions on a consistent and routine basis. This could become a research area for TREES II if there was sufficient user interest in monitoring roads using satellite data.

Protected Areas

Aspects relating to protected areas are covered by discussion under boundaries above and forest types below.

Biomass

This requirement is achievable with satellite-based data in that biomass can be taken as correlated with NDVI. The NOAA GVI product already provides NDVI at 4 km globally, and the IGBP-DIS provides NDVI at 1 km. There therefore seems no need for TREES II to duplicate this provision. However, there is currently no routine provision for NDVI at finer scales.

Forest Types

Radiometrically, TM data have narrower bandwidths than AVHRR and are hence more likely to provide forest type information. However, research using 1 km AVHRR data (see Technical Notes Nos. 1 and 2) has shown that these data can be used to derive a limited range of forest types such as evergreen, seasonal and degraded. Many users, especially those interested in detailed mapping, may require a more extensive classification. For the

information provided by TREES II to be of use there must be agreement among users as to an acceptable set of forest types. The questionnaire sent to users (see Technical Note No. 3) did not elicit any information concerning required classes. Also, as discussed in Technical Note No. 2, there is no clear agreement among researchers as to the optimum classification method.

Timber volume
This would be possible only if percentage forest coverage and forest type relates to timber volume, in that timber volume cannot be directly measured using satellite data. Some research is needed into the relationships between biomass, percent forest coverage, forest type and timber volume.

Biodiversity
It is not clear how biodiversity is actually measured using remotely sensed data. If it is correlated with biomass, forest type, forest age and fragmentation it can be derived from a combination of NDVI, forest type classification and analysis of the shape and size of the forest areas. To be able to analyse the shapes and sizes of areas requires data at high resolution. Only in this sense would it be feasible to provide these data. This is a research area which needs to be addressed before an operational TREES programme can be in a position to generate products for biodiversity.

2.4 Problems in Meeting Scale Requirements

In Technical Note No. 3 analysis of user requirements indicated that the majority of users were interested in data at scales finer than 1:100,000. Data were overwhelmingly requested at the national level, but with interest in global/regional level data from the global change community and UN agencies.

TM data with a spatial resolution of 30 m can be used for mapping at scales of the order of 1:100,000. However, it is generally accepted that 1 km AVHRR data cannot be used reliably for mapping at scales finer than 1:1,000,000 (Hausler *et al*, 1993). The inability to map at fine scales is primarily a function of the variability of land cover types with respect to the spatial resolution of the sensor. Large pixels represent ground areas in which there may be a high variability in the cover type and the classification accuracy is therefore reduced. The ground area which can be represented is in any event no smaller than the pixel size itself. Mis-registration accuracy introduces a further source of uncertainty.

The user therefore has to make a choice between the use of TM data which provide the required spatial detail, but have the accompanying cost and data volume disadvantages discussed in Section 2.5, and the use of 1 km AVHRR data which are cheaper and have a much lower data volume, but cannot produce maps at fine spatial scales. The use of data at coarser resolutions than 1 km AVHRR data would not be able to meet user scale requirements.

Users were primarily interested in provision of information at national level (see Technical Note No. 3, Section 3), with less of an interest in regional and global provision. The provision of information at any level has implications for data dissemination. If information

is supplied for the entire tropical region at 1:100,000 this implies a large number of maps, e.g. the tropical rainforest regions of Africa would require 1900 A1 sheets. If users are to receive only data for selected areas then consideration must be given to how such data would be made available e.g. can a user request data for any specified nation or combination of nations? The provision of data at coarser scales such as 1:1,000,000 has similar implications, but the number of map products required is more manageable, e.g. the tropical rainforest regions of Africa would require 19 A1 sheets.

2.5 Problems in Meeting Frequency Requirements

The majority of users are interested in an annual provision of information, although there is also considerable interest in less frequent provision i.e. on a 3-yearly or 5-yearly basis (Section 2.2). If information is to be provided annually consideration must be given to the data volumes and processing cost and load that this would imply.
The basic data characteristics of the potential satellite data sources currently available are summarised below with respect to data volumes and costs:

- **Landsat TM**
  TM data are available at 30 m resolution with six bands containing 8 bits/pixel and one containing 6 bits/pixel. Thus 54 bits are required to represent a single pixel. One scene covers 34225 km^2 and costs $4,400 at present. There is a 16 day repeat cycle.

- **AVHRR LAC**
  AVHRR LAC data are available at 1 km resolution with five bands each containing 10 bits/pixel. Thus 50 bits are required to represent a single pixel. The usable portion of a scene covers approximately 3,000,000 km^2 and the nominal cost per scene is $100. There is daily coverage.

- **AVHRR GAC**
  AVHRR GAC data are sampled from LAC at 4 km resolution. This seems initially attractive in terms of data volumes. However, considering that user requirements discussed in Technical Note No. 3 were strongly in favour of fine mapping scales it must be concluded that sufficient spatial accuracy to meet user needs could not be achieved using these data (see Section 2.4).

- **SPOT**
  SPOT data are available at 10 m resolution in 1 band and 20m resolution in 3 bands. One scene covers 3600 km^2 with repeat coverage every 26 days. Each pixel is represented by 8 bits.

- **ERS-1 SAR**
  ERS-1 SAR data are not available with sufficiently frequent and extensive coverage to be of use in provision of complete monitoring of tropical forests on a routine basis. However, the data could be used where less frequent monitoring of particular areas is required. Each image covers a ground area of approximately 10000 km^2 with a spatial resolution of 30 m and costs about $1000; each pixel is represented by 16 bits.

The reader is referred to Technical Note No. 2, Section 2 for more detail concerning radiometric properties.

For coverage of the tropical forest regions 1 km AVHRR data and TM data are the only realistic possibilities in the near to mid-term. GAC data are at too coarse a resolution to provide sufficient accuracy and the nature of the resampling is such that entire features can be omitted (see also Technical Note No. 2). SPOT data rates are higher by a ratio of approximately 1:6 than the already very high TM rates discussed below and are radiometrically less suitable than TM or AVHRR for tropical forest monitoring.

The equivalent ground area of a 1 km AVHRR pixel requires 60,000 bits to be represented using TM data and 50 bits to be represented using 1 km AVHRR data; a ratio of approximately 1:1,200. The spatial resolution difference means that for every AVHRR pixel classified 1,111 TM pixels would have to be classified with a corresponding increase in processing time and load. The increased processing required to use TM data in preference to 1 km AVHRR data is therefore considerable. Data costs must also be considered in that a single TM scene can be purchased for $4,400, and an AVHRR LAC scene for $100. With the spatial extent of a TM scene being 34225 km^2 and the usable portion of an AVHRR scene being on the order of 3,000,000 km^2, the cost differential is therefore $(100/3,000,000): $(4,400/34225), i.e. approximately 1:3,857 . Should current proposals make Landsat 6 data available at cost come to fruition this differential would be substantially reduced. However the data processing load would remain unchanged.

It can be concluded from this that the use of TM data to cover the tropical regions on a 3 yearly or more frequent basis is prohibitive in terms of data volume and cost. Although frequent coverage is a major user concern (see Section 2.2 and Technical Note No. 3) requirements which would need TM data across the entire tropics must be considered to be infeasible unless CEC is prepared to invest considerably more manpower and money than have been the case for TREES I.

2.6 Recommendations

Each requirement identified in Section 2.2 is now considered with respect to the constraints and problems discussed in Sections 2.3 to 2.5. For each requirement the optimum data source is identified and potential problems summarised.

Requirement 1 — *fine scale, annual boundary data*

This requirement would need TM data to achieve sufficient accuracy. TM has a 16-day repeat cycle, so that obtaining sufficient cloud free data could be a problem. Areas would have to be labelled as 'unclassified' if cloud free data were unavailable. 1 km AVHRR data could be used if areal statistics were satisfactory as opposed to mapping the exact boundary. Cloud cover problems would still exist, but would be less severe with the daily repeat coverage. The major problem in meeting this requirement using TM would be the volume and cost of data (Section 2.5).

Requirement 2 *medium scale, annual boundary data*
It would be possible to achieve this with 1 km AVHRR data at a mapping scale of about 1:1,000,000, provided that it is possible to mark areas as 'unclassified' if cloud free data are not obtained during the year. Provision of areal statistics is feasible. Satellite data at spatial resolutions more than 1 km would not provide sufficient accuracy.

Requirement 3 *coarse scale, 3 yearly boundary data*
This is certainly possible with 1 km AVHRR data, and cloud free data should be available during this time frame.

Requirement 4 *medium scale, 3 yearly boundary data*
The 3-year time period would mean that greater attention could be paid to the accuracy of the classification than for Requirement 1 so that the results would be more meaningful. While use of TM data would be desirable, 1 km AVHRR data would be adequate.

Requirement 5 *fine scale, 3 yearly boundary data*
As with requirement 1, this would require TM data with correspondingly high data volumes and costs. The 3-year time-frame would however reduce these considerably from those of requirement 1.

Requirement 6 *medium scale, annual fire data*
This is provided by the FIRE programme.

Requirement 7 *medium scale, annually, roads*
This would require TM data except in areas with clearly delineated roads where 1 km AVHRR data might be adequate.

Requirement 8 *fine scale, every 3 years, protected area monitoring*
To derive these data would require the use of TM, possibly supplemented by airborne data (both optical and SAR). This would be possible, although a five-year repeat period might be more realistic.

Requirement 9 *medium scale, every 3 years, protected area monitoring*
This would require 1 km AVHRR data at a minimum.

Requirement 10 *fine scale, annually, protected area monitoring*
This would require TM data on an annual basis with correspondingly high data volumes and costs.

Requirement 11 *medium scale, annually, protected area monitoring*
This would require 1 km AVHRR data at a minimum.

Requirement 12 *fine scale, every 3 years or more, biomass*
At the required scale of less than 1:100,000 it would be necessary to use TM data, or even airborne data. It would be

difficult to cover the whole tropical area at this scale, but it should be feasible to provide data for selected areas.

Requirement 13 *medium scale, every 3 years, biomass*
This is provided by GVI data and IGBP-DIS data..

Requirement 14 *fine scale, annually, biomass*
Similar comments apply as for Requirement 12. To achieve this annually would be an extremely heavy processing load.

Requirement 15 *fine scale, annually, forest types*
TM data would be required, probably supplemented by airborne SAR and airborne optical data. The data volume and costs would be very high.

Requirement 16 *medium scale, annually, forest types*
See discussion for requirement 15.

Requirement 17 *fine scale every 3 years, forest types*
This would be possible using TM data, but possibly only for selected areas (see discussion on protected areas).

Requirement 18 *medium scale every 3 years, forest types*
Provision of these data would be achievable with 1 km AVHRR.

Requirement 19 *fine scale, every 3 years or more, timber volume*
Provided the relationships exist as discussed above in Section 2.3 this would be achievable using TM data. It would be difficult to cover the whole tropical area at this scale, but data could be provided for selected areas.

Requirement 20 *medium scale, every 3 years or more, timber volume*
1 km AVHRR data would be a minimum requirement.

Requirement 21 *fine scale, annually, timber volume*
This would require TM data with corresponding high data volumes and costs, see also comments for requirement 19.

Requirement 22 *medium scale, annually, timber volume*
This would be possible using 1 km AVHRR data, but see comments under requirement 19.

Requirement 23 *fine scale, every 3 years, biodiversity*
TM or SPOT data supplemented by airborne optical and SAR data would be required, providing the restrictions outlined in Section 2.3 are overcome.

Requirement 24 *medium, every 3 years, biodiversity*
TM data should provide adequate spatial resolution providing that the restrictions outlined in Section 2.3 are overcome.

Of the total of 24 identified requirements outlined above 13 could be met by the products and systems outlined in the rest of this report. However, note must be taken of the constraints discussed in the description of each requirement.

- Requirements 2, 11 and 22 could be met by a product derived annually from 1 km AVHRR data – this product would give percent forest coverage and map the forest boundary.

- Requirements 3, 4, 9 ,18 and 20, would be met by a product derived every 3 years using 1 km AVHRR data – this product would provide percent forest coverage of selected forest types and map their locations.

- Requirements 5, 8, 12, 17 and 19 would be met by a fine scale product derived every three years using TM and supplementary data, possibly only for selected areas – this would provide detailed mapping of these areas. It is not considered to be feasible to meet these requirements for the whole tropical area.

Requirements which are not met fall into three groups:

- **Data handling constraints**
  Requirements 1, 10, 14, 15, 16, 21.
  These requirements all would involve annual classification of TM data over the entire tropical area. This can be achieved in the technical sense, but in considering the data volumes involved Section 2.5) and the required manpower it is considered extremely unlikely that this would be feasible in practice.

- **Technical difficulties**
  Requirements 7, 23 and 24.
  These requirements could not be met because of technical difficulty in that the information is not directly derivable from remotely sensed data on a consistent basis.

- **Requirements covered by other programmes**
  Requirements 6 and 13.

Considering the numbers of user requests for a requirement (see Technical Note No. 3, Appendix F), the major areas which would not be met would be:

- fine scale annual boundary data and protected area monitoring
- annual forest type data at any scale
- biodiversity.

The major information requirement areas met in terms of numbers of requests (see Technical Note No. 3, Appendix F) would be:

- boundary data at other than fine scale annually
- protected area monitoring at other than fine scale annually
- forest types at 3 yearly or greater intervals.

As can be seen from the above discussion, the primary impediment to supplying the users with data at their required scales is data volume and cost. The many users who require pan-tropical data annually at scales of 1:100,000 or less will be unable to look to TREES for their information. To some extent these users' requirements could be partially met by providing fine scale data via TM, but this would probably have to be for selected areas only. This implies that the user groups best served by TREES will be those requiring coarser scale data at lower temporal frequencies namely the Global Change Community, UN Agencies, National Governmental Agencies and Intergovernmental Agencies.

3.

Non-technical Requirements

In this section some non-technical issues connected with the future development of TREES are examined.

3.1 Extension of TREES to Non-tropical Areas

Requirement 25: Extend TREES to Non-tropical Areas

Deforestation is not confined to tropical areas, and indeed recent deforestation rates in Siberia since the dissolution of the former Soviet Union are considered to be as great as those in the tropics. While the user survey reported in Technical Note No. 3 did not cover non-tropical areas, there is known to be considerable interest in such areas; in particular, global change studies must of course take account of forest cover change wherever it occurs.

Further, the possible perception of TREES as being an incursion into the sovereignty of tropical nations by the developed world should be avoided. This is necessary to minimise political problems and to increase the potential for collaboration with TREES work and more generally in the implementation of international treaties such as the Convention on Biological Diversity and the statement on Forest Principles (see Technical Note No. 3, Section 2.2).

To extend TREES to global provision in the short term would have a severe impact on its potential for success. Data collection problems would multiply. Classification and geometric registration procedures would be different. Expertise in the specific geographical areas developed during TREES I would be lacking. Therefore, it is suggested that TREES implement a 'pathfinder' study to a single non-tropical area in an attempt to assess the difficulties involved. It is suggested that Siberia, as being both an area of concern and a major area where no other monitoring is known to be taking place (other areas such as Canada, W coast of USA and Scandinavia all have their own monitoring services), should be focused on as an example for boreal forest monitoring. If this extension is successful then in future years TREES could gradually be extended to cover additional areas.

3.2 Technology Transfer and Data Dissemination

Requirement 26 : Provide outputs from TREES in low cost, low technology forms

It is essential that the results of TREES work be disseminated effectively to interested users. Many users have little or no access to sophisticated computing facilities such as GIS and will

require paper products at low cost. Users with GIS or other computing facilities may also require paper data, but are likely also to be interested in electronic data, again at as low a cost as possible. TREES must be able to meet these requirements.

Many users are also in a position to provide ground survey data for verification (see Technical Note No. 3). In particular national agencies have expressed an interest in providing data. Perhaps there could be an exchange system whereby users would receive 'free' information in exchange for verification activity or supplying other data.

During the period of TREES II while TFIS is being enhanced it could be made available to users in a demonstration form so that they could input comments and suggestions. There could also be provision of free 'sample' data to users during TREES II for comment.

3.3 Collaborative Research Effort

Requirement 27: Collaborate with other projects using remotely sensed data for forestry monitoring

Many of the respondents to the user survey drew attention to the existence of similar research efforts in tropical forest monitoring (see Technical Note No. 3, Appendix D). Particular mention was made of:

IGBP-DIS
FAO
UNEP
Woods Hole
RESPAS
NASA Pathfinder
EROS, 1 km land cover database
CIFOR (connected to Woods Hole)

TREES can choose to collaborate in providing information which is different from the other groups in terms of its information content, scale or frequency. Alternatively collaboration can be on a geographic basis in that TREES would focus on particular areas, and each group would combine its results to provide global data.

Despite the perception of other groups, TREES is unique in attempting to provide 1 km data at annually updated frequencies. The provision of data at finer scales could be left to others.

There is also a role for either shared raw data provision, or for a centralised provision to which TREES and others could look for their data. Data supply has been one of the major stumbling blocks of TREES I (see Technical Note No. 1) and a streamlined data supply would vastly increase the chances of success.

4.

Product Specifications

4.1 Introduction

The requirements analysis presented above attempts to encapsulate the requirements into a set of realisable outputs. This was done by considering the following factors:

- the data supply rate and quality
- the likely classes of data which could be extracted from different EO datasets
- efficient means of grouping requirements into single outputs by considering which parameters could be produced from a particular process and grouping those together.

The result is a set of four products and two reports which it is hoped will meet the largest number of requirements in the smallest number of realisable, reasonable products. For each product, the following sections have been specified:

1. Principal Applications
2. Sensors/Data Inputs Used
3. Classes
4. Coverage
5. Frequency of Product Production
6. Precision, Accuracy and Resolution
7. Auxiliary Data Inputs
8. Investigations required.

Each specification statement is followed by discussion points.

The products are:

Product	Acronym
Tropical Monitoring Product	TMP
Boreal (Siberian) Monitoring Product	BMP
Tropical Inventory Product	TIP
Tropical Local Product	TLP
Active Areas Report	AAR
Expert Analysis Report	EAR

4.2 Tropical Monitoring Product (TMP)

This is a pan-tropical statistical product with graphical output as a backup designed to provide simple but robust and accurate inputs for policy and management makers. It will satisfy requirements 2, 11 and 22. Figure 1 shows an example of the classes and global extent of the TMP. Table 1 shows an example statistical table while Figure 2 shows an example chloropleth representation of the national area statistics from the table.

1. Principal Applications
Monitoring of changes in the areal coverage of forest within tropical nations. Assessment of gross boundary changes from map output. Production of hardcopy maps at 1:5,000,000.
The emphasis is on area rather than boundary because the ability to monitor accurate boundary changes at this scale is unresolved. It is believed that area within nations should prove more robust given the average size of a nation compared to registration accuracy. Hence this is primarily a numerical rather than a graphical product. While boundary changes may be visible on the hardcopy output, this product does not claim to indicate the size or direction of boundary changes with any degree of confidence. This is left to the AAR which synthesises this product with other data sources at a much higher scale.

2. Sensors/Data Inputs Used
1 km AVHRR.
This product uses the major advantage of AVHRR; i.e. its frequent coverage. There must be a clear upgrade path to other sources of similar data such as 'Vegetation' and MERIS. Future satellite programmes are discussed in Technical Note No. 2.

3. Classes
Forest:non-forest:other
There has been much debate about which classes can be extracted from the data. This product takes a pragmatic view and uses the minimum possible number of classes in order to provide a simple, robust and repeatable product. The classification would be carried out separately for each tropical region with results reported for each country (see Figure 1) Slightly different classifiers may be required between continents but in general it is suggested that simplicity should predominate. From year to year, the same techniques and methodology must be used in order to maintain a consistent base for the statistics. There will inevitably be discussion over the best technique to use but some classification accuracy may need to be sacrificed for consistency and repeatability to monitor changes. The 'other' class includes cloud and haze where clear images have not been collected during the period.

4. Coverage
Pan tropically, divided by region and nation with very small nations not covered.
National level breakdown is the key level required by the user to give statistics at a level comparable to those collected on other subjects. In addition, any smaller unit would force the error term associated with mis-registration unacceptably high. Research is required into the error term for the area of each nation.

5. Frequency of Product Production
Yearly.
The minimum time required to collect a cloud free image is about three months and it is better to limit collection to the end of the dry season (where there is a dry season). Degrading temporal resolution to one year means that there should be sufficient cloud free images for most regions although a few areas will not be covered. There is no user requirement for monitoring at less than one year.

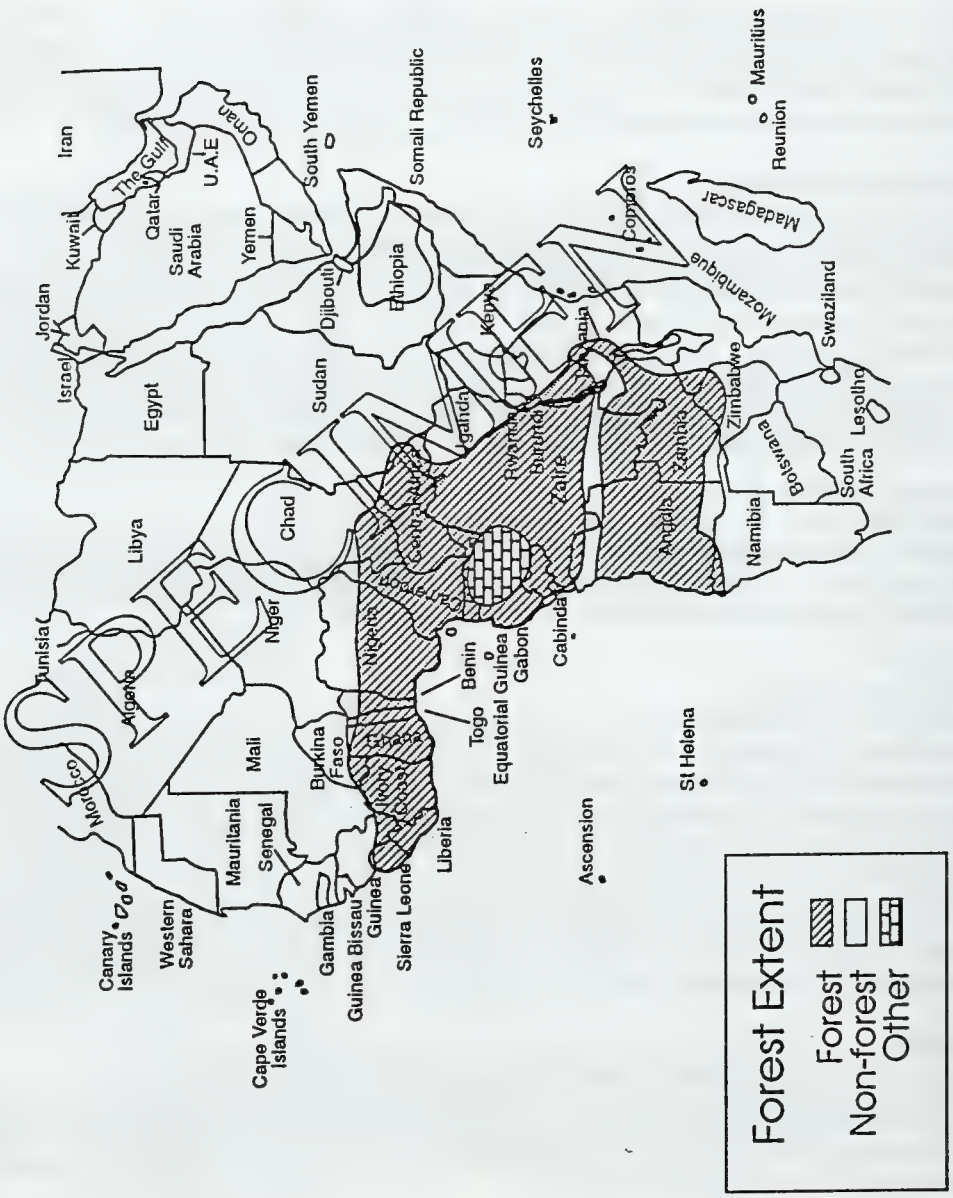


Figure 1 : Example for Africa of the Classes of the Tropical Monitoring Product

Tropical Monitoring Inventory Product (TMP)
TREES II Product 1998

Country	Forest	Non-Forest	Other	Country size	% forest	% Change 1996 - 98
Treeland	532	24	2	558	87	4
West Trees	624	214	31	849	76	-2
Middle Trees	247	384	5	633	36	-0.4
North Trees	523	17	56	596	93	12
Leafy Island	3416	274	27	3423	96	1
Northern Stem	5847	34	17	5898	95	-0.75
Western Stem	327	257	17	601	52	-34

Table 1: An Example Statistical Table (TMP)

6. Precision, Accuracy and Resolution

Precision is X % or +/-Y km2; Accuracy should be a minimum of 80%; Resolution is 1 km.

The precision of the national statistics will vary with the size of nation and the spatial distribution and 'shape' of forest formations. The relationship between area and boundary is complex. A pixel resolution of 1km implies that boundaries can be located to within 1 km and changes in boundaries of less than 2km are not discernable. The measurement of forest area, while subject to the same 1km resolution implication, will usually be more accurate, provided that the area of forest is large relative to the number of boundary pixels. Where the forest is very fragmented, so that the number of boundary pixels is very large relative to the number of non-boundary pixels, areal measurement will decrease in accuracy. A similar argument applies for changes through time i.e. that the measurement of forest area will suffer from less uncertainty through time than the mapping of the boundary location. The work of Kuntz and Kleinn (1993) needs to be examined by the TREES II team in order to make firmer statements about relationship between pixel size, forest distribution and accuracy of results.

Overall classification accuracies of 80% have been achieved elsewhere and using a simple classifier should enable a consistent high level to be achieved.

7. Auxiliary Data Inputs

Coastlines and national boundaries.

The best source is almost certainly DCW.

8. Investigations and trade-offs to be made

The discussions above can be summarised in terms of research required:

- precision and accuracy definitions
- minimum size of nation for which statistics can meaningfully be produced
- the most appropriate and simplest classifier to use to achieve high accuracy
- the scale at which hardcopy output can meaningfully be produced in relation to significant boundary changes and registration errors.

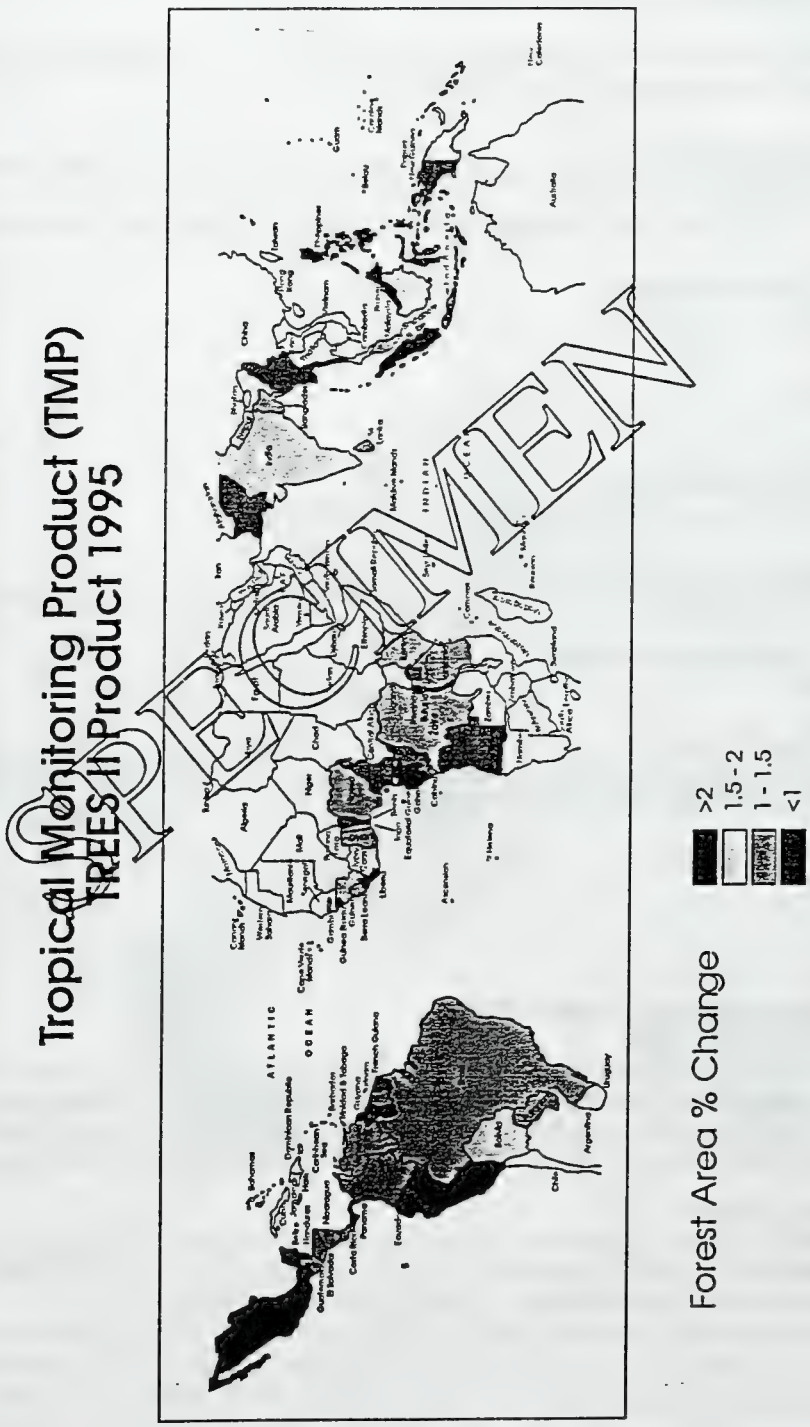


Figure 2 : An Example Chloropleth Representation of the National Area Statistics (TMP)

4.3 Boreal Monitoring Product (BMP)

This is equivalent to the TMP in function but is specific to boreal environments, e.g. Siberia. It is will satisfy the requirements 2, 11, 22 and 25.

1. Principal Applications
Monitoring of changes in the areal coverage of forest within Boreal (Siberian) regions. Production of hardcopy maps at 1:5,000,000.
Much as for the TMP; the major difference being that a different classifier will be required.

2. Sensors/Data Inputs Used
As for the TMP

3. Classes
As for the TMP.

4. Coverage
Siberia divided by federal regions.
As for the TMP. However the projection may need to change.

5. Frequency of Product Production
As for the TMP, although cloud free coverage might be easier to obtain in this period.

6. Precision, Accuracy and Resolution
As for the TMP

7. Auxiliary Data Inputs
As for the TMP, although regions of Siberia are not obviously available. Division into squares of 10° in latitude and longitude might be necessary.

8. Areas of Investigation
As for the TMP.

4.4 Tropical Inventory Product (TIP)

This is a pan-tropical graphical product with statistical output designed to show the extent of and relationships between forest types and boundaries of other political and physical units. It will satisfy requirements 3, 4, 9, 18 and 20. Figure 3 illustrates a specimen TIP over S.E. Asia while Table 2 shows a section of the statistical table which might accompany it.

1. Principal Applications
Area, boundaries and types of forest per nation and sub-national region. Principally a graphical product to show relationships between and areas of many classes of forest sub-classified by other spatial auxiliary data such as protected areas, national parks, vegetation zones etc..
This is a more rigorously defined version of TMP which is made possible by the more extensive use of ground survey for more detailed classification. The TMP is not necessarily directly derivable from the TIP since data from different times may have been used in its production (see Technical Note No. 5, section 5). The output is numerical for area plus graphical output for distribution of forest types and possibly boundary changes at scale to be decided (perhaps 1:1,000,000).

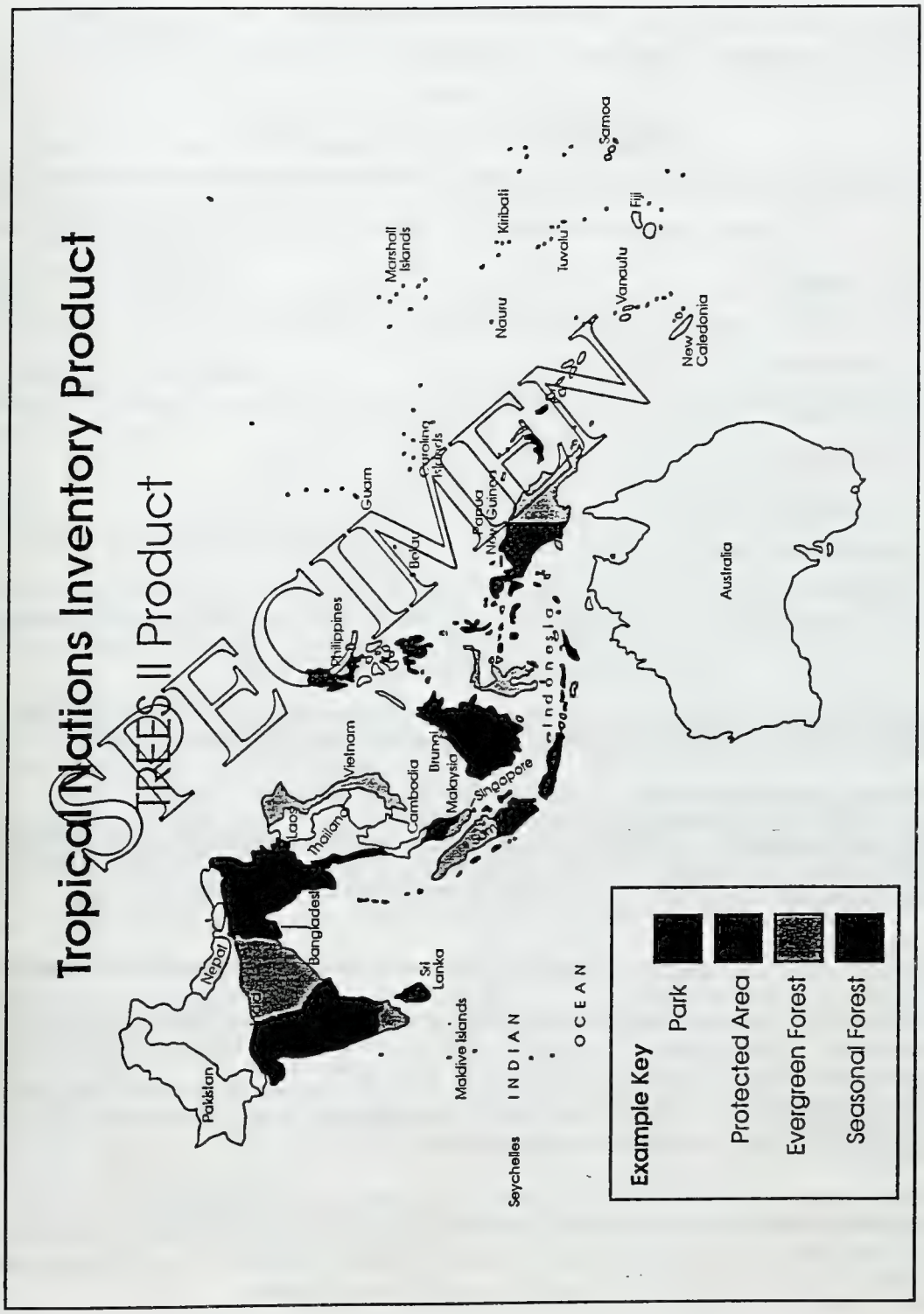


Figure 3 : A Set of Possible Classes for S.E. Asian Tropical Inventory Product

Tropical Nations Inventory Product (TIP)

TREES II Product 1996

Country	Evergreen Forest	Degraded Forest	Secondary Forest	Non-Forest	Seasonal Forest	Protected Areas	Evergreen Forest in protected area	Seasonal Forest in protected area
Treeland	56	23	13	4	5	2	2	2
West Treesland	34	24	31	18	7	3	1	5
Middle Treesland	57	34	5	7	24	5	4	1
North Treesland	42	17	27	8	18	3	1	4
Leafy Island	64	24	18	28	2	5	1	6
Northern Stemland	58	34	17	7	21	2	2	4
Western Stemland	37	24	17	9	5	7	3	2

Table 2 : A Section of a Statistical Table for TIP

While boundary changes may be visible on the hardcopy output, this product does not claim to indicate the size or direction of boundary changes with any degree of confidence.

2. Sensors/Data Inputs Used

1 km AVHRR for classification, TM for survey and validation.

This is still basically a 1 km based product but with much increased use of TM and ground survey for training classifiers. The use of separate TM and/or ground survey for each region (sub-continental scale related to AVHRR image/strip extent) is anticipated.

3. Classes

evergreen forest : degraded forest : secondary forest : non-forest : seasonal forest (all classes tbd following appropriate research).

The definition of classes is critical and must be done carefully in light of research within and outside the TREES project. The classifier may be modified to produce a set of classes appropriate for each continent, region or even sub-region; i.e. the aim is to optimise the classification accuracy and obtain maximum information content in terms of forest type. This implies the use of separate TM and/or ground survey for each region and also that changes in the classifier will occur at each inventory.

4. Coverage

Pan-tropical, by region, nation and sub-national area (with a minimum size cutoff – tbd).

For large countries, e.g. Brazil, the states (e.g. Rondonia) must be apparent. Such sub-division is made to maximise the information extractable and to take account of the forest type changes as one moves from tropical through sub-tropical zones.

5. Frequency of Product Production
3-5 years.
This length of time is required to collect TM and ground survey data and make the appropriate number of decisions about classifiers in each area.

6. Precision, Accuracy and Resolution
The specification and discussion is as for the TMP. However the division of nations into smaller units using other auxiliary data (e.g. protected areas) will tend to decrease precision and accuracy, although the 'better' classifier will counter this.

7. Auxiliary Data Inputs
As for the TMP with the addition of sub-national area definitions and a range of other auxiliary data including protected area, national parks, vegetation zones.

8. Areas of Investigation
As for the TMP with the addition of the need to research multi-class classifiers for a number of different regions.

4.5 Tropical Local Product (TLP)

This is designed to provide highly detailed information over a small area; in particular to satisfy requirements 5, 8, 12, 17 and 19. Figure 4 illustrates how a TLP might appear when using airborne SAR strips and ground survey as input.

1. Principal Applications
It is envisaged that ad-hoc requests for detailed investigation of a small area (10,000 km^2 or less) will drive the production and definition of this product. For example the mapping of protected areas for species diversity, hydrology, deforestation etc..
This product is characterised by being highly detailed at a local scale only. It is the antithesis of the TMP and TIP being geared towards one-off analysis for special tasks. It encapsulates all of the techniques which are not viable at a global or even regional scale, but uses TM as a base and the specific strengths of SAR and ground survey for the uses to which they are best suited at the current level of knowledge. It is unlikely that it can be specified in any generic detail since local data availability will determine the form of the product.

2. Sensors/Data Inputs Used
Landsat TM, SAR (space and air borne), ground survey.
The base data for the product might be a single TM to which is added SAR and any other detail that can be found.

3. Classes
The minimum which should be extracted is forest:non-forest at 100 m (minimum) accuracy/ precision. However, a much larger number of classes should be possible; for example a number of tree species and land use categories.
This product could contain a large quantity of very specific information about the surveyed area including tree species type, tree height, etc., all at 100 m or less spatial resolution.

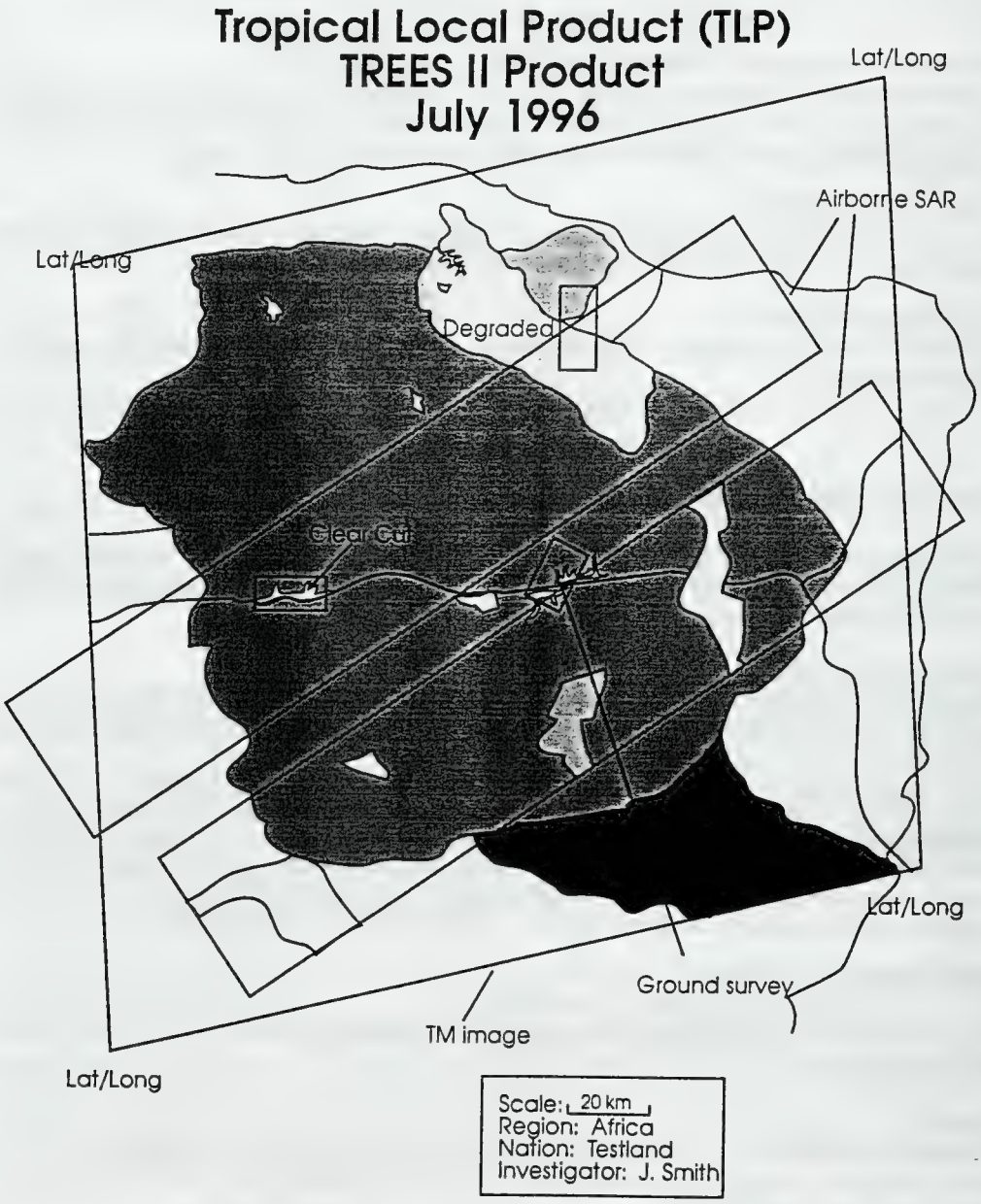


Figure 4 : Example Form of Tropical Local Product

4. Coverage
As requested by users; e.g. treaty verification group for specific protected areas, biodiversity areas etc..

5. Frequency of Product Production
On request only.
If the project is requested to monitor a protected area, where TIP provides inadequate resolution then regular production of TLP may be required.

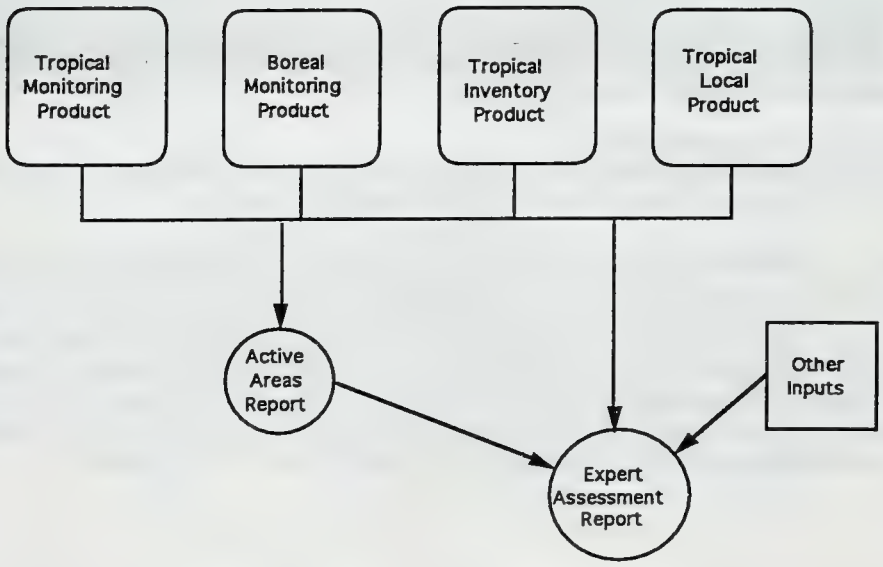
6. Precision, Accuracy and Resolution
Dependent on data availability but at least 100 x 100 m resolution and possibly much more. Precision and accuracy will vary but should be very 'high' given the narrow spatial focus and the combination of data types, especially if ground survey is involved.

7. Auxiliary Data Inputs
National boundaries, boundaries of areas of special interest, high biodiversity and protected areas. In addition, DEMs for SAR correction and local weather conditions will provide highly defined classifications.

8. Investigation required
SAR image segmentation procedures for forest type classification.

4.6 Report Generation

In addition to the four products proposed above, it is considered useful to specify two reports. These are derived from the other products but concentrate on small areas of particular interest where additional expertise or auxiliary data are available. The relationship between the products and reports and input data is shown below:



4.6.1 Active Areas Report (AAR)

This is a derivative of the other products designed to provide detailed information on areas where deforestation is rapid. It meets the same requirements as TIP and TMP but concentrates on boundary changes over small areas and could be seen as meeting requirement 1 for fine scale boundary changes. Figure 5 illustrates the type of information which might be extracted from this report.

1. Principal Applications

Areas of active deforestation may be identified in the TMP, BMP, TIP or TLP products if they are overlaid with previous products of the same type. Large scale graphical output showing changed boundaries or areas of degradation could be produced. The area of change, direction and 'shape' of the change might be outlined.

Whether change can be detected in the products continues to be a matter of debate and research. While the products will show changes which may be genuine (rather than as a result, for example of mis-registration), it is difficult to determine the reasons for such change without more detailed investigation. The AAR provides for such an investigation, in particular by concentrating on further algorithms for change detection and by prescribing a 'report' format which entails the involvement of human intervention, the use of additional auxiliary data and the inclusion of text results from the investigation.

2. Sensors/Data Inputs Used

Based on any of TMP, BMP, TIP or TLP.

3. Classes

Areas of change between each combination of classes.

Particularly when using TIP there will be a potentially large number of polygons created by an overlay, e.g. forest becomes non-forest, secondary forest becomes forest, etc.. It will be necessary to remove obviously spurious change polygons and those which are too small to be of interest. The remaining polygons will form the valid change classes which should then be assessed by the operator. The form of assessment and the rules by which polygons are judged valid or invalid must be the subject of research.

4. Coverage

Any area within that of TMP, BMP, TIP or TLP.

Large scale output will be appropriate of area over which change is detected. National or sub-national scale might be most appropriate.

5. Frequency of Product Production

When the other products are generated and a change is obvious or even suspected from examination of the graphical or statistical output then AARs could be produced.

Discussion. A judgement will be required each time one of the products is generated as to whether detailed change detection should be undertaken. This will depend on which products are used as basis for detection, how tightly defined the thresholds are and what is actually known to be happening on the ground. One could imagine the TMP/BMP being routinely checked against the previous version in a TFIS function and where a significant change in statistics is seen within a nation, then an AAR would be produced for that nation. A change detection function designed to register consecutive products to a high degree of accuracy and then match borders using particular algorithms might be applied.

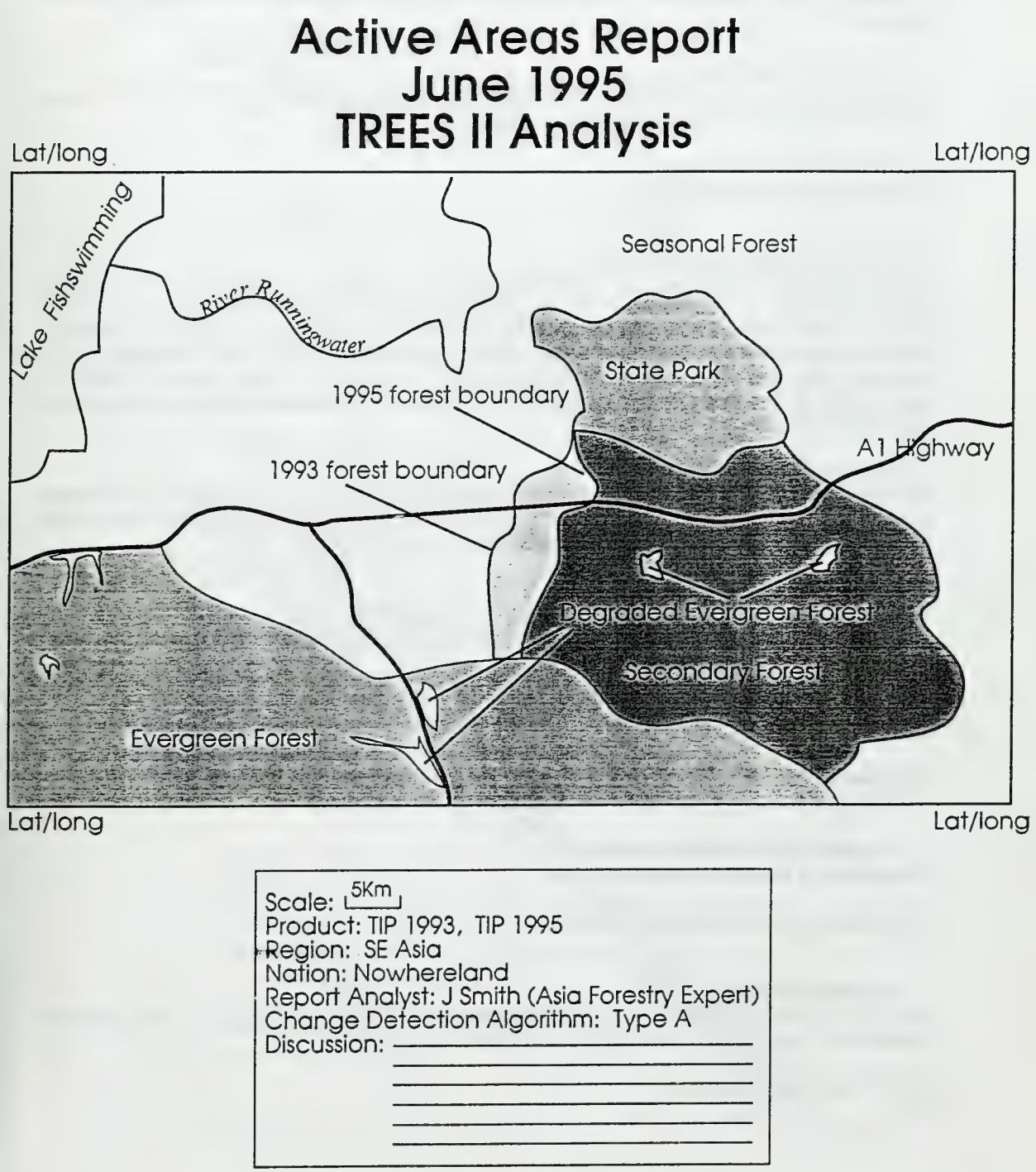


Figure 5: Illustration of Information Content of the Active Area Report

6. Precision, Accuracy and Resolution
Depends on the parameters of the product in use and the results of change detection research.

7. Auxiliary Data Inputs
As for TMP, BMP, TIP or TLP but using large scale features from the DCW, such as roads, plus auxiliary HD data (population) and any local knowledge.

8. Investigations Required
Change detection algorithms.

4.6.2 Expert Analysis Report (EAR)

This report provides a specific point for the products, human expertise and all manner of other related data to be combined. Other requirements not met by the products or the AAR might be met in the EAR, by viewing TREES output as just one of a number of inputs. Hence biodiversity mapping, while not possible from the products, could be reported by another means and supported by TREES products. This would be encapsulated in the EAR thus indirectly meeting requirements 23 and 24. Figure 6 illustrates what sections from an EAR might contain.

1. Principal Applications
To combine many inputs into a text report on a specific area of the globe; for example a combination of a specific TIP area, treaty data, an AAR and forestry expert combine to produce a report on conformance of nation to a treaty covering particular protected areas.

2. Sensors/Data Inputs Used
As TMP, BMP, TIP, TLP, AAR , auxiliary data from all sources.
The major input is not a sensor but a human expert who makes use of products and auxiliary data on an interactive basis.

3. Classes
n/a

4. Coverage
Any area within that of TMP, BMP, TIP or TLP.

5. Frequency of Product Production
Produced on an interactive and ad-hoc basis.

6. Precision, Accuracy and Resolution
n/a

7. Auxiliary Data Inputs
As for TMP, BMP, TIP, AAR or TLP plus a wide range of other data sources which may become primary while the TREES products become auxiliary to it.

8. Investigations Required
n/a

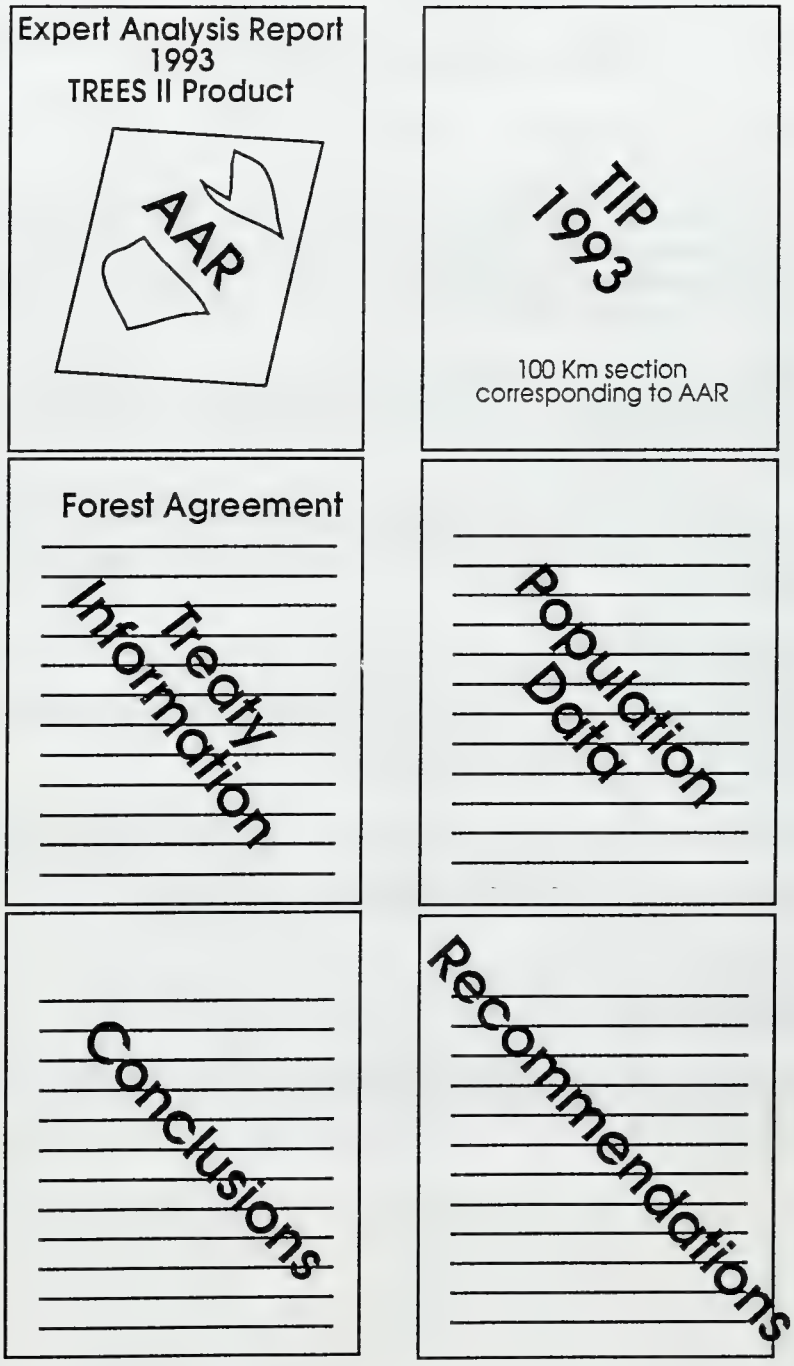


Figure 6 : Illustration of Expert Analysis Report Content

5.

Conclusions

The products described in Section 4 are designed to meet the user requirements as fully as possible within the technical and institutional constraints of the TREES project. Table 3 summarises each requirement with respect to the suggested products. Three reasons were given for not meeting eleven of the identified requirements (labelled 1 to 3 in Table 3):

- the data volume required is prohibitively high.
- the required information cannot be directly extracted from satellite data given the current technology
- the requirement is met elsewhere

From the description of the suggested products given in Section 4 it can be seen that there are several areas for which research issues need to be resolved before operational production can proceed:

- classes to be included in the TIP
- classification procedures to be used for all products
- procedures for determining accuracy of areal statistics, boundary location and change statistics for all products
- methods for improving registration accuracy.

These research areas are further expanded and discussed in Technical Note No. 5, Section 3.

In meeting operational production there are also problems relating to:

- data supply
- data management
- project management.

These are further discussed and expanded upon in Technical Note No. 5 in the context of a framework for the operational TREES system.

Requirem't Number	Requirement Description	Comments	Requirements Met			User Groups	Requirem'ts Not Met		
			TMP	TIP	TLP		1	2	3
1	fine scale, annual boundary data	This requirement would need TM data to achieve sufficient accuracy. TM has a 16-day repeat cycle, so that obtaining sufficient cloud free data could be a problem. Areas would have to be labelled as 'unclassified' if cloud free data were unavailable.				B,E,G, H	√		
2	medium scale, annual boundary data	It would be possible to achieve this with 1 km AVHRR data at a mapping scale of about 1:1,000,000, provided that it is possible to mark areas as 'unclassified' if cloud free data are not obtained during the year. Provision of areal statistics is feasible	√			B,D,E, G			
3	coarse scale, 3 yearly boundary data	This is certainly possible with 1 km AVHRR data, and cloud free data should be available during this time frame.		√		A,C			
4	medium scale, 3 yearly boundary data	The 3-year time period would mean that greater attention could be paid to the accuracy of the classification than for Requirement 1 so that the results would be more meaningful. While use of TM data would be desirable, 1 km AVHRR data would be adequate.		√		B,D,F			
5	fine scale, 3 yearly boundary data	As with requirement 1, this would require TM data with correspondingly high data volumes and costs. The 3-year time-frame would however reduce these considerably from those of requirement 1.			√	B			
6	medium scale, annual fire data	This is provided by another programme.				D,G,E			√
7	medium scale, annually, roads	This would require TM data except in areas with clearly delineated roads where 1 km AVHRR data might be adequate.				C,E		√	
8	fine scale, every 3 years, protected area monitoring	To derive these data would require the use of TM, possibly supplemented by airborne data (both optical and SAR). This would be possible, although a five-year repeat period might be more realistic.			√	B,C,D, E,G,H			
9	medium scale, every 3 years, protected area monitoring	This would require 1 km AVHRR data at a minimum.		√		B,C,D, E,G,H			
10	fine scale, annually, protected area monitoring	This would require TM data on an annual basis with correspondingly high data volumes and costs.				B,C,D, E,G,H	√		
11	medium scale, annually, protected area monitoring	This would require 1 km AVHRR data at a minimum.	√			B,C,D, E,G,H			
12	fine scale, every 3 years or more, biomass	At the required scale of less than 1:100,000 it would be necessary to use TM data, or even airborne data. It would be difficult to cover the whole tropical area at this scale, but it should be feasible to provide data for selected areas.			√	A,F			
13	medium scale, every 3 years, biomass	This is provided by another programme.				A,F			√
14	fine scale, annually, biomass	Similar comments apply as for Requirement 12. To achieve this annually would be an extremely heavy processing load.				A,F	√		
15	fine scale, annually, forest types	TM data would be required, probably supplemented by airborne SAR and airborne optical data. The data volume and costs would be very high.				All	√		
16	medium scale, annually, forest types	See discussion for requirement 15.				All	√		
17	fine scale every 3 years, forest types	This would be possible using TM data, but possibly only for selected areas (see discussion on protected areas).			√	All			
18	medium scale every 3 years, forest types	Provision of these data would be achievable with 1 km AVHRR.		√		All			
19	fine scale, every 3 years or more, timber volume	Provided the relationships exist as discussed above in Section 2.3 this would be achievable using TM data. It would be difficult to cover the whole tropical area at this scale, but data could be provided for selected areas.			√	C,D			
20	medium scale, every 3 years or more, timber volume	1 km AVHRR data would be a minimum requirement.		√		C,D			
21	fine scale, annually, timber volume	This would require TM data with corresponding high data volumes and costs, see also comments for requirement 19.				C,D	√		
22	medium scale, annually, timber volume	This would be possible using 1 km AVHRR data, but see comments under requirement 19.	√			C,D			
23	fine scale, every 3 years, biodiversity	TM or SPOT data supplemented by airborne optical and SAR data would be required, providing the restrictions outlined in Section 2.3 (TN-04) are overcome.				B,C,D, H		√	
24	medium, every 3 years, biodiversity	TM data should provide adequate spatial resolution providing that the restrictions outlined in Section 2.3 (TN-04) are overcome.				B,C,D, H		√	

Table 3 : Summary of Requirements and Recommendations

6.

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Technical Note No. 5

Work Plan

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Appendix : Key for Object Oriented Figures

1.

Introduction

The requirements gathered earlier in this study and reported in Technical Note No. 3 form the basis for the Work Plan in this technical note. In Technical Note No. 4, the requirements were analysed and reconciled with the potential of current and possible future remote sensing technologies. This analysis led to the conclusion that the clearest means of meeting requirements was to propose a set of products towards which TREES should work. The products outlined in that analysis are built on below as the basis for the Work Plan.

Section 2 is concerned with the systems elements required to service the formation of the products. This is not an attempt to design a system for TREES II in either software or hardware terms. Instead, the system elements have been developed and described in order to provide a framework for analysing options and to provide a means by which a clear path for the development of a fully operational system can be planned.

Section 3 details the various 'questions to be answered' which have arisen both during the TREES I project and during the analysis of requirements, product proposals and system elements. Research topics are those areas where data must be further analysed in order to provide a firm foundation for the product specification.

Section 4 addresses the critical issue of management and manning while in section 5, the system and research elements are tied down to a schedule. Cost implications of various outputs are considered in accordance with CEC wishes to understand what might be delivered by TREES II with various levels of funding. Recommendations are summarised in section 6.

2.

System Description

2.1 Introduction and Methodology

The product specifications outlined in Technical Note No. 4 imply a number of supporting system elements. Some of these elements are found in the TREES I project in more or less well developed forms. A systems view is necessary so that a managed move towards an operational system can begin. The purpose of this section is to provide a description of a system outlining how these elements might be knitted together to establish a semi-operational product system. Where studies are required to determine the best set of elements to use, then these are identified and discussed.

The approach taken to describe the proposed system is 'object oriented'. This means that elements of the system are grouped according to natural boundaries defined by physical or logical 'things' into objects or components. This is in contrast to the more traditional function-oriented design method where functional elements are the main building blocks. The elements in TREES I and those proposed for TREES II lend themselves to such an approach for the following reasons:

- the elements are varied, some being physical (hardware, data), some conceptual, some managerial and some institutional
- the proposed products are complex outputs consisting of data from a range of sources in addition to human expertise and cannot therefore be seen from a simple 'data flow-function' viewpoint.

The advantages of this viewpoint are that complexity (in data and function terms) can be hidden inside the components and interfaces can be fixed. This means that changes within components (such as changes in data supply or classification or product specification) do not disrupt the rest of the system. In addition, components can be distributed to different physical locations, different institutions or projects, again with the minimum of disruption.

If readers are unfamiliar with object orientation, then the figures should be viewed as natural, intuitive descriptions and there need be no concern with the background theory. The main point is that each component has a boundary (see following figures). Procedures and data items within the boundary are 'hidden' from other components while if they traverse boundaries then they are visible to other components and interact with them.

An analysis of the system requirements for TREES II leads to the development of six components:

- Data Suppliers
- Data Management

- Images
- Products
- Validation
- Users.

These components are shown in Figure 1 (for object oriented symbol key, see Appendix).

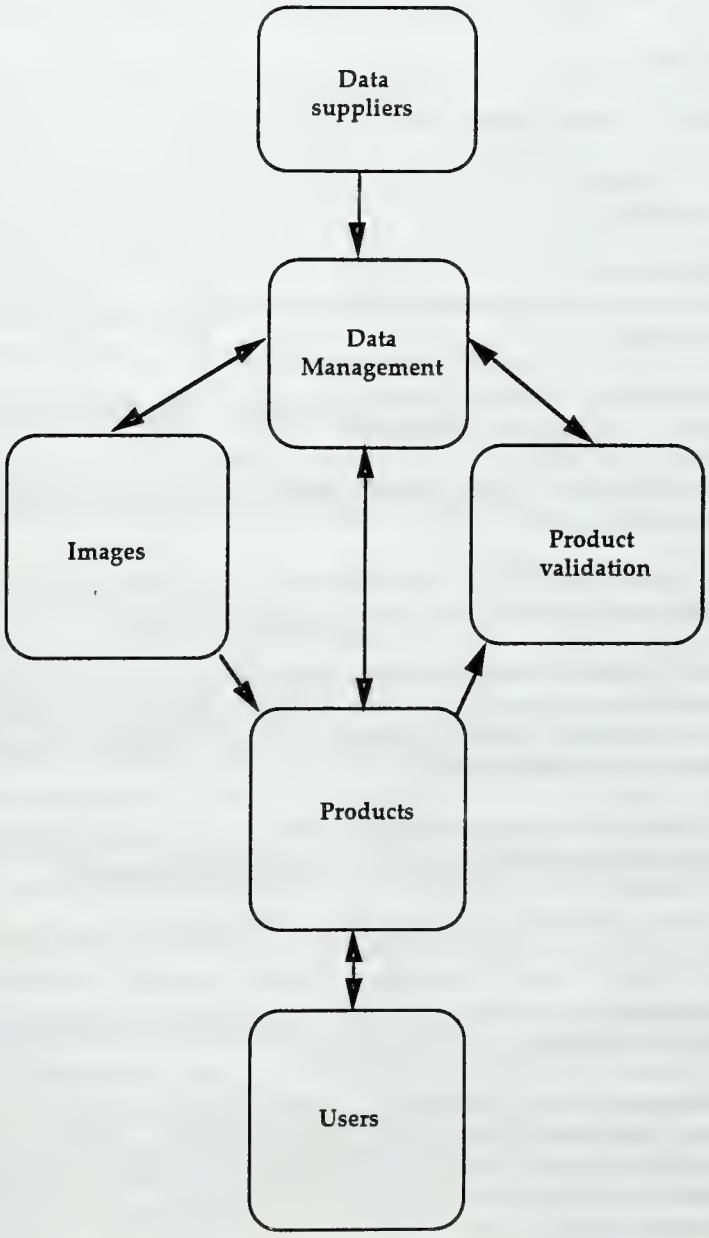


Figure 1 : High Level System Components

The following sections describe each component in terms of the internal elements: procedures, data, inputs and outputs. Each is described in terms of TREES I heritage (where applicable) and proposed TREES II development. The problems and possibilities for the physical and logical location of components is also discussed. The research topics in each section are further elaborated in section 3.

2.2 Data Suppliers

This is divided into two further components:

- routine data supply
- one-off data supply

2.2.1 Routine Data Supply

The basic input for most of the proposed products is a routine supply of data having the following characteristics:

- regular coverage of all areas of interest realising a reasonable supply of cloud free images in appropriate wavelengths
- resolution sufficiently high to provide useful results while not resulting in an unmanageable data flow.

The data were supplied in TREES I by AVHRR 1 km coverage. However, there are four other sources of comparable data which might be used in the future:

- The French 'Vegetation' instrument proposed for flight in 1996 and which would be purpose built for vegetation monitoring. The major advantage over AVHRR is an on-board recorder capable of global storage which would very considerably simplify the data collection process.
- MERIS; scheduled for flight on board ESA's EnviSat in 1998. MERIS should provide high resolution coverage including a vegetation product.
- MODIS; similar to MERIS also scheduled for 1998 on-board one of the US EOS satellites.
- ATSR-2; available from 1994, but suffering a swath width disadvantage compared to AVHRR which limits coverage.

In the future, one or more of these sources, notably Vegetation and MERIS, might well be capable of furnishing the data requirements of TREES more efficiently than AVHRR. It is therefore critically important to TREES II and beyond that the system for forest analysis and products output are as far as possible independent of data source. This has important implications for TREES II and beyond:

- the routine data collection component (including all internal procedures) should be separated logically and possibly even physically from the rest of the system to

encourage independence and non-reliance on one data source and one set of preparation procedures

- subsequent analysis and processing algorithms should be generic and configurable for different source data characteristics

- a long term view should be taken in terms of influencing known future programmes to provide data suitable for the TREES project.

The use in TREES I of AVHRR 1 km data was implemented through contact with various bodies including HRPT stations in the tropics. Thus the procedures of collection, selection of cloud free images and subsequent geometric and atmospheric correction were provided at JRC. This proved a heavy load; something recognised internationally by the fact that major efforts are being made under the IGBP umbrella to collate a global AVHRR data set. This fact combined with the increasingly routine nature of such processing and the level of effort required indicates that the use of an external data collection agency is the way forward for TREES II.

Each procedure shown in Figure 2 is now expanded to analyse the options further.

Procedures - Routine Collection and Selection of Images
TREES I obtained low level products from individual HRPT stations (Australia, Bangkok) and higher level products from NASA (S. America, Africa). These were then processed to a standard form at JRC or using external contractors. The options for the future are:

- Continue and expand the **direct** contact with HRPT stations. The Bangkok station has proved reliable in providing data for S.E. Asia (personnel are contracted by JRC). However, the other two continents have not yielded data from direct contact and intermediate sources have been used. The source of these data in turn has been EDC where LAC collection is being combined with their own direct contact with HRPT stations. TREES II could continue this direct contact, with ESA taking an indirect role through their support to ground station development notably in Africa. The deployment of mobile stations is another possibility which could be pursued where data gaps occur (for example in Central America). The selection of cloud free images should be performed locally if possible through contracting with suitably qualified agents in the field.

- **Indirect collection and selection**. The use of an external supplier to provide the required output. There are several possibilities here. Firstly, a commercial company might be contracted to perform the collection and selection of cloud free images. Secondly, as indicated above, EDC is currently developing a global 1 km AVHRR product under the auspices of the IGBP. The data are collected from HRPT stations and LAC recorded downlink. The data are being collated from 1 April 1992 for 30 months under current funding and a composited, mosaicked product is being produced for the globe. The first is already available for a 10-day period in June 1992. If this product is suitable for use in TREES then is would appear to be an obvious candidate for supply. The advantages of using an international body are that the costs are spread, expertise in processing is centralised (at EDC) and LAC coverage of areas without HRPT (or as backup for failed HRPTs) is more likely. Discussion of the pre-processing and suitability of this product for TREES use is found below.

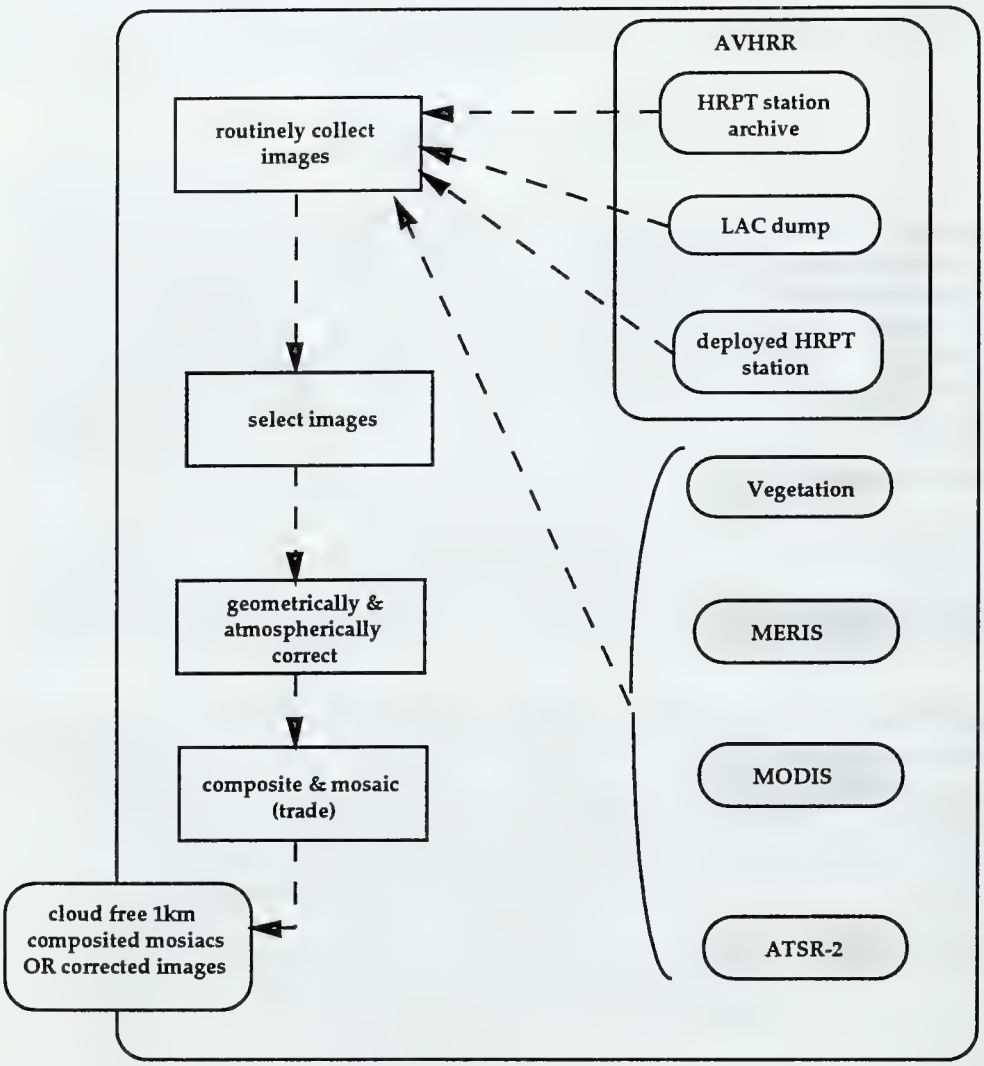


Figure 2 : Routine Data Supply

The institutional and political situation must also be considered under this heading. ESA and CEC are aiming to work together in a data supplier - user relationship respectively. With its interests in HRPT station and ongoing support of the IGBP project, ESA has taken a clear stake in the supply of suitable data. It would appear sensible to recommend that ESA perform the data supply role for future TREES work. There is also clear advantage in such a link when future missions are considered since ESA is obviously the agency with a mandate in data for MERIS, ATSR-2 and possibly Vegetation.

However, two outstanding questions remain:

- During TREES I, ESA was not able to supply suitable AVHRR data to the project team at JRC. Clearly, if ESA is the data supplier for TREES II then a very clear agreement backed by plans and assured finance must be in place to ensure that the correct data is supplied in the appropriate time frame.

- The superficially more attractive route of the centralised IGBP data collection and product (covering all relevant HRPTs and supported by ESA) relies on continued funding at EDC by IGBP. The future production of the IGBP product is currently uncertain. A major meeting of the Land Working Group on 5 July 1993 should clarify some of these issues.

In conclusion, it is clear that ESA as supporter of HRPT stations and of the IGBP project has a major role to play in supplying data. It would appear unwise for the TREES project to continue with the collection of data by direct means due to the cost and duplication of effort involved (it should be noted that TREES I data collection began before IGBP). Therefore the main conclusion must be that ESA should be seen as the major route for future routine data supply. The second conclusion is that considerable effort must be expended to clarify the current and future ESA policy, funding and capability in relation to the supply of AVHRR data to the TREES II project. This effort should be made quickly so that TREES II can proceed on a firm footing. This much is clear. However, the exact form of ESA involvement is the subject of several technical trade-offs. These are discussed below.

Procedures - Composite and Mosaic, Geometric and Atmospheric Correction
The use of the IGBP product noted above appears to be the most attractive option since the data are collected, selected and pre-processed centrally. Some pre-processing steps meet TREES technical pre-requisites:

- **Atmospheric Correction**
  The IGBP product accounts for Rayleigh scattering and ozone and includes NMC water vapour fields for optional correction. Aerosol correction is not applied. This is more than TREES I prescribed, and probably acceptable.

- **Geometric Correction**
  The extent of correction is not entirely clear but is aimed towards sub-pixel (1 km) accuracy with nearest neighbour resampling.

- **Compositing**
  The IGBP product is composited using the standard technique whereby maximum NDVI is used to identify suitable pixels over a 10-day period. This is probably unsuited to TREES because of the use made in TREES I of channels 3 and 4, not just NDVI for classification. This could prove to be a terminal problem for the use of the product in TREES II.

- **Mosaicking**
  Consideration must be given to the requirements of TREES whereby training sites must be related to images from similar dates in order that classification is not impaired. This is discussed further in section 3. It is not known how the IGBP product is handled in this respect. It may also be necessary to move this function to the products component, thus preventing the use of the product.

- **Projection**
  The IGBP product uses a Goode interrupted equal area projection which has not been used by TREES. However, reprojection is not considered to be a major problem.

Given the potential unsuitability of the final IGBP output product, the following trade-off study needs to be made:

- Is the IGBP product unsuitable due to the compositing technique and due to the fact that mosaicking is done before classification? What reduction in classification quality might result from its use? Is the possible reduction in quality offset by the savings made by using an external fully pre-processed product? Is re-projection feasible (given the large volume of the product) and what are the software and hardware implications for handling the product

If the outcome of the trade-off study is that the product is unsuitable, then a second option is to obtain a lower level or intermediate product from the same source, which has not been composited or mosaicked. It is known that ESA receive the Level 0 and the Level 1b product from EDC. Consequently, it can be tentatively concluded that an agreement with ESA to supply the Level 0 or 1b IGBP product to the TREES project should be made. It is also known that there are plans to reduce the data handling load by joining together contiguous images into orbit strips. This will be done by both the EDC and ESA supplied Level 0 data (with both being collated first at EDC and supplied to ESA). Thus the strip Level 0/1b could be supplied to the TREES project. ESA might also be tasked with supplying the most cloud-free strip during a three month period for appropriate locations.

Unfortunately, the Level 1b product content is much as the Level 0 and EDC have no plans to archive the more useful intermediate data set produced after corrections, but before compositing due to its very large volume. Consequently, even though the atmospheric and geometric correction may be appropriate to TREES requirements, they will not be available. Therefore, once the low level data are received, calibration, geometric and atmospheric corrections should be done using appropriate software. The operation of this software could again be done by ESA, as it is primarily an operational task. This assumes that the software has been developed to the state where an operator in (say) Frascati could run it routinely. A particular concern here is that control point selection is a procedure involving manual intervention.

Assuming that IGBP pre-processing does not meet TREES requirements, TREES II must plan to develop a software suite for the task. In order to permit standardisation and maintainability, it is strongly recommended that the software be fully engineered. The options here are in-house development or contracted development. In-house development could only be recommended if one of the TREES II team was experienced in software development to industrial standards and dedicated to the task. If the development is contracted out, then the JRC TREES team should specify the pre-processing. The latter option is recommended.

Since many of the pre-processing steps are widely used, the software itself is best derived by tailoring similar systems. This means that either the TREES I software could be upgraded or that systems such as the MARS SPACE or perhaps the EDC pre-processing software be used. In both of these latter cases, some customisation will be required. For SPACE, this means:

- **Atmospheric correction**
  During TREES I, contractors performing pre-processing were asked to apply Rayleigh scattering corrections only. SPACE also applies ozone correction and water vapour correction (both using a climatic model). SPACE could be adjusted to meet TREES I standards. However, there is some doubt as to the wisdom of the limited number of corrections applied in TREES I. This is taken up under research topics in chapter 3 and Section 6.2. Neither model applies corrections for aerosol.

- **Geometric correction**
  The SPACE coastline matching may need to be extended to cover non-European conditions with perhaps image chip type techniques used for areas far from the coast.

- **Compositing**
  The compositing module in SPACE would be removed.

- **Mosaicking**
  Mosaicking is also performed by SPACE. The training site consideration is the same as discussed for the IGBP mosaicking. It is possible that mosaicking will be moved to the products component such that classification is performed on individual images and the classified images are mosaicked.

The development of software to a standard which can be used for pre-processing on a routine basis either at JRC or by ESA, is not a trivial task. The necessary robustness, ease of use, maintainability, etc., requires an engineering approach. This must be carefully considered early in TREES II. A trade-off study needs to be undertaken to determine:

- the current state of SPACE software (note that re-engineering of SPACE software is currently being considered; additional requirements could be introduced now)
- the cost of changing SPACE software to meet TREES requirements by the TREES team or an external contractor
- the possible use of other systems such as the EDC software [1]

A further option might be to contract a commercial company to receive the low level data from ESA/EDC, then to select, atmospherically and geometrically correct and possibly mosaic the data for delivery to JRC. Various scenarios involving delivery of some intermediate form might also be considered where JRC completes the pre-processing. The major advantage is that JRC retain a very large element of control on the whole data preparation process, which might not be the case were ESA performing pre-processing.

[1] Other systems such as GEOCOMP might also be considered. Customisation would again be required.

Output Data - Cloud Free 1 km Composited Mosaics
The output from this component may be one of several data sets depending on the result of research (section 3) and the trade-off studies discussed above.

In the scenario where compositing and mosaicking is acceptable before classification, the output is a cloud-free 1 km resolution product containing appropriate visible NIR, IR and thermal IR band data. The area coverage should be of the tropics and selected boreal areas in mosaicked form (perhaps four files). The time period covered should be no greater than three months (TBC) from the first to the last image used in the mosaic probably in the second half of the year to catch dry season effects. It is expected that compositing of images will occur in order to locate cloud free pixels in a manner suitable to facilitate classification. Thus, the number of entries into the data manager (See section 2.3) will be of the order of ten per year.

In the scenario where the raw images are classified, then the output from this component is of selected images (or image strips) with minimal cloud contamination. The channels, geographic and time coverage are similar to the first scenario but the number of entries passed to the data manager will be significantly larger. This scenario significantly alters the activity required in different components with more functionality and effort required in images and products and less in data suppliers.

It should be re-emphasised that these outputs could be provided from one of a number of instrument data sources and that the discussion over AVHRR data pre-processing will also apply in some degree to these others.

In summary, the recommendations made are:

1 ESA should be the data supplier
2 An intermediate form from the IGBP processing at EDC should be the basic input
3 The pre-processing should be specified by the TREES II team
4 Pre-processing software based on SPACE should be developed by a software contractor
5 The pre-processing should be performed separately from the TREES II project
6 Further study of the options is vital

2.2.2 One-off Data Supply
The supply of various other data (see figure 3) has been separated from routine data for several reasons:

- the project must initiate requests for these data implying a two-way interaction with the suppliers

- the requirements for data will vary through time and some of the acquisition may be performed by the TREES project team itself.

Due to the diversity of requirements, it would be advisable to appoint a single person to act as point of contact to be responsible for the acquisition of these types of data into the TREES II project; i.e. a 'Data Gathering Leader'. This would ensure that the costs in terms of purchasing data (where applicable) and the liaison with outside bodies would be efficiently executed. In particular, where research activities require different data types from specific

TMP development would normally be the same, but could also be encouraged to coincide with areas of investigation for the TLP). In addition, consultation with other groups should be pursued in order that cost of data purchase or field work is minimised by pooling resources and/or sharing results. For example:

- ground survey undertaken by FAO as part of their national based efforts in forestry management
- field work undertaken by the Finnish forestry department for their own monitoring of national forests might provide important insight and background data for the BMP
- the many possibilities for cooperation in the formation of TLPs; e.g. INPE airborne projects, use of EARSEC project results. This point meets Technical Note No. 4 requirement 27.

Each of the data types which might be acquired by the Data Gathering Leader (DGL) are outlined below:

- The supply of TM images is well established and semi-commercialised. The DGL's role is therefore only to identify within the project which images are required (taking possible synergy into account) and then contact the European supply point - EURIMAGE. At the current cost of $4400 per image, the total cost for TM images is likely in the order of $44000 [2] (this assume approximately 10 images, a figure which is variable with the cost option scenarios discussed later).
- Ground surveys must be undertaken for all four main products. The costs are likely to be high and therefore the DGL must undertake a careful analysis of requirements including synergy between requirements and cooperation with other groups. The use of TREES II project staff in some field survey work is advisable in order that the JRC team builds up a realistic picture of real field conditions. Several potential users contacted by the survey expressed an interest in cooperating in this area.
- The acquisition and processing of spaceborne SAR images will be made by ESA from one of the ERS platforms or the Canadian Radarsat. The DGL's task is to coordinate requirements and liaise with the appropriate agency.
- Due to the nature of the TLP product and the cost of airborne survey, the TREES DGL will usually obtain airborne SAR data in cooperation with other programmes such as those run by INPE, SAREX and the EARSEC project. In this sense, acquisition is opportunistic and very highly dependent on prevailing programmatic, institutional and political situations. This points to the need for the appointed DGL to be aware of and competent in negotiation with a wide range of programmes.
- The data type marked in Figure 3 as 'Treaties' covers any and all political agreements made by relevant countries or organisations concerning forestry or related areas. Where such agreements are accessible in document form, then

[2] For LandSat 6, a significant cost reduction for TM images is expected

these should be obtained for use in the extended TFIS (product) element of the system. CIESIN is named as a source of some documents and a knowledge base for the existence and location of others. Other institutions such as the World Bank, and the Inter-American, Asian and African Development Banks might be contacted. A yearly search of such databases might be suggested. Once obtained, paper versions could be scanned into electronic format for use as auxiliary data with all products.

- Other reports are ad-hoc in supply and may be obtained from any number of sources; for example TREES consultants such as Myers and Lucas.

- Protected areas, tropical forest extent from other sources and population are all examples of spatial information which would form a valuable input to the proposed products. In particular, data on forest extent and type from other sources might be used in the development of classifiers. However, the major use of these data is to provide a backdrop to enable the interpretation of products. For example, TIP classes might be compared with protected areas boundaries. This is discussed further in Section 2.4.3. Some of these data have already been collected by the TREES I team. An on-going programme by the DGL to liaise with groups such as WCMC and CIESIN should be undertaken.

The role of the proposed CEO development must also be considered in relation to these auxiliary data; i.e. the development of non satellite data sets for user services element.

The DGL role is critical to the development of the system processes and to the enhancement of product value. Leadership for the routine data supply might also be handled in this role.

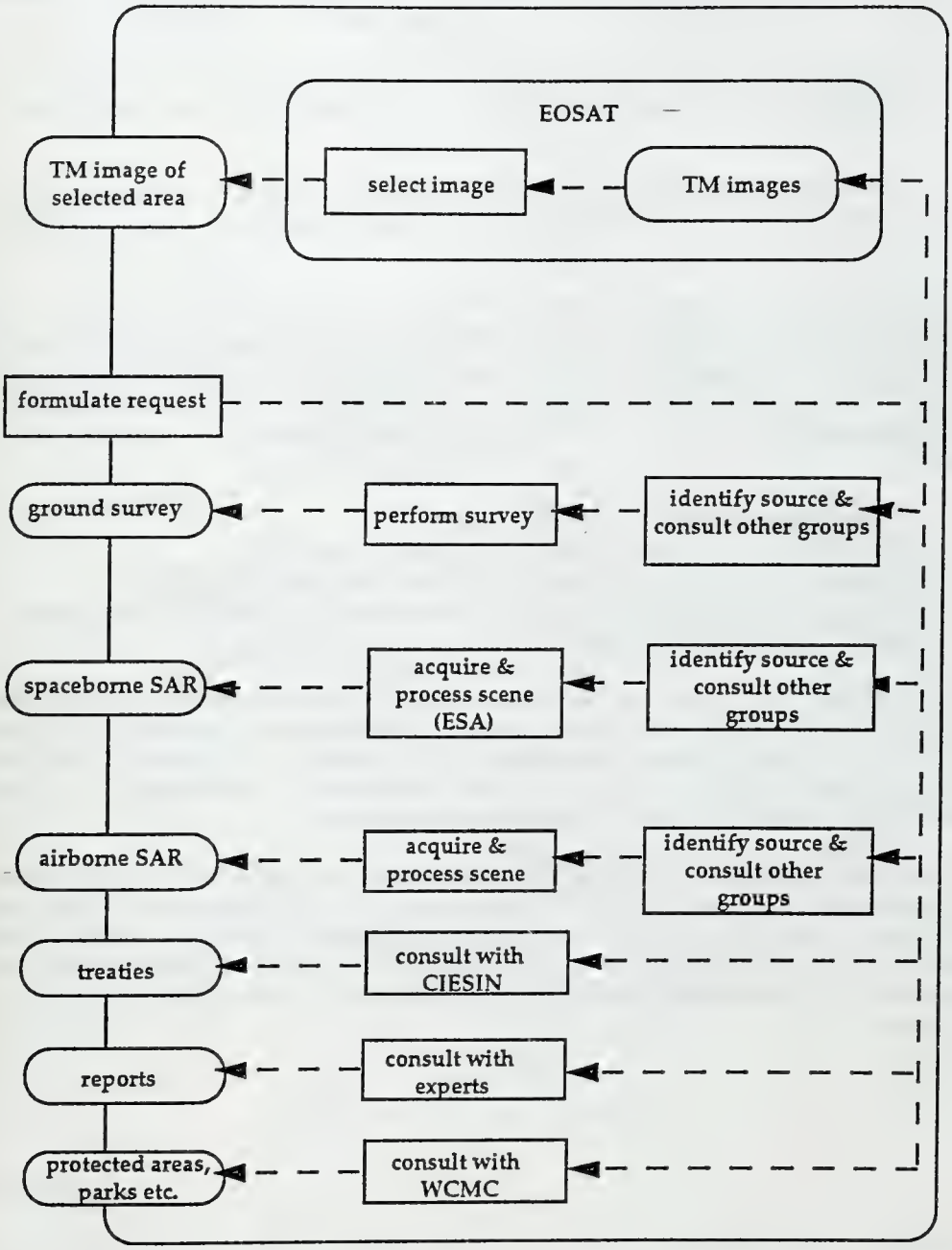


Figure 3 : One-off data supply

2.3 Data Management

Figure 4 indicates the various interfaces between elements of the proposed system. It can be seen that the pivotal element is 'data catalogue and archive'. The importance of this element arises because of the move towards a semi-operational system in TREES II especially:

- The requirement to maintain the integrity and value of data and products. This means that all data should be catalogued and archived with an appropriate level of metadata.

- The number of products, auxiliary and intermediate data sets will increase as the operationalisation of TREES progresses, necessitating central control of data resources.

This trend has been identified in the JRC MTV Unit and has led to the development of a prototype data management and browse system known as the 'Image Browse Information System' (IBIS). This system is being developed in part to service the TREES project. The proposed functionality of IBIS is adequate to service much of TREES II although if the system proposed here is implemented, then the following additional functions will be required:

- cataloguing and archiving of vector data sets
- cataloguing and archiving of electronic text based data sets
- cataloguing and archiving of hard copy text and graphical hardcopy
- association of hardcopy text, electronic text, graphical (h/c and electronic) in the database with a particular report title.

These functions are required to handle auxiliary data of all types, output products (especially statistical output) and output reports (which consists of several media types). Since IBIS is principally an image management system, some or all of these requirements might be better handled by extending the data management functionality of TFIS (see section 2.5) or by manual document configuration maintenance.

If it is decided to extend IBIS (perhaps for vector datasets), there are two implications. Firstly, consideration should be given to early discussion with the sponsors of IBIS such that functionality can be added as required and secondly, the role of a 'Data Manager' should be considered. This role might be MTV unit wide or specific to TREES. In either scenario, the importance of a Data Manager cannot be over emphasised in maintaining the value of project work.

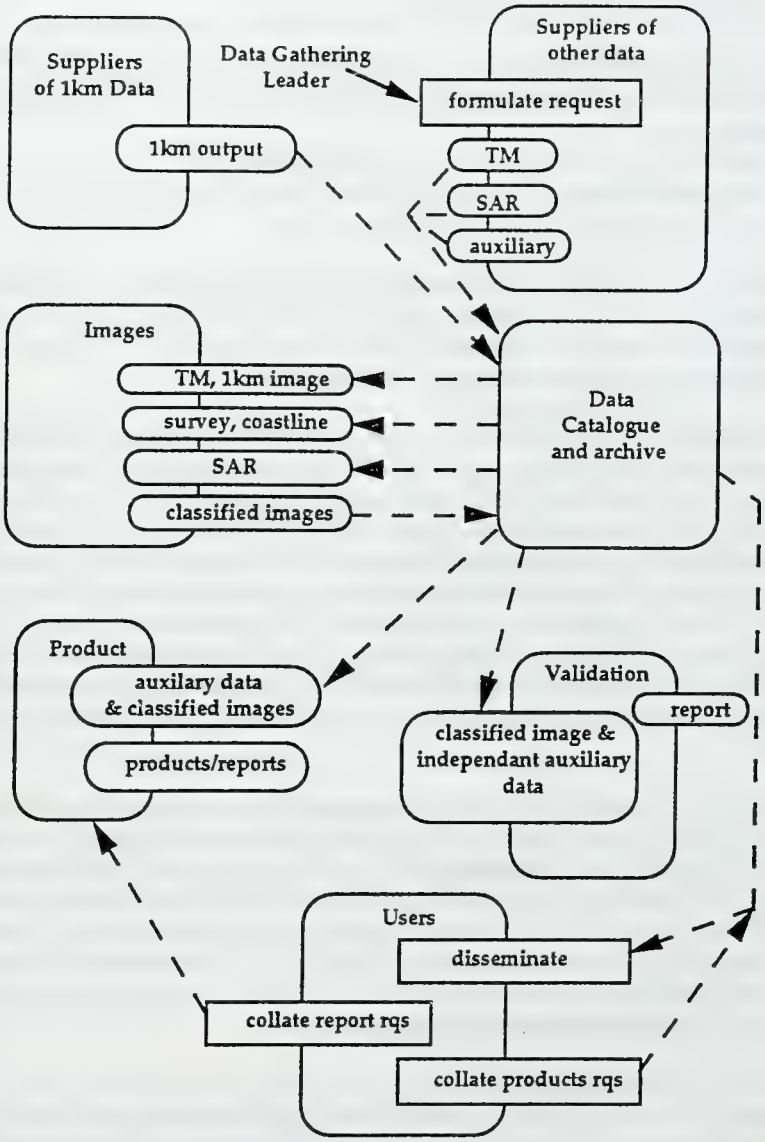


Figure 4 : System Interfaces

2.4 Images

One of the main areas of research during TREES I has been in the classification of images. This will continue to be a major component of TREES II both in a research and system sense.

The image component (Figure 5) comprises the assemblage of various images (AVHRR, TM and SAR) with ground survey in the classification procedure to produce a classified image (the coastline data set aids the classification process). In the case of the monitoring and inventory products (TMP, BMP, TIP, Figure 5) the major input is the 1 km product. For the

training of the classifier, the other inputs are auxiliary but once trained on a certain area (at least for the TMP), these are dropped and the classification process becomes more routine. There are a number of research subjects here:

- Should the classifier operate on a mosaicked product or individual corrected images (this is the driving study required to determine how the data suppliers component operates)?
- What form is the classifier; supervised, unsupervised etc?
- What part can be played by expert system and neural network technology?
- How often are test sites revisited for each product?

The internal structure of this component cannot be further developed until these questions are answered (see section 3, requirements R1,R2, R3, R4, R5). However, there are several important issues which must be considered in moving towards an operational system, whatever the precise form of the classifier. These issues are:

- The classification procedure is likely to be a mixture of manual and automated processes. In order that consistent products are created, the classification procedure must be clearly and extensively documented. The documentation must be oriented towards enabling non-experts to operate the procedures. The level of skill, experience and supervision necessary to operate the procedure must be stated since it is anticipated that as operationalisation proceeds then the system will be gradually handed over to non-specialist operations staff. In addition, the time required to classify each image or mosaic needs to be estimated so that overall time to produce classified images to meet image requirements can be calculated. This is critical to the management of the whole system and its ability to output products to the prescribed time-table.

- The software in the 'images' component interfaces to data management (Figure 4). The interface of the IBIS system must be available to that system on which the classification procedure is operated such that the image or mosaicked products can be extracted and classified image returned to the archive. The inventory must also be updated. The classification procedure itself may be executed using a standard package configured to the determined procedure. It is important for procedures operated frequently (e.g. for TMP classification) that the software is optimised to minimise load on the available hardware platform.

For TMP, BMP and TIP classifications, the 1 km product forms the basis of the output image. Depending on the mosaicking scenario, the output will be a classified image or a classification of a continental or regional scale mosaic. For TMP and BMP this will be:

• AVHRR	S.E. Asia	forest:non-forest:other
• AVHRR	Africa	forest:non-forest:other
• AVHRR	S. America	forest:non:forest:other
• AVHRR	(eg) Siberia	forest:non-forest:other

For TIP:

• pan-tropical	regions/nations	multi-class

Figure 5 shows the structure of the TLP component. The major difference is that the base data are a TM scene, which is supplemented by SAR and/or ground survey. In addition, since the TLP is less routine in production, the classification procedure is likely to be more ad-hoc and involve an expert on an ongoing basis. Therefore the importance of specified procedures is less. The content of the product is highly variable and will depend on the inputs available.

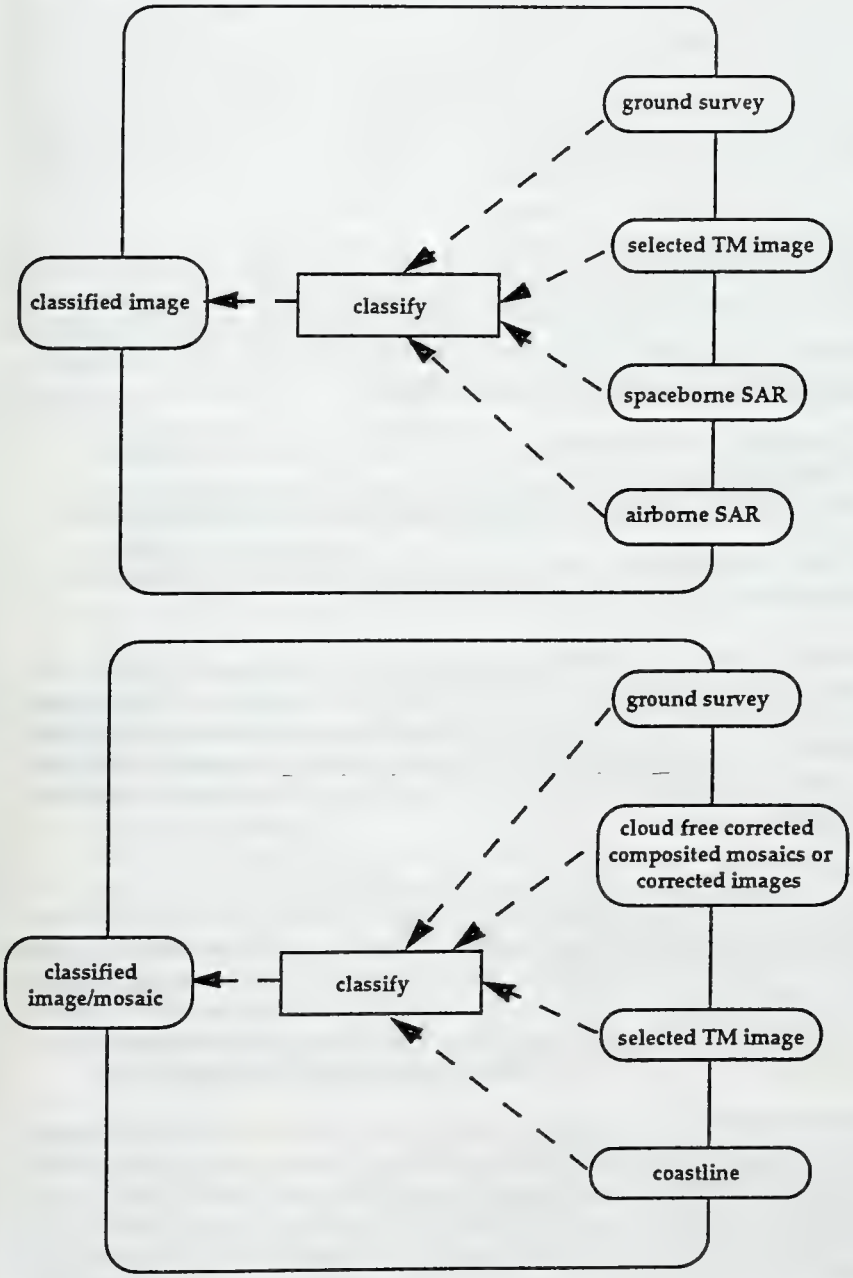


Figure 5 : Images Component
(a) top: TLP (b) bottom: TMP, BMP and TIP

2.5 Products

The 'products' component is similar to the system developed in TREES I known as TFIS. However, in moving towards an operational system, the functionality of TFIS will need to be significantly expanded.

This component has two roles. In the short term, it will assist in research into classification criterion for all products by providing a platform for comparing experimental classifications with auxiliary data (for example WCMC tropical forest atlas data). Its more general and longer term function is to synthesise the various input sources (including non-satellite data) into forms suitable for output as the products and to provide an information system supporting expert analysis. The current TFIS has some functionality, but it will need to be significantly enhanced in order to be able to output products and support interactive consultation. Specific functions are outlined below.

2.5.1 Area Analysis Function

The functionality required is to return area extent per nation for each class for the classified TMP, BMP and TIP products. This function will use the coastline, national boundary and other auxiliary maps to overlay with the classified TMP, BMP and TIP images. The output will be the number of km^2 of each class by area. Sub-national areas may also be analysed in this way if large enough. Three preparatory stages are implied:

- all image and auxiliary data will have to be matched to a standard coastline - probably DCW; this is a major task
- all images will have to be transformed to an equal area projection before area coverage is output
- the minimum size of nation/area which can meaningfully be analysed in this way must be determined (see section 3, requirement R.8).

The normal GIS function of ArcInfo available through AML are sufficient to enable the auxiliary and image data to be combined to produce the appropriate statistics. This is done by rasterising the vector national boundaries and producing classes from the resulting raster overlay. It would therefore be useful to prepare such a raster version of appropriate tropical and boreal areas to enable the analysis to be performed quickly. This analysis is required for TMP, BMP, TLP and TIP.

2.5.2 Change Analysis

Change in this context means identifying specific areas where changes in boundaries or the patchy degradation of forest is particularly marked. Whether such changes can be monitored in either TMP, BMP or TIP products is unknown (see section 3, research topic R.9). The basic process is that of matching the current with the previous classified image. Output should be in the form of 'active area' analysis; i.e. identification of the area where change exceeds critical thresholds. Specific investigations are covered in section 3.

Once these questions are answered, the overlay of current with previous classified images using ArcInfo functions will enable changes to be highlighted. The overlay of two raster images (e.g. TMP from consecutive years) produces an intersected raster image. The vector version of this image contains 'change polygons' which can be analysed automatically or interactively to reject polygons which are unlikely, spurious or too small to be significant (eg. changes at the scale of the registration accuracy). Where meaningful polygons remain then these can be output in the form of large scale hardcopy maps of the areas showing

changes with boundary changes or patchy degradation indicated (i.e. the AAR). The functionality to perform this type of analysis can be developed in ArcInfo.

2.5.3 Interactive Consultation

The TMP, BMP, TIP and TLP products can be produced in a relatively mechanical way. The AAR and EAR however are the output from an interactive session with TFIS. The EAR in particular results from an examination of all other products and combining these with other non-spatial information. It should be possible to pan in and out to TMP, BMP, TIP, TLP and AAR in order to examine particular features. Where non-spatial data such as treaties or reports are in electronic form, then presentation on the screen with the spatial data should be possible by associating text pages with polygons (see CIESIN GREENpages for example where pages of treaty information are linked to nation polygons so that spatial and textural information can be presented and viewed together). The resulting hard copy output should form a central part of the expert's report the rest of which is prepared using non-electronic external sources such as reports, newspapers etc. (see EAR illustration in Technical Note No. 4). Association of text with, for example, national polygons is possible in Arcinfo although additional AML programming is required.

A number of auxiliary data sets could be gathered for use in producing EARs. For example, CIESIN allows access to the following:

- FAO comprehensive demographic estimates and projections
- Global change encyclopaedia (GEOSCOPE)
- Global ecosystems data
- UN demographic yearbook
- CIA world factbook
- GEMS/Food
- Global environmental policy database
- UNCED collection
- World resources database (WRD)
- World demographic estimates and projections (1950-2025)
- Demographic indicators (1990)
- Sex and age (1990)
- Interpolated national populations (1950-2000)
- Interpolated populations by sex and age (1950-2000).

The EPA (NGDC) has recently released two CD-ROMs containing a wide range of spatial data including:

- FNOC elevation, terrain and surface characteristics
- Terrainbase (an updated ETOP05).

The overlay and mosaic functions require some development although both are straightforward. A further function not found on the figure is product management. Section 2.3 indicates that additional functionality in terms of cataloguing and archiving of multi-media reports is required. This may best be met by development of the INFO capabilities of ArcInfo.

Non-functional Development

As TREES II progresses, the products component will change its emphasis from being a support tool for classification to being a product producer (and possibly a data manager) and then an interactive tool for experts to use. As this occurs and users become more involved, there will be opportunity physically to disseminate the component to other sites. In this scenario, one might see TMP, BMP and TIP products being routinely produced by the TREES II team at JRC but then disseminated to two or three sites where the extended TFIS will be used by others further to analyse the products and produce AARs, EARs and other outputs. These other sites could be Universities, the CEC, WCMC or more far flung users. Obviously these users would require ArcInfo and associated software and hardware facilities. The fully operational TREES III could be seen as an even more distributed version of this scenario.

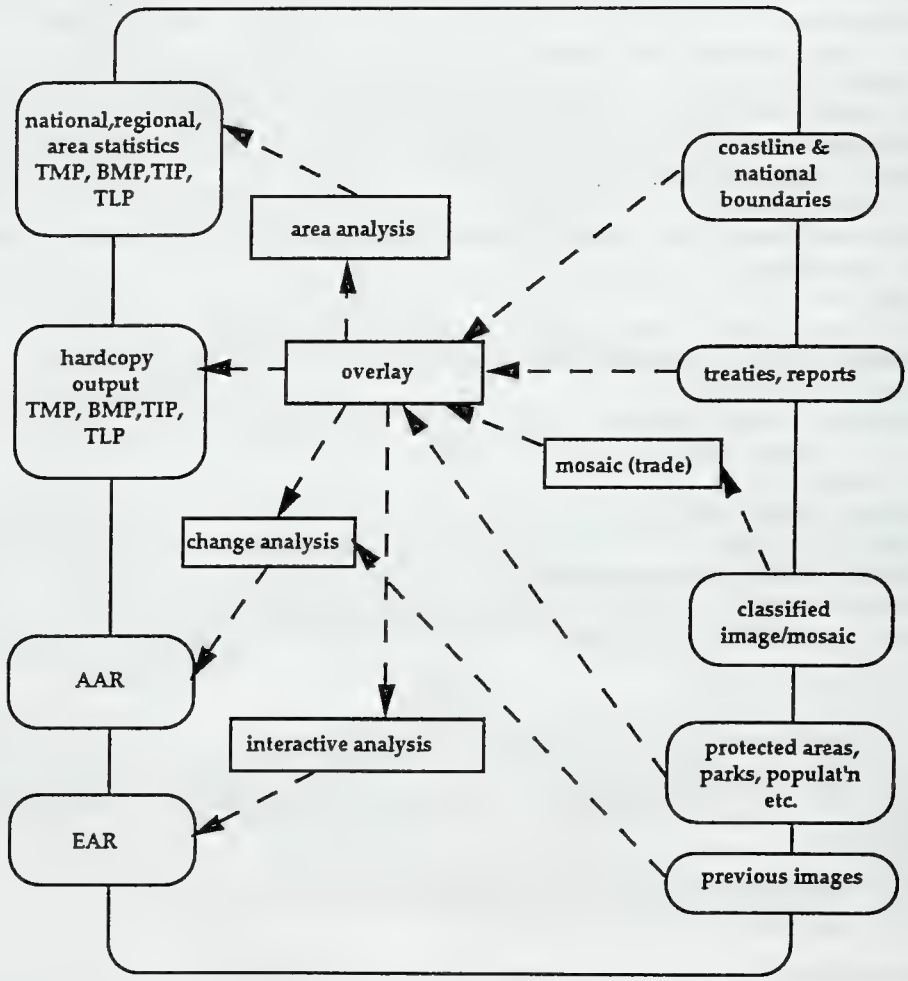


Figure 6 : Products Component

2.6 Validation

A validation exercise (Figure 7) was carried out in TREES I involving TM and ground survey in S.E. Asia. It is necessary to identify such a component for TREES II for several reasons:

- one of the major distinctions between a research programme and an operational system is the need to provide independent and on-going validation of product quality
- to separate and hence avoid confusion between ground survey and TM data collected to train the classifier and that collected to validate the classification.
- clearly to identify 'validation' as logically separate from other parts of the system and which may therefore be performed by a separate group and/or perhaps on a different physical site.

Validation applies primarily to the TMP, BMP and TIP products. The input is each product in turn. The comparison function uses the independent data from one or more sources:

- Ground survey data which may have been collected at the same time and from similar sites as the training data but was not used to develop the classifier.
- TM images; either those used in training (using different sub-images) or different TM images altogether. It is assumed that visual interpretation of the TM images would provide classes appropriate to the product being validated.
- Data from external sources such as the WCMC tropical forest data or the FAO statistics (compared for example to TMP statistical tables).

The comparison function itself should comprise two types of procedure:

- Visual comparison between hardcopy map output and point values from ground survey, TM interpretation or maps from external sources (which would probably not be global in extent).
- Use of TFIS functions to overlay products with map data from external sources appropriate to the time period of the product. Since TREES provides the only global product, there are no external global sources regularly updated. However, suitable maps produced through the 1990s should be collected if possible into electronic form.

Careful consideration must be given to the significance of such comparisons in relation to statistical sampling theory and the quality of the independent data.

The report generated should detail the comparison made and discuss implications for the classifiers used in producing the product. Where the validation report shows mismatches between independent data and products, then a decision is required as to whether the product classifier should be re-assessed. Factors influencing this are:

- the size of the mismatch - is it inside or outside the tolerance of the product

results

- the significance of mismatches varies between the TMP, BMP and TIP; in particular it may be considered more important to maintain consistency in the monitoring product over time than make fine adjustment.

There is a great deal of overlap between the functions of this component and those in products and images. Once sampling and statistical questions are solved, the development of this component should therefore be straightforward. Despite this, it must be considered vitally important. In addition, it may be possible to involve users in validation work; i.e. supplying products in exchange for validation data. Technical Note No. 3 contains comments from users to this effect.

This component will always require expert input in the interpretation of the comparison report. This, and the fact that independence of operation is required, points to the eventual separation of validation from the rest of the system. For example, validation could stay at JRC when TREES III goes to an operational site.

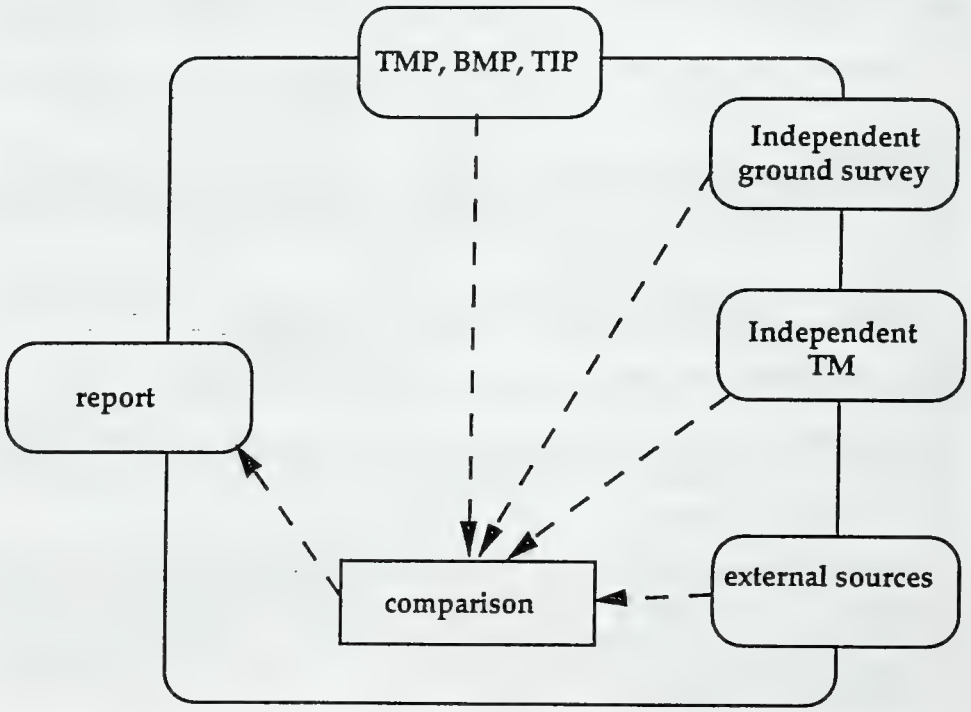


Figure 7 : Validation Component

2.7 Users

One of the most important considerations in moving from TREES I research into TREES II semi-operation is to establish a clear link with the users of the products. A component has therefore been identified which encapsulates users (see **Figure** 8) and the functions necessary to relate the TREES II system to them.

The collation functions are split into those for products and those for reports. The first might consist of responses to publicity. A yearly flyer indicating the availability of TMP, BMP, TIP and TLP during the year ahead could be produced and posted to all respondents from the user survey (Technical Note No. 3). The flyer would indicate product availability and form. Responses to this could be serviced quite simply (also see discussion on dissemination below). TLPs may be produced on a more ad-hoc basis, although this is likely to be driven at a programme level by instrument and data availability than directly by user request.

The collation of requests for reports is more problematic since some degree of interaction and choice of area is required. It is likely that a small number of major users would retain contact with the project and that discussion of results from the products would generate requests for specific reports. For AARs, requests could be serviced by TREES project staff while for EARs, an outside expert from one of the user groups (or an independent expert) would interact directly with TFIS.

The monitoring of feedback from users is a critical procedure during TREES II. This will enable the team to be kept in touch with their users and build up a realistic picture of what is required.

The disseminate function could consist of one or more of the following:

- distribution by mail of hardcopy maps and statistical tables (TMP, BMP ,TLP and TIP)
- distribution by mail of paper reports (AAR, EAR)
- distribution on electronic media (e.g. CD-ROM, floppy, network) of ArcInfo (or other GIS) format graphics and statistical tables for use in users GIS (TMP, TIP and BMP)
- distribution on electronic media (e.g. CD-ROM, floppy, network) of selected statistical and graphical information in hypertext formats for use in non-GIS applications.

The most important of these will probably be the traditional map format output. This is particularly to meet Technical Note No. 4, requirement 26. Figure 9 shows how many TIPs would be produced in terms of map sheets at 1:1,000,000 for Africa; while Figure 10 shows the level of detail which would be shown on the A1 map sheet at the same scale. Similarly, TMP coverage at 1:5000,000 is shown in Figures 11 and 12. The BMP would be similar. The TLP and AAR may be produced as a large format graphic at 1:100,000 as illustrated in Figure 5. in Technical Note No. 4. The EAR may be simple A4 text and graphic documents containing pages as illustrated in Figure 6. in Technical Note No. 4.

The electronic versions of TMP, BMP, TIP and TLP could be produced in vector format in one of several GIS formats; e.g. ArcInfo, SPANS, ILWIS or ASCII. Statistical tables would be in ASCII. Non-GIS display systems could be supported although the volume of graphical data would probably preclude full resolution display.

User Development

It is critical to TREES II that products are used. In particular, routes for dissemination must be developed. It would be advisable to develop the user component as follows. A number of pilot users should be identified. These should include at very least two sophisticated user (having their own GIS); two unsophisticated user (requiring paper products) and two from an intermediate category (having PC range machines). Interim products output by the project should be forwarded to these users in several of the formats suggested above. Close contact should be maintained with this user group which would have perhaps 12 members. Comments should be sought on products and a sub-set of users could be invited to review meetings at periodic intervals. Such meetings might be hosted by JRC or another body such as WCMC or the CEC. This feedback from users is a critical element of TREES II. In particular, this feedback will enable the team to understand which of the requirements met by each product is more or less important to users. This will help the team to continue to develop and refine the product specifications and to maintain a realistic understanding of the requirements.

It is recommended that this work is at least partially undertaken by outside experts with user contacts. This would lead naturally to the splitting off of the component as TREES II matures and TREES III (fully operational) is considered. The collation of orders, dissemination of products and monitoring of feedback might then pass to a separate body.

A second major development aim may be met by the proposed Centre for Earth Observation (CEO). Access to the CEO is planned to be via networks and interoperable catalogues. Users will dial in, see what data are available and possibly retrieve data to their own site across international networks. Should TREES II be linked to the CEO network then there is a clear opportunity for disseminating products via this route. The link between the TREES system and CEO would probably be via a shared data management and browse function such as that represented by the component discussed above. Such a link would enable the TREES II team to assess the usefulness of different electronic formats (e.g. GIS standards). The types of users would be those classed above as sophisticated and intermediate.

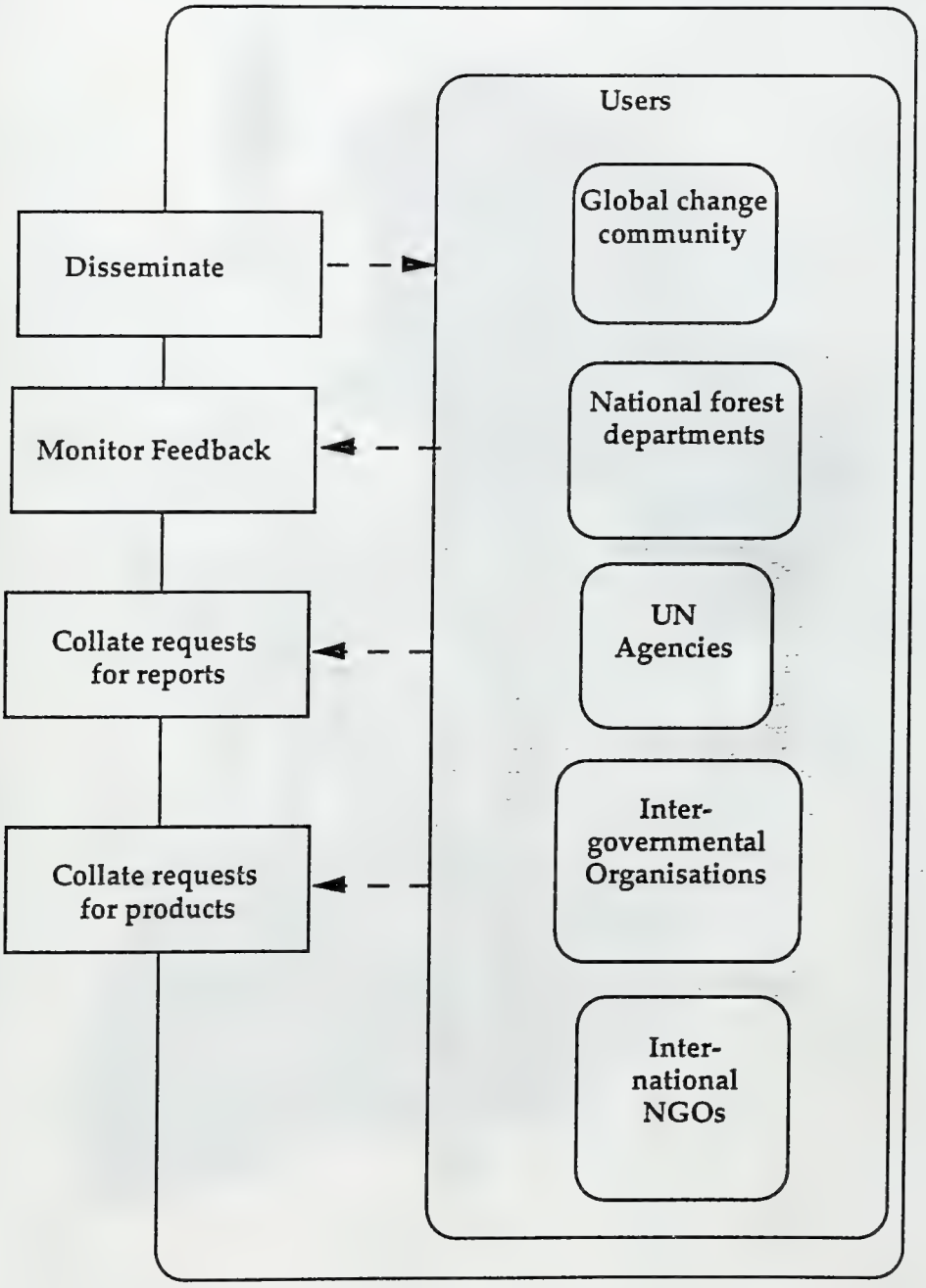


Figure 8 : User Component

Figure 9 : A1 Maps Sheet Coverage of Africa at 1:1000,000 (TIP)

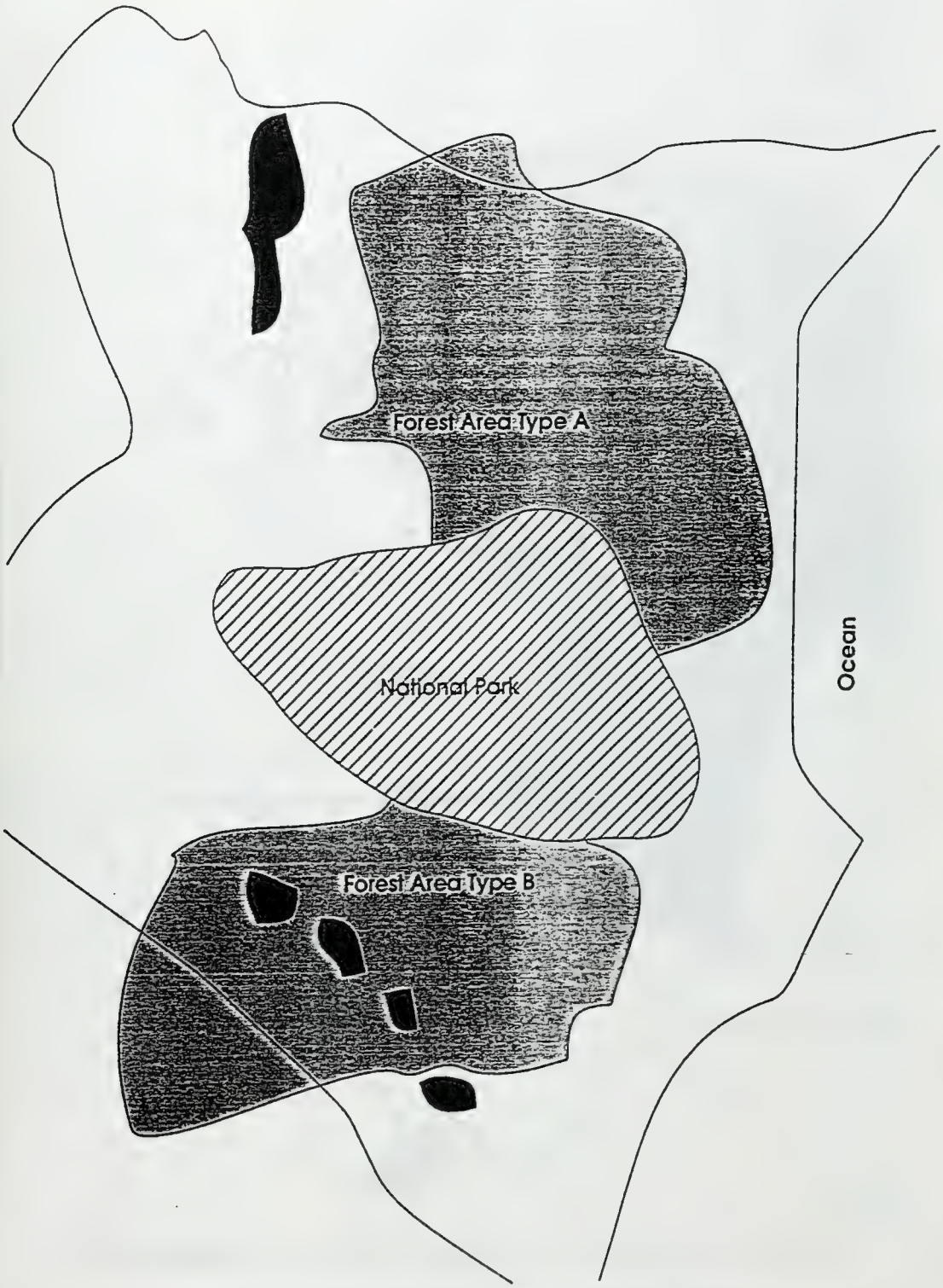


Figure 10 : Details Level for A1 Maps at 1:1000,000 (TIP)

Figure 11 : A1 Maps Sheet Coverage of S America at 1:5000,000 (TMP)

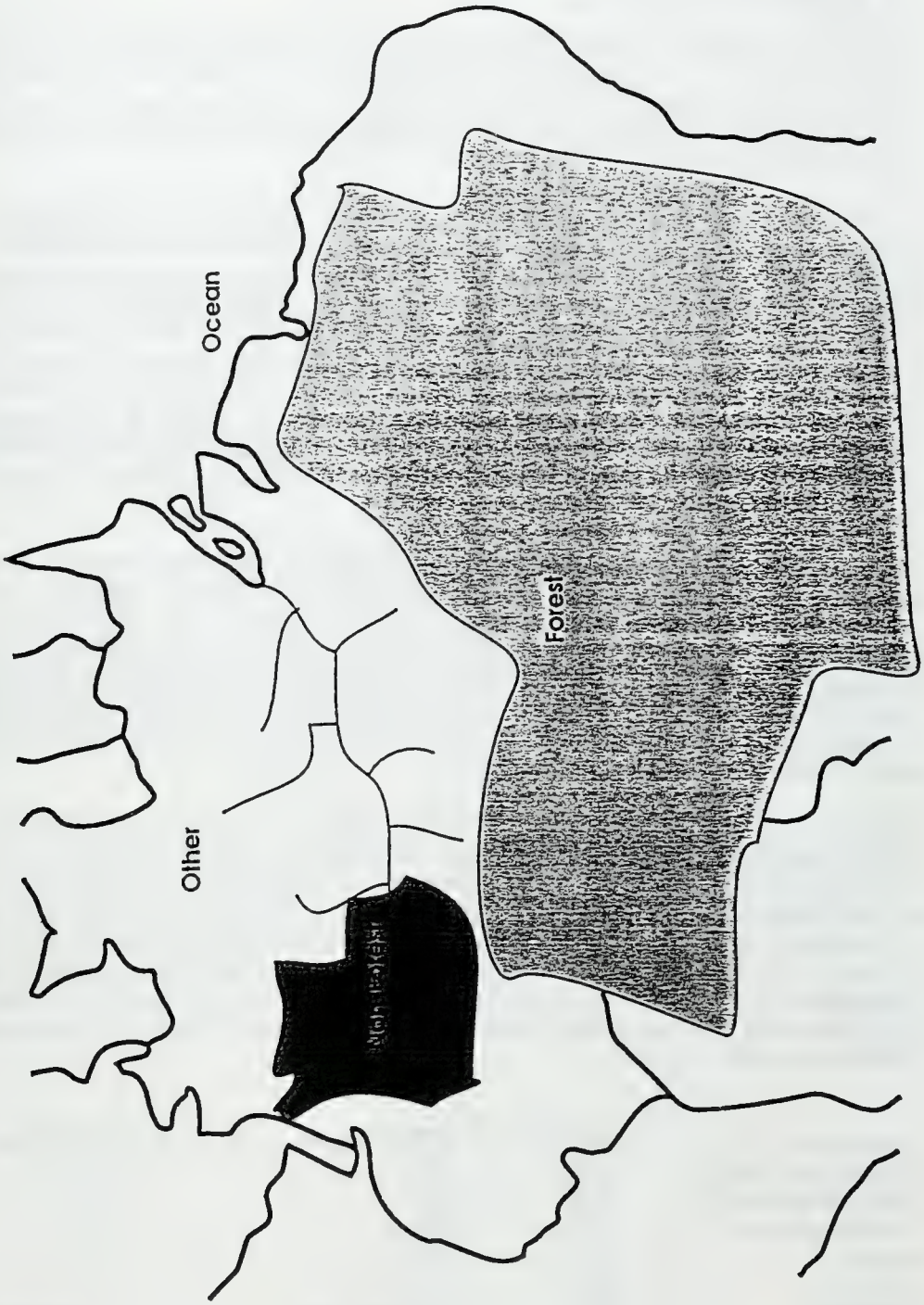


Figure 12 : Detail Level for A1 Maps at 1:5000,000 (TMP)

2.8 System Development

Figure 4 showed the system as a whole with data flow between components. As already noted, a number of components (both suppliers, images, products) have been partly developed during TREES I. The data management and users components are proposed to complete a system view. The question now arises as to how these components should be developed during TREES II.

Most of the research activity is centred on the image component and as such the resolution of research issues must be seen as a main driver on the timetable for development. In particular, the classification procedure used will determine the functions required in routine suppliers and products in respect of mosaicking and compositing. In turn, the use or not of mosaicked products input to images will determine the load on the data management function; with load increasing massively if raw images are ingested by the project. Similarly, the extent to which images received by the project can be pre-processed (i.e. atmospheric and geometric corrections) will determine the extent of the procedures required. Source independence (looking to MERIS and 'Vegetation') is an important factor to consider in these decisions in order to avoid the danger of building a system too dominated by the peculiarities of AVHRR.

The two components 'routine data supplier' and 'images' should therefore be carefully considered. Reasoned decisions need to be made before the development of other components goes ahead. The development of the products and data management components is the second priority. The existing functionality requires enhancing as described in Sections 2.3 and 2.5. However, the extension of TFIS to support classification work should be the higher priority of the two. Validation and user components are the lowest priority in the short term although it must be stressed that these components are critical to the operational TREES system.

The point made in the introduction to this chapter that components analysed in this way could be distributed must also be considered. The removal of routine data supply from the TREES II team has been recommended. However, other components, notably validation, products and users have also been discussed in this light. The latter two in particular ought to receive attention as candidates for separation in the sense discussed in the individual sections; i.e. the duplication of the enhanced TFIS (products) to other sites to enable higher level information products to be derived by users and for the user component, the involvement and guidance of user oriented groups. In summary, a scenario for component distribution might be:

Component	Current site	TREES II site	TREES III site ?
Routine data supply	JRC	ESA ?	ESA
One-off data supply	JRC	JRC	CEC
Data Management	JRC	JRC	CEC
Images	JRC	JRC	CEC
Validation	JRC	JRC	JRC
Products	JRC	JRC/multiple	CEC/multiple
Users	none	JRC/expert group	expert group

The final point to be made concerning system development is the need fully to document the various components. The component breakdown proposed here could easily form the basis of a document. Important elements to include are:

- results of trade-off studies, especially those into the source of AVHRR data, pre-processing steps, the load on the data management component etc.
- a plan for the acquisition of auxiliary data for both the training of classifiers and the interpretation of products which must be related to product outputs
- requirements statements for the software functions required of IBIS and TFIS over the TREES II development period
- classification procedures (as in Section 2.4).

A high level development plan for components is found in section 5.

3.

Research Requirements and Recommendations

3.1 Introduction

Research areas were identified in general terms in Technical Note No. 4 following each product description. The following list outlines these areas and assigns a reference number to each which is then used in subsequent parts of this report:

Research topic	Ref. number
• Decision on the classes to be contained in TIP	R.1
• Derivation of classification techniques and rules for TMP	R.2
• Derivation of classification techniques and rules for TIP	R.3
• Derivation of classification techniques and rules for BMP	R.4
• Selection and use of training and test sites for all products	R.5
• Methods for improving registration accuracy between images, and between image and coastline/national boundary data	R.6
• Determination of appropriate projections for production of areal statistics	R.7
• Methods for determining accuracy and precision of areal statistics	R.8
• Methods for determining accuracy of boundary locations	R.9
• Methods for determining change detection	R.10
• Methods for segmenting SAR data	R.11

In the following sections each research topic is discussed in turn.

3.2 Research Topics

3.2.1 Decision on TIP classes (R.1)

This is an important component of TIP production. The classes actually required by users which are also feasible to extract from the data need to be established before any serious classification work can be undertaken as defined in R.3. The product specification given in Technical Note No. 4 (Section 4.4) indicates that evergreen, seasonal, and degraded and secondary forest are required. This list needs to be refined and its applicability to each of the three tropical forest regions needs to be examined. It is suggested that a short consultancy project is initiated which would report during the first part of Year 1 of TREES II. The consultants should be a mix of those with tropical forest experience and those with remote sensing experience. The output from this consultancy would be a set of classes for each tropical region to be included in the TIP product.

3.2.2 TMP Classification Technique and Rules (R.2)

TMP is intended to be a rapidly produced and disseminated product. Using data collected over the period of a year a forest:non-forest classification is produced with areas containing cloud (or corrupted for some other reason) flagged as unclassified. Areal statistics are then

derived on a national and regional basis, with hardcopy maps produced at 1:5,000,000 (see Technical Note No. 4, Section 4.2). An accuracy of 80% in the classification is required.

In order to achieve this goal there must be a trade-off between classification accuracy and speed. A classifier must be used which does not require extensive user interaction and ground survey. To this end the classifier must be simple and use replicable rules which do not have to be drastically modified from year to year.

The goal of this research topic will be to determine the classifier which best meets these requirements. It should be noted that the majority of previous research into classification techniques has focused on the production of the 'most accurate' map. For the purposes of this research the 'most accurate' is not necessarily the best; i.e. the 'most consistently repeatable' is of equal importance.

The research should be carried out on an empirical basis by testing a large variety of classifiers on areas for which there is sufficient data for validation and which a forest expert could help locate The most reasonable set to use would be the data collected for TREES I since these are readily available, familiar to the researchers, and have sufficient supporting data. It is envisaged that the optimum classification procedure might not be the same for each of the three continental tropical regions (although it would naturally be desirable) due to floristic differences, so that test areas should be selected for each of these regions and analysed separately.

In examining various classifiers the researchers should consider the impact of reducing the number of bands and/or the number of scenes required. Processing costs are likely to be substantially reduced if fewer scenes are required. Simplicity and speed are improved by reducing the number of bands. However, if imagery from a particular date is required the research should establish how sensitive the classification would be to the precise date, in the event that data would have to be used from an alternative date.

Kuntz and Kleinn (1993) describe the relationship between the percentage of an area identified as forest, the pixel size, and the percent of a pixel occupied by forest. An appropriate percent pixel occupied by forest, which implies that that pixel is classified as forest, needs to be selected to correspond to the imposed pixel size of 1 km. This also relates to the work of Cross, et al (1991), into the application of mixture modelling techniques to forest cover classification using AVHRR. One of their findings was that AVHRR data tended to underestimate forest cover, particularly in areas with large numbers of pixels of mixed cover.

It is suggested that the following classification procedures be examined, although this list is not intended to be exhaustive or prescriptive. All of these techniques are known to researchers in the field and are represented in the literature.

1. Simple Threshold of Band 3 (Thermal)
Band 3 has been shown (see Technical Note No. 2) to provide the best basic forest:non-forest discrimination. Would a Band 3 threshold provide sufficient accuracy in all the regions, and how dependent would this be on the date of the imagery used?

2. NDVI
While NDVI is known not to provide good tropical forest discrimination (see Technical Note No. 2) its use in provision of a simple forest:non-forest product should not be

neglected. The variation in NDVI over a season is known to provide phenological information which could be input into a classifier. Calibration problems are reduced since the basic measure is a normalised index. However, to be of use, it is probable that data from at least three dates would be required in order to determine the seasonal variations. For the TMP which is dependent on data collected over a very short time period, it may not be realistic to rely on a classifier which requires several images. Being NDVI based, the IGBP product should provide insight here.

3. Simple Box Classifier using Bands 1-3
This has been used with some success by INPE and may well be adequate for the accuracy levels required for this product.

4. Ratio/Combination of NDVI and AVHRR Band 3
Various combinations of NDVI and band 3 data could be examined to see which offers the best discrimination.

5 Supervised Maximum Likelihood
This should be examined with a variation of bands and number of images. The selection of training areas has always been a difficulty with this classifier, since the training area statistics have to follow a normal distribution which is not required of the box method.

6. Unsupervised Clustering Procedures
TREES I work has already established the utility of this unsupervised classification (see Technical Note No. 1), however no work has been undertaken on attempting to determine whether a sub-set of bands/images would provide equally, (or sufficiently satisfactory) results. The difficulty with unsupervised methods is that many classes are produced which must then be labelled, requiring considerable user-interaction. For a product containing only two classes this would be a considerable burden since typically an unsupervised method may produce about twenty initial clusters. The supervised maximum-likelihood method would probably be less user-intensive for the TMP product.

7. Mixture Modelling
This technique has been applied with some success to forest mapping with AVHRR data (Cross, et al, 1991). While the technique has been shown to improve classification accuracy its application for the TMP classification may be too time-consuming to be useful. Expertise in Neural Nets is available within IRSA.

8. Neural Nets
For a fast procedure which only requires extensive user intervention in the preliminary 'training' phase the application of neural nets to the production of the forest:non-forest classification should be seriously considered.

9. Visual Interpretation
This is an interpretation technique which should not be underestimated. The problems with visual interpretation are replicability and consistency. However, it is a rapid and low-tech method which in this case might prove to yield results that are sufficiently accurate for the requirements.

The result of the research described above will be a report (Section 5.3) which indicates for each classifier the accuracy, man-hours, CPU time and robustness (e.g. sensitivity to precise dates of imagery or sensitivity to which bands are used). From these results it should be

possible to select a maximum of two potential classifiers which could then be used for preliminary TMP production. Results from assessment of this product could then be used to select a single classifier for each region which would be used for operational production.

3.2.3 TIP Classification Techniques and Rules (R.3)

The research issues for the TIP classifier have much in common with that for TMP in that a simple cost-effective procedure should be found. TIP differs from TMP in that more classes are derived (as defined from results of R.1), and the time-scale is three-yearly rather than annually. The emphasis in the procedure is therefore less on speed and more on accuracy. Further, the procedure is assumed to utilise input from TM data and to some extent from ground survey. Nevertheless a classification scheme needs to be selected and then used repeatedly, rather than selecting a different procedure each time the product is made.

The specific classifiers to be examined should be those used for the TMP evaluation (see Section 3.2.1), although it seems unlikely given previous research experience that the simple threshold methods would prove adequate. More attention should therefore be paid to the maximum likelihood, unsupervised, mixture modelling, neural nets and visual methods, and to variations in these.

The result from the investigation would be a research report along similar lines to that produced for the TMP classifiers showing which method was likely to provide the best results for each tropical region.

3.2.4 BMP Classification Techniques and Rules (R.4)

The BMP product is similar to the TMP, but is produced only for Siberia. The classification methods to be used must be investigated in a similar manner to the TMP classifications in order to establish the quickest and least user-intensive procedure to derive a forest:non-forest classification at 80% accuracy.

It is suggested that the same classifiers be investigated as for R2 and R3. The use of NDVI is expected to provide better results for this area than for the tropics and should receive more attention. This may be particularly important since cloud-free data are more likely to be available so that use of a time-series of data may be more feasible than for the tropics. Although it must be remembered that data will only be available in the summer months when there is sufficient light.

For the Siberian region there are no TREES I data available for testing, so data will have to be collected during the first year of the project. This may also include some TM data for provision of validation. An alternative would be to collaborate with the already extensive Scandinavian research, especially that of Tomppo of the Finnish Forest Research Institute, and use their data for derivation of a classification procedure which could then be tested on Siberia. The Finnish research involves extensive ground validation, and the use of both AVHRR and TM data, so that there should be a wealth of test data.

The result of this investigation should be a report along similar lines to that produced for TMP.

3.2.5 Selection and Use of Training and Test Sites (R.5)

An important issue is the use of training sites from year-to-year. All the classification methods require that some threshold is chosen, or some labelling is carried out, so that there must be areas whose class is 'known'. It is clearly desirable to have a minimum of these

sites so that field survey and checking can be minimised. Further, it is desirable to use the same test sites for as long a period as possible to minimise the effort involved in their selection.

The TMP/BMP classification is produced annually and requires a minimum of user interaction. There is insufficient time to visit test sites and undertake extensive checking, so that a set of sites needs to be chosen whose classification is unlikely to change each year. For the TIP classification there is a three year time-frame so that field survey and/or use of TM data for checking is possible. To minimise effort, the TMP sites must be a sub-set of the TIP sites which are likely to remain unchanged over a three-year period. The classification of the TMP sites would be checked every three years. These sites need to be chosen in the expectation that surface cover will not change over three years. The BMP sites should be equally stable.

An additional problem is that sufficient sites must be available to allow threshold selection/derivation of training statistics/class labelling (according to which classification method is used) over the whole of a tropical region. In an ideal situation, with infinite time and money, there would be a set of sites for each AVHRR image (or strip section). This would require a dense site network, since from image-to-image the actual ground area covered will obviously vary, or it would require site selection after the imagery was obtained (as was the case for the TREES I work). For an operational product it is not realistic to keep re-selecting sites, nor is it feasible to select the sites after the data have been obtained. It is therefore suggested that some research effort be expended in determining a minimum number of suitable sites which are sufficiently dense to allow separate classification of each image. For the TMP/BMP data this would be a set of sites which are clearly 'forest' and whose classification is unlikely to change in a three-year period. For the TIP data a similar set would be required covering every class and well spaced across the region. Again the assistance of a knowledgeable botanist would help.

An additional consideration here concerns the relationship between the number and location of ground survey sites and the spatial extent of the images making up the input. Mosaicked images reduce the data handling load but create difficulty in associating sites with single date sections of the mosaic. This has been noted in Section 2.8 on system development as a major study point since it influences the design of several elements.

In the foreseeable future the major data source for TREES may switch from AVHRR to an alternative source (see discussion in Section 2.1.1). The potential impact of such a switch on the selection of training sites must be considered. For example, a data source with a smaller swath width might require more sites; although the stability of its radiometric calibration might mean that fewer sites would be necessary. The important point is that TREES must not become locked into a situation where the data source and the training site selection are too heavily interdependent.

It is not envisaged that ground survey be carried out at each of these sites. Validation of their class can be made using TM data. However at least one site per region should be selected for detailed study and ground survey. These sites would then form the basis of the TLP products described in Technical Note No. 4, Section 4.5.

The results of analysis of this problem should be a brief report produced in conjunction with the results of the classification tests for the TIP classification (R.3). This report should indicate the selected test sites for each region and the sub-set of these which are to be used

for TMP.

3.2.6 Methods for Improving Registration Accuracy (R.6)

The TREES I work registered the AVHRR data to the WDBII coastline and national boundaries. If accurate areal statistics are to be derived on a national as well as regional basis then the accuracy both of this registration and of the WDBII data themselves is important. Where data are being compared for different times a change from forest to non-forest must not be confused with an unintended boundary mis-registration.

This research area is concerned with establishing methods to improve the registration accuracy so that such effects are minimised. For TREES I geometric registration was carried out using the AVHRR orbit model then nearest neighbour resampling using ground control points derived from the WDBII data. Some effort needs to be invested in assessing alternative resampling methods which might give greater accuracy.

Inaccuracies in WDBII coastline data and their impact both on image registration and on the production of national and protected area statistics also needs to be considered. If small islands are missing or inaccurately represented what impact does this have on the presentation of the corresponding statistical data? If the coastline boundaries or the national boundaries are inaccurate how does this impact the areal statistics, the boundary statistics and the accuracy of change detection? It is known for example, that in the Amazon basin, some rivers are mislocated by up to 15 miles (A. Millington pers. comm.). This has major implications for the registration of images and boundary change analysis. This relates also to the research problems outlined under R.8.

Recently the DCW coastline and national boundary data have become available and are considered to be more accurate than WDBII. The inaccuracies in both data bases need to be examined with respect to the type of data derived from TREES in order to determine which data base is the most suitable. Some of the auxiliary data already used in TFIS are fitted to national boundary data other than WDBII or DCW. For example, WCMC use Mundocart as a base. The TREES research should consider whether a switch to DCW would be beneficial, and should also consider the costs and difficulties of so doing.

Results of this investigation should be presented by the middle of the second year of the TREES II project. A recommendation should be made as to the optimum geometric registration procedure. The impact of inaccuracies in registration on the interpretation of the products needs to be quantified as far as possible.

3.2.7 Projections for Production of Areal Statistics (R.7)

This is a component of the TFIS work which needs to be determined. Currently the classified AVHRR data are included in TFIS as Lat/Long. To produce statistical data they must be resampled to an appropriate projection that maintains accurate area, distance and shape. The data from the non-tropical region must be resampled in a manner which is compatible with the tropical data.

The TFIS upgrade required by the end of the project (see Section 5.6) will have to contain a suitable automated procedure. However, it is not considered necessary to produce a specific research report during the project.

3.2.8 Accuracy and Precision of Areal Statistics (R.8)

Each product described in Technical Note No. 4, section 4 has a component stating the required accuracy. In order to determine whether the required accuracy has been met the results must be validated against known data. These data will be derived from TM data and from ground survey. An additional comparison can be made between the TMP and TIP classifications. It should be possible to 'degrade' the TIP classification into a TMP classification and so compare the two directly. This would be of particular interest where both are derived from the same data set using different classification schemes. The work plan outlined in Section 5 indicates that the interim products of each type will indeed be produced from the same data and so can be compared in this manner.

Results for each product are to be presented on a national basis showing statistics for the forest coverage within each nation. The precision to which these can be represented depends upon the size of nation. The requirement for 80% overall accuracy implies that 80% can be achieved for any nation within a region. However, the inaccuracies may not be entirely spatially random, and there may be nations whose size, shape or geographic location is such that 80% is not achievable. A study needs to be done of the size of the nations within the tropical forest regions to determine whether they are all capable of representation with 1 km AVHRR at the required accuracy level. For the TIP product, if protected areas are to be identified within nations, then this study should also determine the restrictions on representing and classifying these areas.

Accuracy considerations tie in closely with the choice of classifier described in R.1 - R.3. It may be that in order to achieve a 75% accuracy level for all nations one classifier would be suitable, whereas a different and more complex method would give 90% accuracy for all, but a few nations which would only be achievable to 50% accuracy. A trade-off therefore exists between the complexity of the classifier and the desirability of classifying all nations to a high level of accuracy.

Results of this investigation should be included in a report to be delivered by the middle of Year 2 of TREES II and which will also contain results for research areas R.9 and R.10. The report should state the expected accuracy for each nation/protected area to be classified, and should state the minimum size of area which can be represented.

3.2.9 Accuracy of Boundary Locations (R.9)

The product data consist both of areal statistics and boundary maps. Where boundary maps are used these must be consistent with the scale of the data. If registration accuracy is correct to ± 0.5 pixel a boundary change for a 1km pixel would have to be 2 km in order to be properly identified. Such a shift can be represented at a scale of 1:1,000,000 as a line 2 mm wide, or at 1:5,000,000 as a line 0.4 mm wide. In areas where there is a clearly moving forest front this is a realistic representation. However, in areas where the forest is being fragmented into small units the boundaries may not be sufficiently clearly identifiable. Some additional research to that undertaken in TREES I on the size and shape of deforested areas (see Technical Note No. 1 Section 2.3) needs to be undertaken with respect to determining the amount of shift which can be adequately monitored in different regions. Production of boundary maps for the TMP and BMP products needs to be restricted to those areas where the boundary change is sufficiently great. Thus, the TMP data may not include boundaries at all if the change is not sufficient to warrant this. There needs therefore to be a link with the TFIS output described in the next section and the production of boundary statistics.

Results of this investigation should be included in a report to be delivered by the middle of Year 2 of TREES II and which will also contain results for research areas R.8 and R.10.

3.2.10 Change Detection (R.10)
The ability to detect change depends on a number of factors :

- registration accuracy of the data sets (R.6)
- spatial resolution of the data (R.9)
- classification accuracy(R.2 - R.5), which in turn depends on:
  - sensor radiometry
  - sensor spatial resolution
  - accuracy of atmospheric correction
  - nature of the classifier itself.

The minimum size of identifiable boundary change that can be represented must be established so that only where changes are greater than this minimum would a boundary change map be produced.

The reports derived from the data products (see Technical Note No. 4, chapter 4) require an analysis of the specific changes. This implies that TFIS must include a function whereby such changes can be measured. This is a fairly simple procedure using Arc/Info, but its analysis and presentation require consideration. For the forest:non-forest data there is only a binary decision, but rules must be derived for dealing effectively with 'unclassified' areas which will be different between two dates. For the more complex TIP classification there would be certain changes which would be unlikely (e.g. evergreen forest to seasonal forest); if such changes are found they must be flagged and made the subject of further investigation to determine whether they occurred due to inaccurate classification or to inaccurate registration.

Results of this investigation should be included in a report to be delivered by the middle of Year 2 of TREES II and which will also contain results for research areas R.8 and R.9. It must include a set of rules which identify whether a change in classification is both possible and sufficiently great to warrant investigation.

3.2.11 Methods for Segmenting SAR Data (R.11)
During TREES I some work was carried out on methods of segmenting the ERS-1 SAR data. This research should be continued in order to establish whether tropical forests can be distinguished using ERS-1, and whether different types of forest can also be distinguished. The TREES I procedure used a contextual classifier applied after segmentation and local averaging to isolate areas of rugged terrain and reduce speckle (see Technical Note No. 1, Section 5) The classifier was therefore not applied at all in areas of high relief. To be of use for tropical forest monitoring it is unrealistic to be so restricted, since many forested areas are in mountainous regions. The segmentation rules must therefore be modified to deal with such areas. The problem of geocoding after classification must also be considered in the absence of accurate DEMs for the majority of the tropical forests.

Results of this work should be available by the end of Year 2, so that the methods can be applied to derivation of the TLP classifications. Results should be presented in a report which must identify segmentation procedures which can be used and their limitations.

3.3 Recommendations

Topics R.1 to R.8 inclusive are all critical to the development of TMP, BMP and TIP. The remaining three topic (R.9 R.10 and R.11) relate to the AAR and the TLP. Of the topics, R.4, R.10 and R.11 can be considered less critical. The schedule in section 5 reflects this in terms of output reports required under various cost options. We can therefore summarise the research requirements as two:

- a set of critical research topics must be addressed (R.1, R.2, R.3, R.5, R.6, R.7, R.8, R.9)
- a set of desirable research topics should be addressed (R.4, R.10 and R.11)

4.

Management and Team Development

4.1 Introduction

The original TREES project was focused strongly on research; a challenging target had been set at the beginning which had not previously been undertaken and consequently the techniques and methodologies required were not apparent at the beginning of the project. It was therefore necessary to approach the problem by allowing scientists freedom to devise creative solutions to the various problems involved. With so many uncertainties in both approach and anticipated results a management structure was employed which allowed flexibility in the project direction depending upon the outcome of the research. During TREES II, the nature of the project will gradually change, moving away from research and toward operational product generation, though there will always be strong elements of research to support the operations. This change in focus must be accompanied by a change in management structures which will continue to encourage innovative research while supporting and controlling the operational aspects of the project. The following sections identify the key areas for attention in terms of project management and team development, addressing aspects of resourcing which caused difficulties during TREES I and recommending changes to be adopted for TREES II.

4.2 Planning and Control

The purpose of planning and controlling the project is to attain maximum efficiency in running the project, ensuring that the proposed schedule is met within the resources allowed, whilst coping with risks to the project in terms of changing internal and external circumstances. A planning and reporting cycle should be maintained which allows the project leader to maintain control of the direction of the project without constraining the scientific innovation of the project staff.

The cycle should begin with the generation of a project plan by members of the project team (not just the project leader). The plan should cover the following key topics:

- overall objectives of the project
- description of the tasks to be undertaken
- list of expected outputs from the project
- schedule showing how the outputs are reached
- definition of the project organisation, staffing and responsibilities
- estimates of effort allocated to each task for each person
- definition of project management procedures
- identification of major risks to the successful completion of the project, including action to be taken to ameliorate these risks.

If sufficient time is given to planning the project, the plan will serve as a valuable resource to the team. Its generation could be seen as an unwelcome chore, but if properly constructed it can free the team from inefficiency associated with poor communication of objectives, ineffective allocation of resources and the impact of unexpected circumstances. This allows effort to be devoted to the central scientific and operational aims of the project.

Monitoring of progress against the plan should be undertaken, preferably on a monthly basis. This monitoring should lead to a status report which can be used to assess whether forthcoming targets will be met. This report should be distributed to *all* team members, to ensure communication of the status and direction of the project to all interested parties. If circumstances change during the course of the project, the plan should be updated to reflect the changes, which may impact any of the areas covered by the plan.

4.3 Schedule and Deliverables

Section 5 of this report proposes a schedule for the accomplishment of key tasks in the project, with the associated deliverables at each stage. Once the detailed objectives and scope of the project have been set, this schedule should be updated to reflect that which can reliably be met with the resources available to the project.

The setting of milestones and deliverables within the project schedule fulfils a number of purposes of value both to the external perception of the project, and the internal planning. Many of the deliverables are prototype or interim products, which demonstrate the progress of the project to the outside world. These products demonstrate that the funding of the project is bearing fruit in tangible results. They also allow relationships with potential users to be established and developed since the products can be used to demonstrate the utility of the information that the TREES project can generate. The remaining deliverables are research reports which are either necessary for the successful undertaking of other project tasks, or provide for the dissemination of project results or research findings to the wider scientific community.

The value of these self-imposed deadlines for the production of research reports is in maximising the personal research productivity of each of the team members. It is proposed that each of the research reports could become self-standing papers in appropriate journals. This will raise the profile of the staff involved, enhancing their research careers, and maintaining maximum motivation through the project.

4.4 Human Resources

The success of the TREES I project was partly inhibited by the difficulty and slowness of recruiting permanent scientific staff through the Commission. This made the planning of staff resources difficult, and left shortages in manpower which caused bottlenecks in the project process leading to unrealistic demands on the available staff.

The success of the TREES II project, like any research-based project, is critically dependant upon the timely availability and motivation of staff with the correct experience and

expertise. Accepting that delays and difficulties in recruiting high calibre staff are inevitable, it is necessary to pay close attention to staff planning to ensure that the key posts are filled. Staff resources available to the project may be split into the following categories:

- permanent staff who are employees of the Commission on a long term basis (5 years)
- temporary staff who are employees of the Commission on a short term basis (1 year)
- contractors who are employees of other organisations and may be assigned to the project for a range of time periods.

While a wide range of permutations and combinations to staff deployment are available, the plan suggested here is based on the following premises:

- key research should be undertaken by permanent employees, to maintain the intellectual base of JRC
- since JRC is a research establishment employing scientific staff who are best equipped and motivated to undertake research, operational tasks should be undertaken by temporary staff or contractors
- to reduce the management overhead on contracts, contractors should where possible be assigned significant logical units of work, to be undertaken on- or off-site.

It is proposed that a proportion of the posts to be filled in order to execute the TREES II project be defined as the "core team", and be assigned to permanent members of staff. The core team should comprise 30-50% of the total team and be assigned roles of key scientific or organisational importance. Many of the key roles require less than a full-time person, and so could be combined within one post. The key roles are as follows:

- Project Leader: responsible for high level leadership of the team in accomplishing the objectives set at the start of the project. Responsible for developing the intellectual capacity and cohesion of the team, for strategic planning, and for upward communication to the project's institutional and political controllers.
- Project Administrator: Responsible for assuring the smooth day-to-day running of the project by ensuring all the resources required by the various project functions are available. Responsible for detailed project planning and collecting information on progress for reporting to the Project Leader.
- Science and Research Leader: Responsible for coordinating the research aspects of the project, ensuring high standards of science are attained and that the intellectual benefit of the research remains within JRC.
- Data Gather Leader: Responsible for ensuring that all the input data resources needed by the project are available in a timely manner. These resources include all types of remotely sensed and auxiliary data needed through the life of the project. Responsibility for these data passes to the Data Manager once the data

are ingested into the project.

- Data Manager: Responsible for ensuring all the data used and produced by the project is properly catalogued and securely archived. Responsible for defining the project's data management policy and ensuring it is adhered to. Responsible for liaison with IRSA and CEO.

- Software and Systems Engineer: Responsible for the commissioning and management of all software developments required to undertake the TREES project.

- External Relations Coordinator: Responsible for developing relations with potential end users of TREES information, and maintaining a high profile for the project within the user and scientific community. Responsible for the dissemination of TREES products and the collection of user feedback, through newsletters, meetings and workshops.

- Project Librarian: Responsible for ensuring all the project procedures, results and reports are properly documented collated and archived, and made available to external users through the External Relations Coordinator.

These roles will fill more or less time, depending upon the functionality chosen for the project. However, each of them is needed, whatever the funding level; lower funding levels will simply mean that more roles will need to be combined into single posts. Logical groups of roles to combined under different scenarios would be:

- Data Gather Leader and Data Manager (unless Data Manager is an MTV wide post)
- Science and Research Leader and Data Gather Leader
- Data Manager and Software and Systems Engineer
- Project Administrator, External Relations Coordinator and Project Librarian

The choice of combinations will depend upon the exact project structure, and the availability of suitably qualified staff.

In summary, it should be understood that good management is critical to TREES II. This is because the project staff represent the most valuable resource. The planning of utilisation of human resources should be undertaken with particular attention. The preceding sections have set out a number of principles for accomplishing successful use of staff resources, which can be modified and adapted to the actual, specific project needs.

5.

Deliverables and Schedule

5.1 Introduction

The deliverables of the TREES II project are outlined in the following sections and an outline schedule provided. The schedule focuses on the data collection, research reports and product deliverables required. The data collection is described in Section 5.2 and is designed so that suitable data are available for use in the research components and in the product derivations. The research reports are described in Section 5.3. Each research report attempts to answer one or more of the research requirements identified in Section 3. The reports are scheduled in such a way as to provide timely information for the production of each interim and final product. Section 5.4 describes the product deliverables. For each product there is a 'final' version and one or more 'interim' versions using either partial data or incompletely defined production rules. The production and subsequent analysis of these 'interim' products is considered to be an essential component of the development of the operational production of the 'final' outputs. The work schedule is given in Section 5.5. A schedule is given for full restricted and basic functionality cost scenarios and an attempt is made to analyse the trade-offs involved in making a selection between the different cost scenarios.

5.2 Data

TREES II can be considered as driven by the requirement to produce output products as described in section 4 of Technical Note No. 4. This section describes the relationships between these products and the data required for their production.

At the most general level level the 'data' are used to make the 'products'. The products themselves are defined as four separate classes, using the acronyms previously defined in Technical Note No. 4. The data are divided into two classes: TREES I data which are defined as all the data collected during the TREES I project, and data collected during the TREES II project. Each of these classes is further subdivided into different components consisting of AVHRR data, TM data, SAR data and ground survey data. These relationships are illustrated in Figure 13.

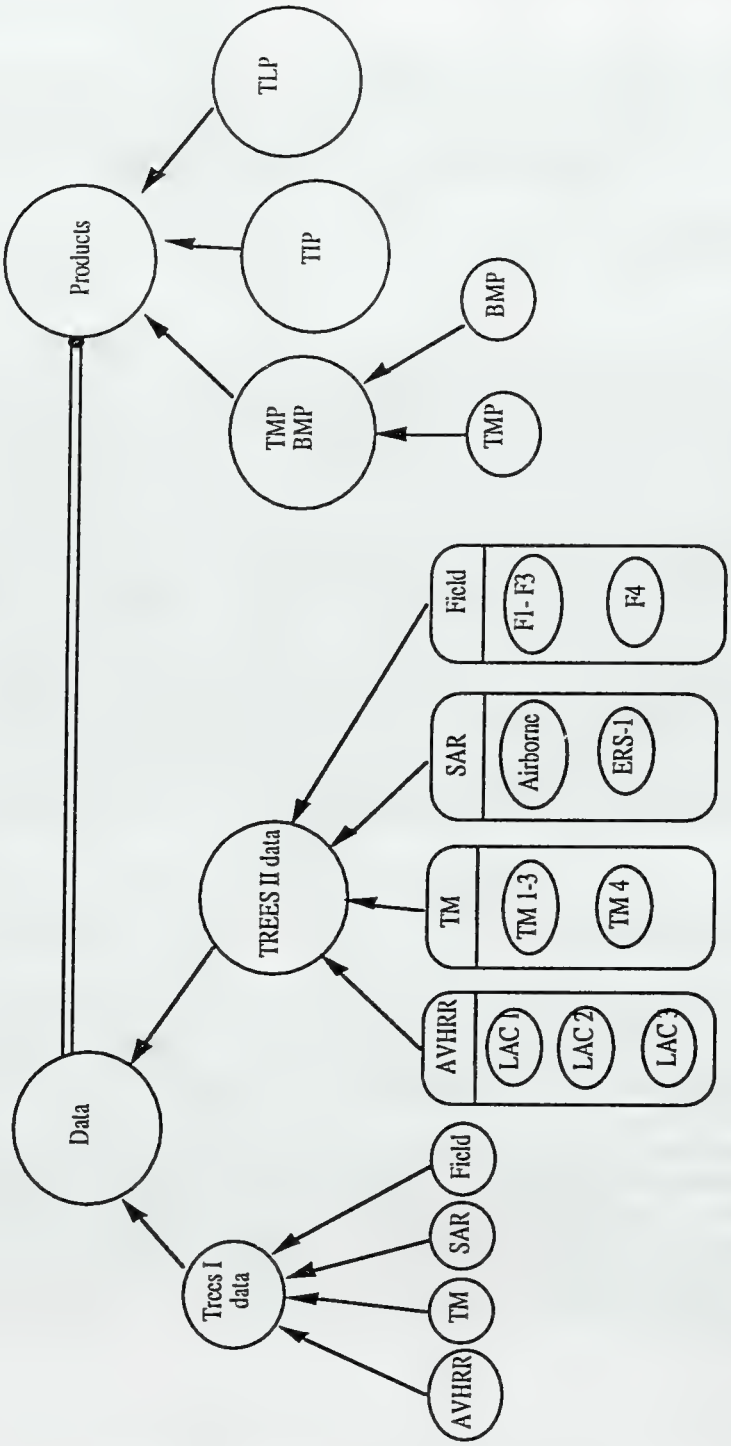


Figure 13 : TREES II Data Requirements

The TREES II data as described in Figure 13 is:

- LAC1 refers to LAC data collected during Year 1 of TREES II, LAC2 to LAC data collected during Year 2 etc.. Since it may take some time to set up the chosen data collection scheme (section 2) it is possible that LAC1 may be incomplete. The deliverables are designed in such a way that this data set would not be essential except that LAC1 data are required for the interim BMP product unless suitable data can be obtained from E. Tomppo of the Finnish forestry service.

- TM 1-3 refers to TM data collected for specific test sites in each of the three tropical regions. Each site chosen for a TLP product will require complete coverage with TM data over the 3-year project period. Additional TM data will be required for validation, with TM data for each test site.

- TM4 refers to TM data collected for the Siberian test area.

- SAR data are divided into airborne and spaceborne sets. Within each there would be four sets, one for each of the four TREES II regions. At least one spaceborne set should be available for each of the TLP sites.

- The ground survey data are sub-divided in the same manner as the TM data. It is envisaged that ground survey will only be undertaken at each of the TLP sites, and that only one visit per site will be necessary. This is scheduled to take place during Year 2.

The TREES II data will be used for all the products. TREES I data will be used initially during the TREES II project. The reason for this is that new data are unlikely to be available until at least the start of Year 2, and new ground survey data until later still. This will be the case whether or not the data collection is undertaken in-house or contracted out (see Section 2). Further, the TREES I data set consists of a valuable resource set containing considerable amounts of ground survey and TM data which it would be unfortunate not to exploit.

However, the current state of the TREES I data is that collection has been completed for S.E. Asia and Africa, but not for S. America. There is considerable uncertainty regarding the processing state of these data. We understand that atmospheric correction has not been routinely performed on the S. American data and the S.E. Asian data. It is not known whether this is also the case for the African data. If these data are to be usable for multi-temporal study then atmospheric correction is essential. While it is appreciated that there is some uncertainty in the correction over tropical areas this should not be taken as sufficient justification to avoid applying whatever corrections are available. Correction algorithms are available at JRC (possibly used on the MARS project). These should be applied to the existing TREES I data so that all the data is pre-processed to a uniform standard. Only after this has been done can these data be used for further study.

For each of the four basic product classes TREES II should produce several examples. The last product in a series is considered to be 'final', the lower numbered products are 'interim' (see Section 5.4) These are described in Figure 14 with an indication of which data set will be used for which product. T1, T2, and T3 refer to the three TMP products described below; B1 and B2 to the two BMP products and so forth. Figure 15 illustrates use of the TREES II data in more detail.

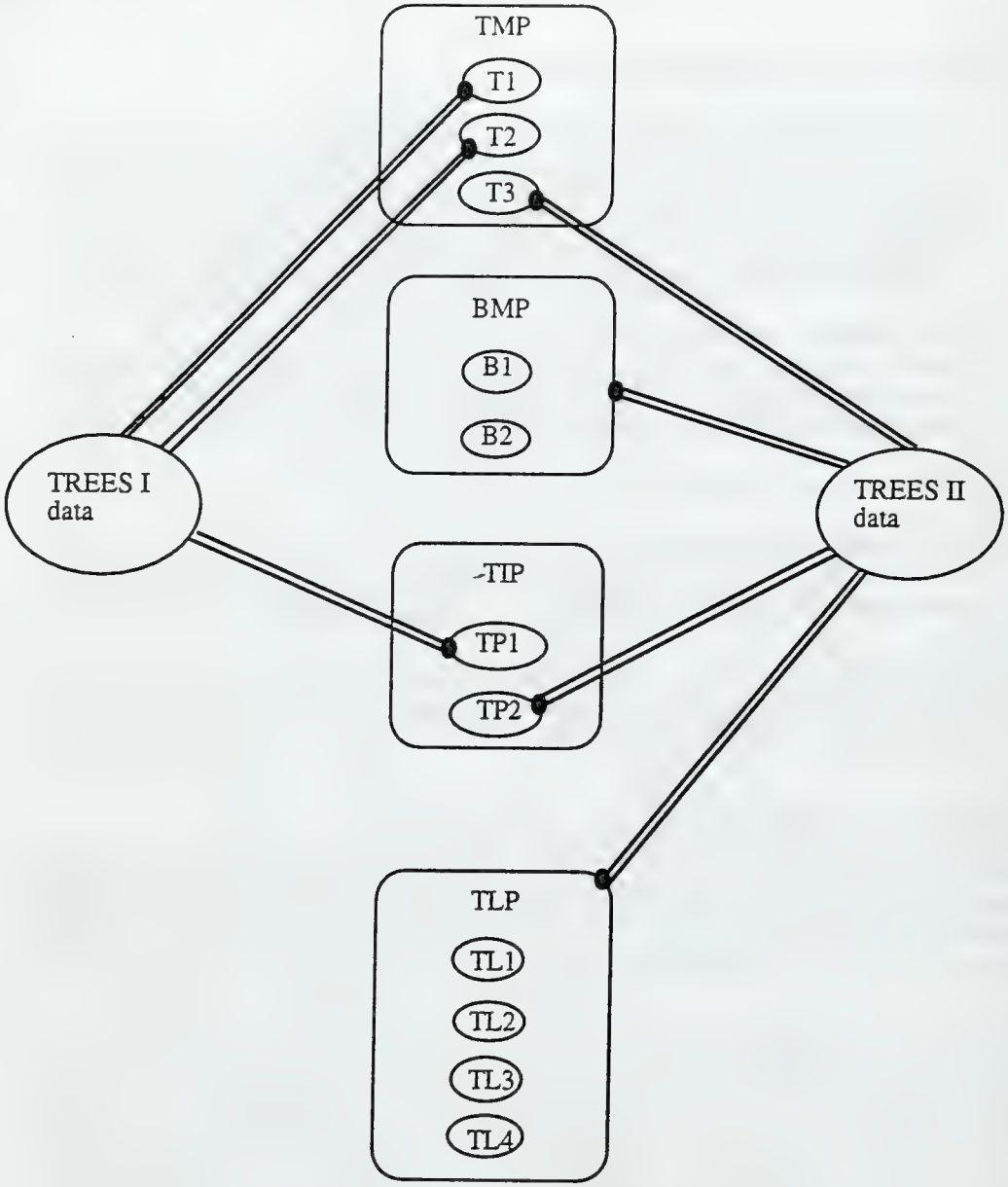


Figure 14 : Products and Data Relationships

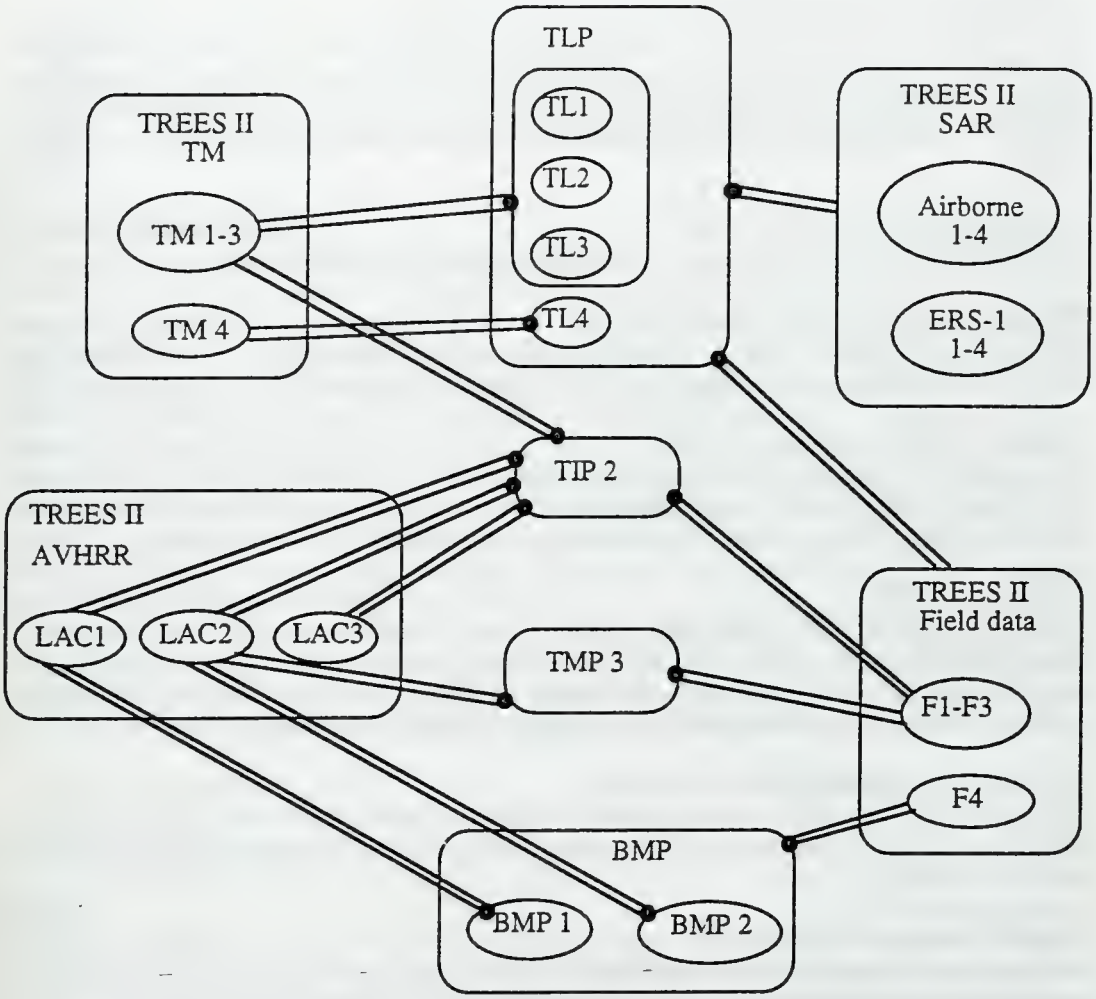


Figure 15 : Detailed Data Relationships

5.3 Research Report Deliverables

Each report contains results of research undertaken to fulfil the various research requirements described in Section 3.2. and refers to the research requirement identified in the list in Section 3.1. It is envisaged that each report could form the basis for a paper in a refereed research journal. Such publications would increase the profile of the TREES project.

1. Report on classification schemes *Due 1st quarter Year 1*
This report will contain the results of the research and consultancy required for R.1

2. Report on test classifications for TMP *Due mid Year 1*
This report will contain the results of investigations carried out for R.2. It will identify at most two classification schemes suitable for production of the interim TMP classification.

3. Report on test classifications for TIP *Due end of Year 1*
This report will contain the results of investigations carried out for R.3 and R.5. It will identify one, or at most two, possible candidates for production of the interim TIP product. Test sites suitable for use in both TIP and TMP production will also be identified.

4. Report on TMP#1 *Due 1st quarter Year 2*
Following production of TMP#1 there will be a short evaluation exercise using whatever ground TM data are available, plus an evaluation of the effort/cost. This will lead to a report to be delivered early in Year 2 with recommendations, i.e. which method is to be used in future. This has to be done quickly so that production of TMP#2 can proceed.

5. Report on test classifications for BMP#1 *Due 1st quarter Year 2*
This report will contain the results of research for R.4, and will identify at most two possible candidates for use in the interim BMP production. Suitable test sites should also be identified to fulfil R.5.

6. Report on geometric registration *Due mid Year 2*
This report will focus on the possibilities for improving registration accuracy between images and between images and the DCW coastline data, as identified in R.6. The report should also contain a statement concerning suitable projections for use in providing areal statistics (R.7).

7. Report on statistical accuracy *Due mid Year 2*
This report will include results of studies for R.8, R.9 and R.10, i.e. all the work concerning statistical accuracy and change detection procedures.

8. Report on SAR segmentation *Due end Year 2*
This report should contain results from research into ERS-1 SAR segmentation as described by R.11.

9. Report on TMP#2 and BMP#1 *Due early Year 3*
Results of product#2 must be evaluated by the start of Year 3. After this the 'final' rules for these products will be developed and will not change. It is expected that different procedures are likely to be suitable between the tropics and Siberian test areas. However, the research should also be aiming towards integrating these as far as possible, i.e. if there is

a method which is the same for both areas it would be preferable provided that the accuracy is not too low.

10. TIP#1 validation *Due mid Year 3*
Similar to evaluation of TMP/BMP above. Recommendations then feed into the production of TIP#2.

11. TIP/TMP comparison *Due mid year 3*
A comparison of the TIP and TMP products should be interesting see R.8 described in Section 3.2.8. Every three years both products are going to be produced, and if results are to be published which disagree there could be a problem, e.g. an area classed as forest by TIP and non-forest by TMP, (or areal statistics which disagree). Even though the products do not normally have exactly the same data input (TIP uses the TMP data, plus data from the preceding and following years) for the TREES II period the interim TIP product and the interim TMP products will both be derived from TREES I data and so will be directly comparable. The TIP product should be 'degradable' into a TMP product, and one could then produce a confusion matrix between the two classifications. Since TIP is supposed to be more accurate than TMP this would give an interesting handle on the accuracy of the latter. The TIP:TMP comparison should be reported on by the middle of Year 3, so that production of the 'final' products is not hindered.

12. Final report *Due end Year 3*
Summary of results and recommendations for proceeding towards operational implementation as TREES III. Final rules for all products should have been developed.

5.4 Product Deliverables

TMP #1 *Due before end Year 1*
By the end of Year 1 one or more (see research report discussion section 3) "interim" products will be generated. These will use the classification rules and procedures derived from the research into the TMP classifications (see Section 3.2.2) and the TREES I data set, since the data collection for year 1 (LAC1) may not be complete, and the TREES I data have the supporting TM and ground survey data, which will be necessary for training and validation. It is desirable, but not absolutely essential, that the complete tropical region is classified. Sufficient should be classified to enable meaningful validation and subsequent modification of the classification method.

TMP#2 *Due mid Year 2*
By mid Year 2, a TMP#2 "modified" product will be generated. The TREES I data will be used again, in order to enable comparison with the interim products. Results from validation and research will be used to modify the methods used for products #1.

TMP#3 *Due early Year 3*
By early Year 3 a "final"TMP#3 product using LAC set#2 will be generated. Results from the TMP and TIP comparison will be used, plus validation thus far to produce a set of final "cast-in-stone" rules which should not subsequently change. (and hopefully do not differ from deliverables #2). This sets up further routine production such that a TMP/BMP product is produced by the middle of the year following the collection of the relevant data set, i.e. TMP#4 is due early Year 4 using LAC set#3.

BMP#1 *Due mid Year 2*

This product will use data from the first year of LAC collection (LAC#1) since TREES I data are not available for the test area.

BMP#2 *Due early Year 3*

Specifications as for TMP#3.

TIP#1 *Due end Year 2*

By end of Year 2, an "interim" product TIP#1 will be generated. This will use data from TREES I only in order to enable comparison with TMP#1 and #2, and also to ensure that sufficient cloud-free data are available. In this respect the product is a re-visiting of the wall-to-wall coverage of TREES I in the light of experience, and with increased user inputs to define the classes more appropriately, and to work towards a more automated procedure.

TIP#2 *Due end Year 3*

By end of Year 3 a "final" TIP product TIP #2 will be generated. This will mostly use LAC set#2, with additional data from set#1 and set#3 where required to reduce cloud cover problems, plus the corresponding TM data and field data. This sets up the operational production such that the next TIP product would be three years later using LAC set#5 plus additional data from set#4 and set#6 where required. The TIP product is therefore produced at the end of the year for which the main data collection was made. The production could be staggered by regions if necessary.

TLP products *Due mid Year 3*

It is envisaged that a TLP product will be derived for a set of test sites where there is at least one test site per region (regions being defined as S. America, Africa, S.E. Asia and Siberia). Thus, there will be a minimum of four products. Should time and costing permit there could be additional test sites. In order to minimise costs and logistics the test sites used to derive and validate the other products should be the same sites as used for the TLP products. Data will be TM data, SAR data (both airborne and spaceborne), and field data. The field work will probably take place during Year 2, so that the TLP products will be in final form by the middle of Year 3. It is likely that interim products will also be derived during the validation of the other products which can then be used to assist in deriving the final products.

TFIS Upgrade *Due end Year 3*

The upgrading of TFIS occurs in parallel to the product scheduling. The necessary components of TFIS are described in Section 2.4, and the research required to achieve the upgrades in Section 3. It is not envisaged that any specific reports need be produced, but the research undertaken must be outlined in the final report.

5.5 Work Schedule

This section describes the work schedule for TREES II in terms of the data collection, output of reports and products and systems developments required and gives 'rough order of magnitude' costs. Three functionality scenarios are defined: full, reduced and basic.

The products can be divided into 'interim' and 'final' deliverables, in that products generated during the final year of the project are considered to be final and therefore should be complete and produced in as operational a manner as possible. The interim products are considered as stepping stones towards this goal, and may therefore not be complete in their coverage, not be produced in an operational manner, nor provide the required accuracy.

The scheduling of the products leads naturally on into an operational production at the end of the project. Thus, the so-called LAC#3 data set would be used the next year for a routine TMP production, and TIP#3 would follow on naturally three years after the end of TREES II. TMP products are finished within three months of the relevant data collection. TIP within a year of the relevant data collection.

Each research report is designed to address specific research questions raised by the product specifications. Their scheduling with respect to the products is important, because they provide direct input in terms of the required techniques etc.. Each report could make a reasonable journal/conference paper and so help with the dissemination of results (in the research sense) that is rather lacking in TREES I, and help with the research careers of those involved.

A schedule showing system development is included. All system components are required whatever option is taken; and there is relatively little difference envisaged between the general level of development in each case; i.e. the number of products and research reports does not directly influence the 'size' of the system.

5.5.1 Full Functionality Scenario

The full functionality scenario provides for all research topics to be investigated and reported and several products of each type to be produced. The cost table (Table 1) gives an estimate for the size of team and other costs incurred to cover the work and the timeline for the various elements is shown in Schedule 1.

The discussion of management requirements in Section 4 indicates the need for a management/administration team of eight staff and a research and operations team of seven staff. One of the operators could work at ESA/ESRIN where pre-processing might be sited. The second operator will become important later during the project as image classification becomes more routine. The cost of airborne campaigns is speculative in the sense that information is not easily available and the need for TREES II to fund such campaigns is undecided (collaboration with other programmes may provide input). The expert reports are related to research topics where the TREES team requires input from outside consultants. This occurred in TREES I and it is wise to continue to take such advice. The conferences and travel expenses are driven by the need to consult widely with other projects and to develop user contacts.

The total cost over three years is 7.5 million ecu.

5.5.2 Reduced Functionality Scenario

In this option the management/administration team has been reduced by combining roles and the research and operations team reduced. The BMP product has been removed along with the research and data collection required for its production. The number of TMP and TIP products is also reduced, along with field and airborne campaigns. Other costs reduce to match the team size and needs for software development. Table 2 shows the breakdown and the timing of the activities is shown in Schedule 2. There is of course a major political disadvantage in this option in that monitoring of a non-tropical area is a stated user requirement (see Technical Note No. 4, Section 3). The possibility of extending TREES beyond the tropical scope is considerably reduced without this preliminary 'pathfinder' effort and once TREES III is operational it becomes much more difficult to add functionality. The production of the TMP product is also put at risk, since with only one interim product there is less scope for recovery from mistakes, and for refining the production rules.

The total cost over three years is 5.3 million ecu.

5.5.3 Basic Functionality Scenario

In the basic functionality scenario, the TLP product is removed altogether reducing data, research and several other costs substantially. In particular, airborne SAR campaigns and SAR research would not be required. There are further reductions in research effort along with commensurate reductions in supporting areas. Table 3 shows the cost estimate, while Schedule 3 timelines the tasks. There is a major disadvantage in this option in that several important requirements are not met (5, 8, 12 17 and 19). The TLP products are likely to be highly valued by users who are substantially in favour of obtaining information at fine scales. They also provide information which can be used in production of the coarser scale products, which if lacking could put these products at risk. In addition, the use of minimal 'interim' products reduces the ability to correct mistakes and refine the operational procedures.

The total cost over three years is 2.8 million ecu.

5.6 System Development Schedule

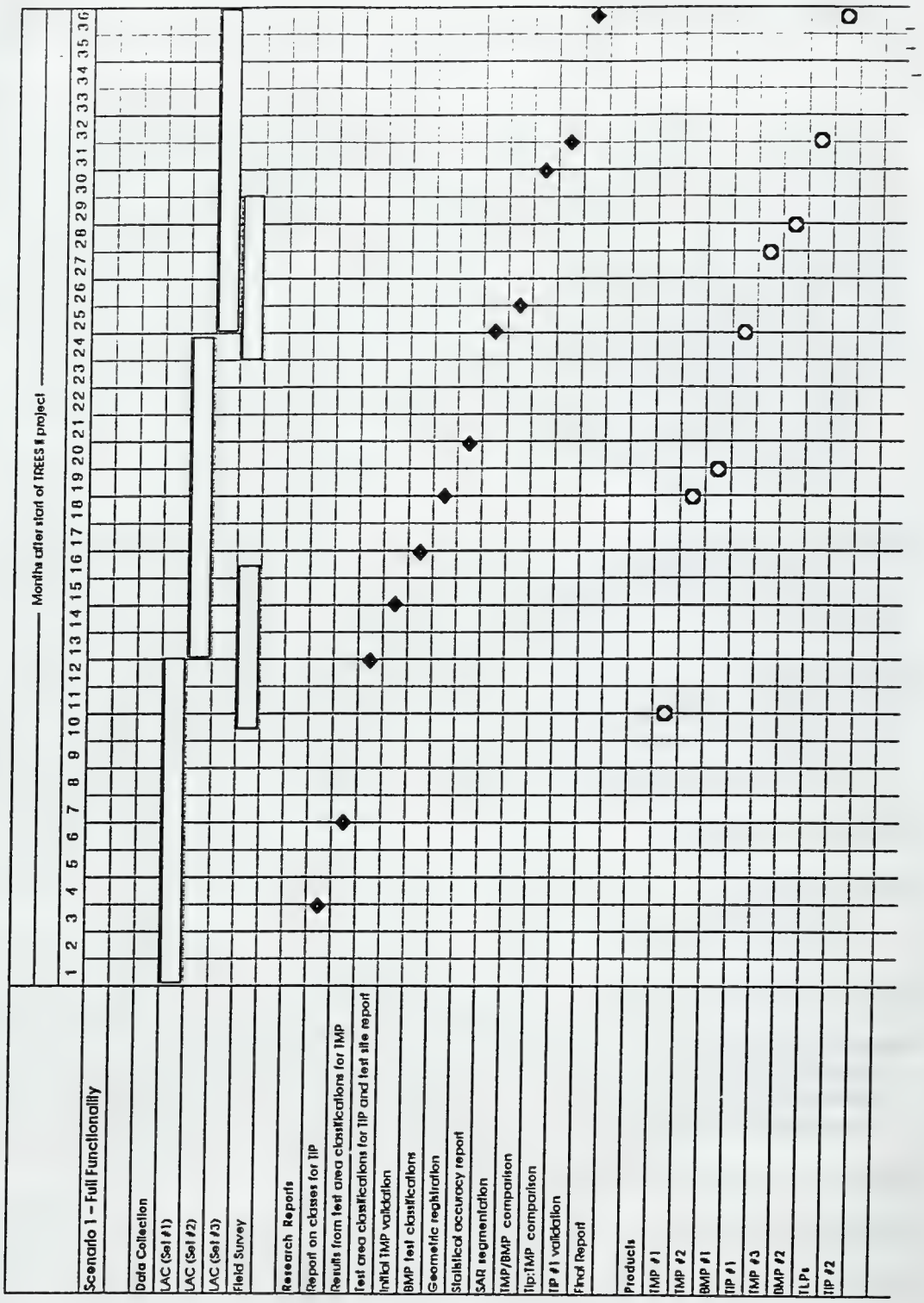
Section 2.7 discussed the relationship between system components in terms of the order of development. Having outlined a schedule for product and research report generation, it is now possible to add component development. The schedule is dependent on the results of trade-off studies especially those into data supply (see Schedule 4). The schedule shows two levels of activity for each component. The thicker lines show periods when actual development occurs while the thinner lines indicate ongoing operation.

Year 1 (1994)

Data suppliers (routine) dominates the first year when development (directly or by contract) of software for the pre-processing operations is undertaken. While there is a trade-off issue here as to how much pre-processing needs to be done, what is clear is that considerable effort needs to be invested by the TREES team on this component; in particular, the effort to separate as many operations as possible from the rest of the system by using the EDC/ESA route discussed in Section 2. Also in Year 1, an effort to incorporate extra functionality into TFIS to enable it to support the research report activity (i.e. the area analysis function).

Item	Annual Kecu	Total Programme Kecu
Management and Administration		2400
Project Leader		
Project Administrator		
Science and Research Leader		
Data Gather Leader		
Data Manager		
Software and Systems Engineer		
External Relations Coordinator		
Project Librarian		
Research and Operations		1490
4 Research Scientists		
1 Application Scientists (Year 3)		
2 Operators		
Data Acquisition		
AVHRR Processing	90	270
SAR Data	40	120
TM Data	90	270
Miscellaneous Processing	10	30
Hardware and Software		350
Field Campaigns		
Field Work (2)		300
Airborne Campaigns (2)		1000
Expert Studies (2 per year)	100	300
Software Developments		
TFIS development		100
Standard pre-processor		200
Standard product generator		200
Staff Travel to Conferences/Meetings	40	120
User and Expert Meetings	50	150
Promotional Materials		160
	TOTAL	7500

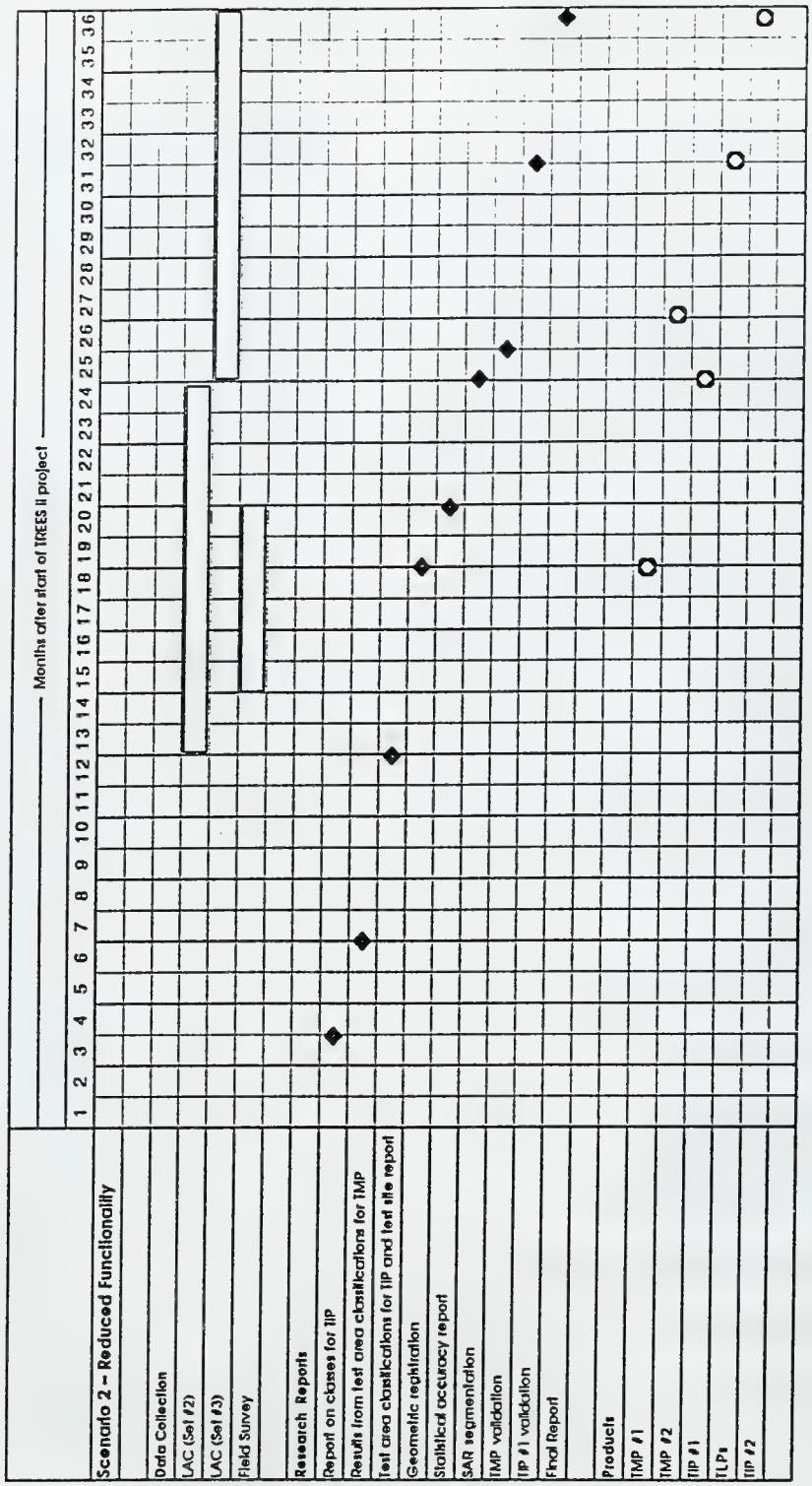
Table 1 : Full Functionality Scenario



Schedule 1 : Full Functionality Scenario

Item	Annual Kecu	Total Programme Kecu
Management and Administration		1860
Project Leader		
Project Administrator/Librarian		
Science and Research Leader		
Data Gather Leader		
Data Manager/Software and Systems Engineer		
External Relations Coordinator		
Research and Operations		990
3 Research Scientists		
1 Application Scientists (Year 3)		
2 Operators (Year 3)		
Data Acquisition		
AVHRR Processing	90	270
SAR Data	20	60
TM Data	40	120
Miscellaneous Processing	10	30
Hardware and Software		200
Field Campaigns		
Field Work (1)		150
Airborne Campaigns (1)		500
Expert Studies (2 per year)	100	300
Software Developments		
TFIS development		100
Standard pre-processor		150
Standard product generator		150
Staff Travel to Conferences/Meetings	40	120
User and Expert Meetings	50	150
Promotional Materials		150
	TOTAL	**5300**

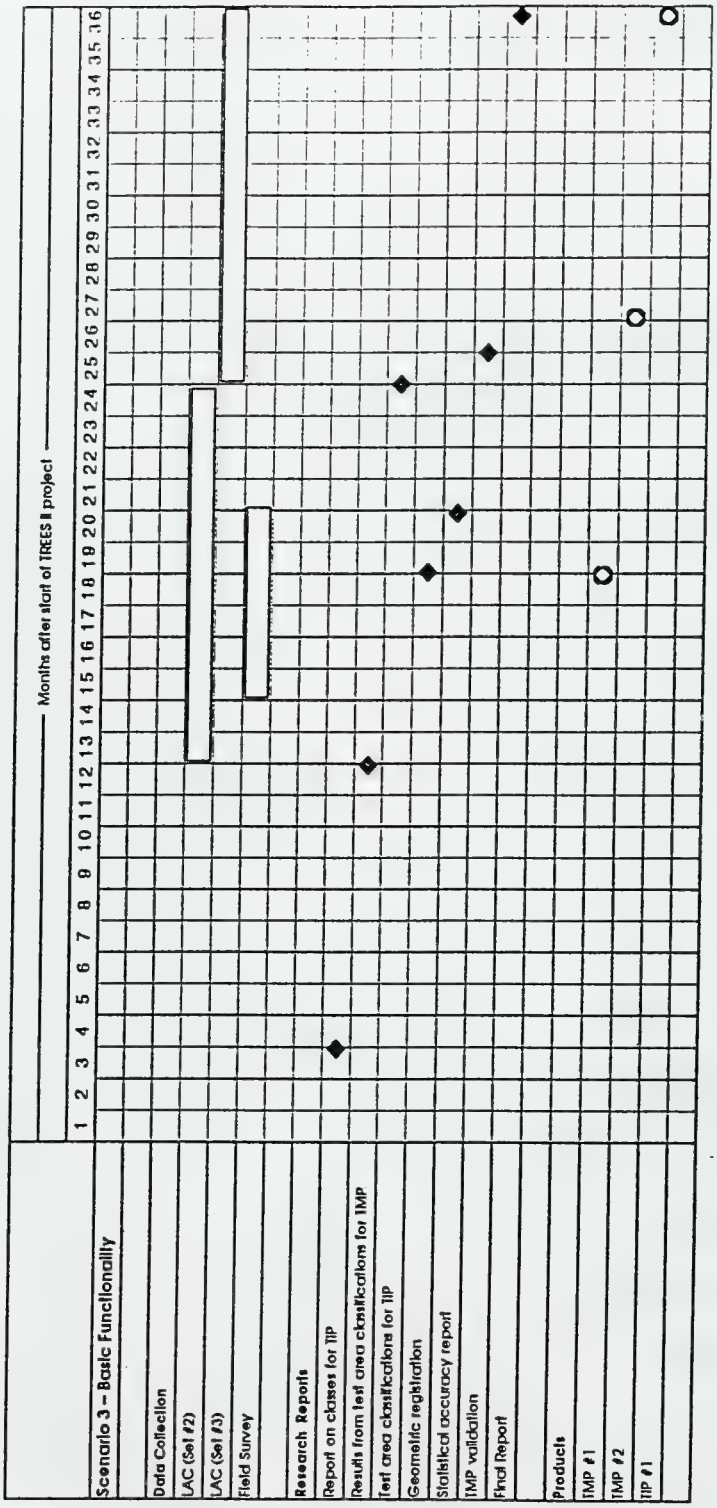
Table 2 : Reduced Functionality Scenario



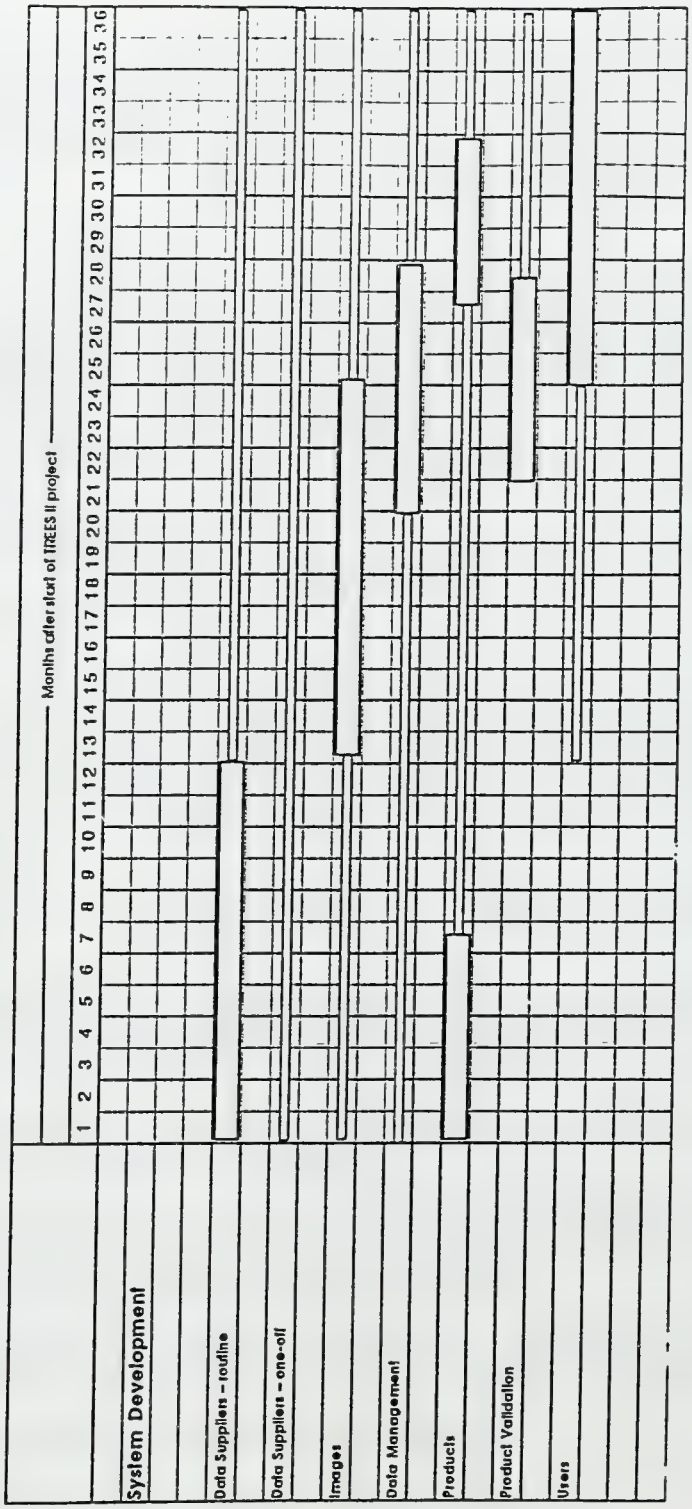
Schedule 2 : Reduced Functionality Scenario

Item	Annual Kecu	Total Programme Kecu
Core Team		960
Project Leader		
Project Administrator/Librarian/External Relations Coordinator		
Science and Research Leader/Data Gather Leader		
Data Manager/Software and Systems Engineer		
Research and Operations Team		530
2 Research Scientists		
1 Operators		
Data Acquisition		
AVHRR Processing	90	270
SAR Data		
TM Data		
Miscellaneous Processing		
Hardware and Software		100
Field Campaigns		
Field Work		150
Airborne Campaigns		
Expert Studies (1 per year)	50	150
Software Developments		
TFIS development		60
Standard pre-processor		150
Standard product generator		100
Staff Travel to Conferences/Meetings	40	120
User and Expert Meetings		75
Promotional Materials		100
	TOTAL	**2800**

Table 3 : Basic Functionality Scenario



Schedule 3 : Basic Functionality Scenario



Schedule 4 : System Development

Year 2 (1995)
Once research activities start to yield results, the images component can be built. This will involve the development of the procedures (part manual, part automated) needed to classify data for products. Later in the year, IBIS will have to be enhanced to cope with the increasing demand from the now established data suppliers. Procedures for validation of products should also be started.

Year 3 (1996)
Images, data management and validation should be completed by early in the year. By this stage, the format and content of the products should be clear. The final tasks are firstly an upgrade to complete the products component by incorporating the change analysis and interactive consultation elements and secondly user development. As indicated, the user component should have been receiving some attention during Year 2 in order that contacts are established. However, in Year 3 a concerted effort is necessary to disseminate products to selected users and receive feedback such that a user base for full operational use of TREES can be established.

Thus by the end of year 3, TREES II should have produced a fully functioning but still pre-operational system but should be in a position rapidly to operationalise.

6.

Recommendations

The major features of this work plan are a number of recommendations for TREES II . These are detailed in Sections 2, 3, 4 and 5 of this technical note. The major recommendations are as follows.

In starting TREES II, a major objective is to move from a phase which has been predominantly research-oriented to one which is pre- operational. The system level recommendations which seek to drive this move are:

1 **Development and specification of a set of outputs or products which meet user requirements.**

This task has been started in this report by specifying a set of products. These are not full specifications and a number of questions are outstanding which should be answered during TREES II. It may become necessary significantly to alter product specifications, delete products altogether or add new ones. The important points are that a clear link exists between user requirements and the output from TREES, and that the output from TREES II can be characterised.

2 **To engineer a set of system components which will enable products to be output.**

The system outlined in the work plan is derived from elements many of which were developed during TREES I. Additional components have been added in order to create a system which leads towards operationalisation.

3 **To study options and determine the best means of providing a routine supply of processed 1 km data to the project.**

The ingestion of these data during TREES I was a major operation which must be contained and if at all possible removed from the JRC team. This will enable the TREES II team to concentrate on the specialist areas of research and product development.

TREES I demonstrated that valuable information can be derived from the data sources used. However, a number of areas remain outstanding where additional research is required:

4 **A set of critical research topics must be addressed**

5 **A set of desirable research topics should be addressed**

The management and team development aspects are critical:

6 **Clearly identify roles and responsibilities for all team members including special positions such as data management, data gathering, systems development, science leader etc..**

The necessity to meet schedules and deliver value for money means that responsibilities must be clearly understood at technical and non-technical levels. This is not easy in an environment of permanent and contracted staff.

7 **To involve a mix of people with skills in research, operation, engineering, management, negotiation and liaison.**

The user component of the system discussion emphasised the need to communicate with users. The contact with potential users reported in this study must not be seen as a one-off. It is vital to develop a clear understanding of the user community and its requirements.

8 **Establish links with users, distribute products and monitor feedback.**

Lastly, it is necessary to estimate the financial cost of the TREES II project. There are however a large number of research topics and trade-off studies involved in its development. This means that the final form of a system in terms of necessary functionality cannot be determined at this stage. In turn this means that the costs of development, research, software and data acquisition can be estimated only very generally.

However, the discussions and recommendations above have been brought together into the the three options discussed in the section above. It is not possible here to recommend which of these options is taken. It is a matter for CEC to determine the value of meeting or at least probably meeting the requirements in each option.

In summary, it can be said that with the full functionality scenario, a TREES II project following the suggestions and recommendations in the technical note will almost certainly be able to meet around half of the requirements identified in Technical Note No. 4. Thus TREES will be able to make a significant contribution to the management of tropical forests and associated activities. In the reduced functionality scenario the boreal monitoring requirement is not met and research and products generation elements are much reduced. Boreal monitoring is a non-technical requirement whose value must be weighed by the CEC. In the basic functionality scenario a significant number of requirements are not met, especially those associated with SAR.

In conclusion it can be said that TREES II presents a valuable opportunity to utilise remote sensing technology in tropical forest monitoring. With clear requirements, the project can make a considerable contribution to the knowledge and understanding of this vital issue of global significance.

7.

References

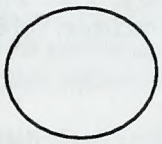
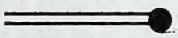
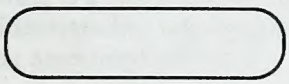
Cross, A.M., Settle, J.J. , Drake, N.A. and Paivinen, R.T.M., 1991, Subpixel measurement of tropical forest cover using AVHRR data, *IJRS*, vol 12, no 5, pp1119-1129

Kuntz, S. and Kleinn, C., 1993, Some aspects of the role of definitions of land use classes based on satellite remote sensing - an example from forestry, *Proc Int Symp on Operationalisation of Remote Sensing*, Van Genderen, J.L. et al (eds), Enschede, vol 8 pp 83 - 90

Appendix

Key for Object Oriented Figures

Key to class diagrams

Symbol	Key
	Class
	Object
	Instance
	Object/class is derived from object/class at arrow head
	Object/class/instance at bullet end uses the other object/class/instance
	Data set in object
	Procedure in Object
	Data movement in and between Objects