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FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS

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ENVIRONMENT PROGRAMME

GLOBAL ENVIRONMENT MONITORING SYSTEM

Pilot Project on Tropical Forest Cover Monitoring

BENIN-CAMEROON-TOGO

Project Implementation: Methodology, Results and Conclusions

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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GLOBAL ENVIRONMENT MONITORING SYSTEM

PILOT PROJECT ON
TROPICAL FOREST COVER MONITORING

BENIN CAMEROON TOGO

PROJECT IMPLEMENTATION: METHODOLOGY, RESULTS AND CONCLUSIONS

Report prepared
by
The United Nations Food and Agriculture Organization
as cooperating agency with
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UNITED NATIONS FOOD AND AGRICULTURE ORGANIZATION

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FOREWORD

The present report was prepared by the pilot project coordinator (R. Baltaxe, Forest Resources Division, FAO), based on the results obtained in the project countries by C.L. Vanpraet (FAO project expert in Togo), J. Guellec (Centre Technique Forestier Tropical, project consultant in Benin and Cameroon), and the national project teams in Benin (Director L. Okio) and Cameroon (Director J. Ngaha), set out in Project Reports Nos. 1, 2 and 3 respectively covering Togo, Benin, Cameroon.

The ecological map of the vegetation cover of Togo was compiled by C.L. Vanpraet and those of Benin and Cameroon by J. Guellec. The final map legends and colour schemes were prepared by the project coordinator and the over-all design of the maps and the supervision of their printing was undertaken by H. Engeler, FAO cartographer.

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SUMMARY

The pilot project on tropical forest cover monitoring was formulated in the context of a joint UNEP/FAO programme for the surveillance of the world's tropical forests, originating in a recommendation of the 1972 UN Conference on the Human Environment. Financed predominantly by UNEP, the project was executed by FAO and implemented in Benin, Cameroon and Togo. Project activities were undertaken between August 1975 and February 1979, with field work lasting from November 1976 to October 1978.

The project's major operational objective was to obtain data on the present forest cover of the three participating countries and on the quantitative and qualitative changes of the forest cover which had occurred in some representative critical areas. In the virtual absence of multi-date Landsat cover assessment of change at the country level was not carried out.

Maps of the forest and other vegetation cover were prepared for the whole of Benin and Togo at 1:500 000 and for the southern two thirds of Cameroon at 1:1 million, using a multiphase procedure by which keys derived from ground survey, reconnaissance flights and aerial photo-interpretation over limited areas were extrapolated for the interpretation of the entire Landsat cover of the areas mapped. The detail and accuracy of the maps is variable and the level of accuracy could not be quantitatively assessed. The indications are that for the areas having Landsat cover of at least moderate quality the detail and accuracy are consistent with the scale of the maps.

The method employed was based on the visual interpretation of un-enhanced Landsat imagery, using only the simplest instruments. Its applicability is therefore limited only by availability of qualified and experienced personnel. The relative scarcity of the latter constituted an important constraint on the project's execution and accounted for its long duration, although only about 14 man months were required for the actual survey, interpretation and mapping of some 490 000 km^2 in three countries.

The method adopted for analysis of the quantitative changes in the vegetation cover in selected areas consisted of interpreting aerial photographs of two dates, mapping the results at a scale of 1:50 000 and measuring the area of each vegetation class from the map for each date. The vegetation class at a series of locations (represented by the dots of a dot grid) at the two dates was also recorded to provide data on the qualitative nature of the changes observed. This method is simple and effective but was susceptible to several constraints, including the ready identification of areas where significant changes had occurred, the availability of aerial photography of at least two dates covering such areas and, when recent photography was not available, the difficulty, under tropical weather conditions, of obtaining new photography at the time required.

Although the original programme of change analyses was not entirely implemented due to such factors, valuable information was obtained concerning rates of change of the vegetation cover and the size of the areas affected. This led to the conclusion that in Benin and Togo periodic observations of areas susceptible to loss or degradation of the woody vegetation cover are required at intervals of less than five years to avoid the risk that a substantial

proportion of the existing cover would disappear between observations. An approach to the identification of such critical areas, based on an index of stability derived from the vegetation map and ancillary data, has also been outlined.

In many cases such periodic observations (monitoring) will require recording conditions on the ground by aerial photography and a system based on the use of a 35 or 70 mm camera mounted on light aircraft has been proposed, enabling advantage to be taekn of short periods of suitable weather.

In the part of Cameroon mapped by the project, monitoring will primarily concern the expansion of areas of degraded forest and encroachment on forest outliers in the savanna, both of which show up well on Landsat imagery. In view of the large extent of the forest zone a practical approach to locating areas of change will therefore be to compare imagery of successive dates, subsequent analysis being conducted as described above. For two sample areas in Cameroon it was also shown that the area of change in forest cover could be assessed by computer analysis of the Landsat data.

As well as the present report, the pilot project produced a comprehensive report for each of the three countries. The Togo report provides the fullest account of the ecology and dynamics of the vegetation classes; the Benin and Cameroon reports provide the fullest detail concerning the interpretation of the Landsat imagery, including interpretation keys, observations about each scene interpreted and a detailed description of the procedure for the reconnaissance flights. The present report draws on the range of the findings in the three countries for a detailed discussion of monitoring procedures and of a range of topics based on the general experience of the project, including the assessment of Landsat imagery for the work undertaken, vegetation classification and eco-floristic zonation, staffing, training, as well as outlining a statistical sampling procedure for monitoring and an alternative approach to mapping. For the fullest details on the project's activities, findings and conclusions all four reports should, however, be consulted.

The vegetation cover maps were used to estimate the area of the vegetation and land use types mapped. The results confirmed the subjective observation of a general trend towards the loss or degradation of the remaining forest and other woody vegetation cover - considerably advanced (as regards true forest) in Benin, somewhat less so in Togo, and considerable (mainly as regards degradation) and relatively localised in Cameroon. It was therefore concluded that monitoring the forest cover in critical areas will serve a useful purpose in all three countries, to provide concrete data on which to base interventions for controlling further losses leading to permanent harmful effects.

The main recommendations for all three countries were: to establish a unit to conduct tropical forest cover monitoring; to train an adequate number of staff to conduct these activities; to conduct further studies of past changes in the vegetation cover; to ensure a two-way flow of information about developments likely to cause changes and concerning the changes observed. A proposal for expanding tropical forest cover monitoring activities to other parts of the tropics is outlined in Appendix 1.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

The United Nations Environment Conference held in Stockholm in 1972 included among its proposals a World Forest Appraisal Programme. This stemmed from FAO's background paper for the Conference, entitled "Environmental aspects of natural resources management - Forestry" and led to recommendation no. 25, namely:

"It is recommended that the Secretary-General take steps to ensure that continuing surveillance, with the co-operation of Member States, of the World's forest cover shall be provided for through the programmes of the Food and Agriculture Organization of the United Nations and the United Nations Educational, Scientific and Cultural Organization.

(a) Such a World Forest Appraisal Programme would provide basic data, including data on the balance between the world's forest biomass and the prevailing environment and changes in the forest biomass, considered to have a significant impact on the environment;

(b) the information could be collected from existing inventories and on-going activities and through remote sensing techniques;

(c) the forest protection programme described above might be incorporated within this effort, through the use of advanced technology, such as satellites which use different types of imagery and which could constantly survey all forests."

In 1973 FAO accordingly submitted a proposal to UNEP for the formulation of such a monitoring programme. This was deliberately restricted to deal with the tropical forest only, it being considered more important and urgent to launch a monitoring programme in the tropics, where forest cover is generally more exposed to uncontrolled harvesting or clearing, than in temperate regions. Acting as cooperating agency with UNEP, FAO undertook the formulation of such a programme in 1974 (project 0202-73-005) and published the results in a report entitled "Formulation of a tropical forest cover monitoring project" (FAO, Rome, 1975).

The present pilot project was subsequently formulated and signed by UNEP and FAO in August 1975. Although the "Formulation" had dealt with tropical forest cover monitoring on a global scale, the pilot project was limited to execution in three countries - Togo, Benin, Cameroon - and included collaboration with Nigeria where similar work was in progress (project document, article 3.01).

In conformity with article 2.02 of the project document collaboration was established with Unesco for the adaptation of that agency's "International classification and mapping of vegetation" to the monitoring of tropical and sub-tropical forest cover (see 2.1).

The objectives of the pilot project, set out in article 2.02 of the project document, were as follows:

- to obtain for these four countries data on the present forest cover and on the quantitative and qualitative changes of the forest cover which have occurred in critical areas;

- to refine, test and possibly correct the general methodology as outlined in the report of project 0202-73-005 by applying it to these four countries;

- to prepare the extension of the tropical forest cover monitoring project to the whole African tropical and sub-tropical region and to the Latin America and Asia regions.

Agreements between the Governments of Togo, Benin, Nigeria and Cameroon and FAO concerning the execution of the pilot project were drafted in late 1975 and discussed with the authorities concerned. The Agreement with Cameroon was signed in July 1976, with Benin and Togo in October 1976.

The authorities in Nigeria proposed a radical revision of the draft Agreement to reflect Nigeria's role of contributor to the project, rather than that of beneficiary. A revised version was agreed upon in May 1976, but in spite of discussions and correspondence on the subject up to May 1978 the Agreement was not signed by the Government.

Article 12 of the Agreements with Togo, Benin and Cameroon stated that "FAO undertakes to publish at the end of the project a report containing in particular a small-scale map of the present vegetation cover of the whole of the country, as well as information on the qualitative and quantitative aspects of the degradation of the forest cover in a critical area." ("some critical areas", in the case of Cameroon).

During the negotiation of the Agreement in Benin the Government laid stress upon the inclusion of the preparation of audio-visual material by the project concerning the impact of degradation of the vegetation cover on the environment, for use in rural areas, and this was inserted as article 13.

1.2 ACTIVITIES UNDERTAKEN

Only a chronological outline of the main activities is given here. Aspects of these which had a particular bearing on the execution of the project's programme and the achievement of its objectives are dealt with in detail in Chapter 2.

Between the signature of the project document in August 1975 and the appointment of the project coordinator in April 1976 contact was made with the Government agencies in the countries concerned and the first drafts of the Agreements referred to above were prepared. The preparation of a vegetation classification was initiated, some Landsat imagery of the project area was obtained and a start was made with recruitment procedures.

These preparatory activities were pursued by the project coordinator. Equipment, remote sensing and other documentation was ordered and arrangements for office accommodation and counterpart staff were made in the three participating countries. Field experts were appointed in November 1976 and a short training course in photo-interpretation for counterpart staff was held in Yaoundé early in 1977.

Field activities continued through March 1978 in Togo, until August 1978 in Benin and October 1978 in Cameroon. To be able to conclude the vegetation mapping and all the related work by that time in Cameroon it had earlier been decided to restrict this to the southern two-thirds of the country, covering all the forest and some of the savanna areas. The field activities in all three countries included interpretation of Landsat imagery for vegetation mapping, supported by interpretation of aerial photographs, ground surveys and aerial reconnaissance flights. The selection of study areas and investigation of changes in their vegetation cover over the past twenty years or so was another major activity in the field, as was the compilation of the various project maps and preparation of draft technical reports.

Fellowships were arranged for two counterpart staff from Benin and for the project co-director from Cameroon. Other technical activities included the preparation of a contract for aerial photography for Cameroon, procurement of some enhanced Landsat imagery and a trial of computer processing Landsat data for monitoring changes in forest cover.

In Benin the Government found the results of the project's work both inherently useful and of potential value for application to planning rural development activities in general and forestry projects in particular. In June 1978 the Government therefore raised the question of assistance for continuing the project's activities after its termination. At the Government's request the project coordinator assisted with the formulation of a project covering activities for a further three years for submission to potential donors. In January 1979 FAO authorized a project under its Technical Cooperation Programme with a duration of six months for the continuation of the pilot project's activities while the longer term follow-up project was under consideration.

Project activities concluded with the drafting of the final reports and preparation of the vegetation maps for printing by the project coordinator as field work in each of the project countries came to an end.

1.3 PREVIOUS WORK

The project document (3.01) states "The reasons for selecting Togo, Benin, Nigeria and Cameroon are mainly the existence of similar activities ......" in the context of current or earlier FAO/UNEP forestry projects.

In Benin project BEN/73/014 executed a reconnaissance inventory in 1976 of some 856 000 ha in the area between Djougou and Bante. Although the inventory results had not been published at the time, they provided some floristic data for the pilot project's survey. The consultant who prepared the pilot project's vegetation map had earlier done the aerial photointerpretation for this inventory and was therefore familiar with the forest cover of the area. The same project also conducted an inventory of the Lama forest, of about 10 000 ha, in the south of Benin.

In Togo forest inventory of four areas had been conducted in 1969/70 by project TOG/68/510 (Rapport technique No. 3, FO:SF/TOG 10, 1971). The results were used as a source for the species composition of the forest areas concerned and permitted a comparison with the area and condition of these forest at the time of the pilot project's survey.

In Cameroon project CMR/72/008 had carried out an inventory of the Deng-Deng Forest of some 300 000 ha and other inventories of some 2.6 million ha had been carried out by the Centre Technique Forestier Tropical. The results of these inventories were used mainly as a source for the species composition and thus the classification of the forests mapped from the Landsat imagery.

1.4 WORKING ARRANGEMENTS

In Benin the Government counterpart agency was the Ministère du développment rural et des coopératives, which nominated a lecturer in Geography at the University of Benin as project co-director and counterpart to the FAO expert, prior to the latter's entry on duty in February 1977. Two forestry technicians who had worked on the inventories conducted by project BEN/73/014 were also assigned to the project. In September 1977 five geography students from the University also joined the project team on a part-time basis. A botanist from the University of Benin participated in most of the project's field surveys.

In accordance with the project document the FAO expert had been assigned to execute the project's work in Benin and Togo. This arrangement proved impractical and from August 1977 he was assigned exclusively to Togo. A suitable full-time replacement could not be found and instead a consultant was assigned to Benin for two months in 1977 (September-November) and two months in 1978 (June-August). The consultant instructed the couterpart technical staff who conducted most of the project's field surveys during his absence. After instruction and some initial guidance by the consultant the bulk of the photointerpretation, mapping and analysis of the study areas was done by the counterpart staff.

The Government could not provide the office space as foreseen in the project document and this was rented by the project. All field trips by expatriate personnel required specific authorization. A light aircraft became available for rental towards the end of the project and was then used for some reconnaissance flights to check the Landsat interpretation.

In Togo the Government counterpart agency was the Direction des forêts et des chasses, two of whose officials were appointed to collaborate with the project. While providing a valuable contact, these officials could not be released from their normal duties and did therefore not participate in the day to day work of the project. The Director of the Forest Production Division of the Ministère du développement rural was appointed as co-director and counterpart to the FAO expert. However, his normal duties only permitted him to deal with administrative matters but not to participate in the project's technical activities. The project also maintained close contact with the Minister of Rural Development and with the Office de développement et d'exploitation des ressources forestières (ODEF) which, through its acting director, rendered valuable service to the project. This included the provision of some part-time staff to participate in the field surveys.

Office accommodation for the expert was generously provided by the UNDP Resident Representative. From the outset the project was able to rent the President's helicopter from time to time which greatly facilitated reconnaissance surveys for vegetation mapping and the selection of study areas.

In Cameroon the Government counterpart agency was the Service des Eaux et Forêts of the Ministry of Agriculture. A forest officer was appointed as full-time co-director and counterpart to the FAO expert from March 1977. Three technicians from the Forest Service were also assigned to the project and participated in the training course held in Yaoundé (2.4) in February 1977. Later in the year two of these technicians were transferred from the project and one replacement was assigned. A botanist from the National Herbarium worked with the project team in the field for three weeks in 1978.

In accordance with the project document an expert was assigned to Cameroon for thirteen months, from November 1976 to November 1977. Little progress with the preparation of the vegetation map was made during this period. This and other work was then executed by the consultant also employed by the project in Benin, who worked three and a half months in Cameroon during 1978 (February-March, June, September-October), three weeks in Paris and a week in Rome.

Office space was rented by the Government, which made a cash contribution to the project of 10 million francs CFA. Considerable use was made of rented light aircraft during the consultant's missions, which were generally available provided notice was given sufficiently long in advance.

In accordance with paragraph 26 of the respective Agreements a national project coordinating committee was established by the Government in Benin and in Cameroon.

In the interest of coordinating the project's work it was intended to convene the FAO experts and their counterparts for a visit with the project coordinator to the three project countries and Nigeria in mid-1977. However, the delays encountered up to that time in the execution of the project's programme in all three countries caused this to be abandoned. In June 1977 the expert then working in Benin and Togo and his counterpart from Benin, with the coordinator, visited the remote sensing and photographic laboratories at the Federal Department of Forestry in Ibadan, Nigeria. Although agreement in principle had been obtained from the Nigerian authorities for the project to make some use of these facilities, the power supply problems which interrupted their functioning as well as the lack of time in the project's schedule prevented this. In October 1977 the expert from Togo visited the project in Cameroon with the coordinator for joint consultations. At this time it was arranged that the co-director from Cameroon should visit the project in Togo, but Government authorization was not obtained in time to implement this before field surveys in Togo were completed.

Guidance of the field staff to ensure a standardized approach to the project's technical activities and frequent negotiation with the Governments concerned over the technical and administrative aspects of the project's execution were undertaken by the project coordinator who also maintained contact with a wide range of technical institutions. In the course of these activities the coordinator made eight visits to Togo, nine to Benin, four to Nigeria and ten to Cameroon, as well as visiting Kenya, Upper Volta, England and France.

1.5 PRESENTATION OF THE REPORT

Chapter 1 provides the background to the project and an outline of how it was conducted. Chapter 2 takes up aspects of its execution not treated elsewhere in the report which are directly or indirectly related to the application of remote sensing to tropical forest cover monitoring and therefore of particular interest and relevance.

Chapter 3 provides a detailed account of all stages of the vegetation mapping and Chapter 4 does the same for the investigation of the changes in the forest cover of selected areas. Together they constitute the core of a methodology applicable to the preliminary stages of tropical forest cover monitoring. Chapter 5 discusses the implications of the project's experience and results for the conduct of such monitoring. Chapter 6 presents a summary of the conclusions to be drawn from the project's work and of related recommendations for tropical forest cover monitoring in the project countries.

CHAPTER 2

PROJECT IMPLEMENTATION

This chapter provides an account of some project activities and findings which were ancillary to the two major objectives of vegetation mapping and investigating change in vegetation cover. Since for the most part they had a direct influence on the execution of the two main activities and/or on the conclusions to be drawn from these they are treated in some detail.

2.1 VEGETATION CLASSIFICATION

The project document (article 3.01) states "... consultant services will be secured for the elaboration of classifications to be used (in collaboration with Unesco)..."

A contract for the preparation of a vegetation classification for the use of the pilot project was accorded to Unesco in November 1975 and sub-contracted by that agency to the Institut de la Carte Internationale du Tapis Végétal (Toulouse), under the direction of Professor Legris.

It had been specified by FAO that the classification should take due account of those of Unesco and Yangambi and among other considerations

- give due weight to the stage of degradation and reconstitution of the major forest and savanna formations encountered in the various climatic zones;
- be based on physiognomic criteria and reflect their interpretability on remote sensing documents of differing resolution;
- provide a key illustrating the appearance of various vegetation types on photographs and remote sensing documents.

The classification, embodied in a report (Méthodologie d'une classification, application en télédétection) delivered in December 1976, satisfied most of these conditions fairly adequately. It was particularly developed in the presentation of ecofloristic zones for the project area, based on bioclimatic factors, an aspect further elaborated in the course of the project's work. It gave less weight to considering the potential dynamics of the stages of degradation or reconstitution of the major formations, to which the ecofloristic zonation is particularly relevant. This aspect has been treated by the project in Chapter 4 of the report on Togo, "Les classes de végétation cartographiées", and is equally relevant to similar formations in Benin and Cameroon.

The classification itself was essentially that of Yangambi (Trochain, 1957; Aubréville,1957) based on physiognomic characteristics such as the height, structure and crown closure of the arborescent vegetation and consequently well adapted to identification on aerial photographs and satellite imagery. Its main application was as a useful starting point for the legends of the vegetation maps prepared for Togo, Benin and Cameroon, which were subsequently developed according to the formations encountered, their relative extent and importance, and the degree to which they could be consistently interpreted on the satellite imagery (3.6).

2.2 PROCUREMENT OF SATELLITE IMAGERY AND OTHER DOCUMENTATION

Some Landsat imagery, mostly dating from 1972 and '73, had been ordered in 1975 to be available for the consultants preparing the vegetation classification described above. In May 1976 a computer listing of the Landsat cover of Togo, Benin and Cameroon was obtained from the Eros Data Centre and a selection of the relatively cloud-free imagery was made and ordered.

It was noted that the computer listing was not complete and the indication of the percentage cloud cover over a scene was not always reliable. Because the imagery for the coastal areas of Togo and Benin and for much of southern Cameroon was obscured by cloud (Appendix 6), a good part of this was also ordered after ascertaining on FAO's Landsat Browse File that, for those scenes recorded at more than one date, different areas were cloud-free at different dates.

Both the U.S. Geological Survey (1975) and the World Bank (1976) had published Landsat coverage maps which were obtained in late 1976. Although these displayed the cover only up to July 1974 and May 1975 respectively, they provided a useful overview. Later information, particularly on new cover for West and Central Africa becoming available through June 1976, was obtained from the Landsat catalogues issued two to three months after data acquisition and held by FAO's Remote Sensing Unit.

The bulk of the available Landsat cover for the project countries was obtained by the end of 1976 or early 1977, when work in the field was due to start. The existence of a few scenes, for parts of Cameroon, became known only later and these were then acquired.

The Eros Data Centre, the main source of Landsat imagery, has reorganized both its cataloguing and production systems during 1978, effecting a number of improvements. But at the time of the project's initiation some difficulty was experienced in obtaining reliable and exhaustive information on the availability of Landsat cover for the extensive area represented by the three project countries.

The interval between ordering imagery and its delivery to the project in the field was usually two to three months, occasionally longer. This included FAO's purchasing procedures and transmission by pouch.

In April 1977 steps were taken to obtain new Landsat cover for the project area from Landsat-3, launched in March 1978. Although NASA (United States National Aeronautics and Space Administration) had agreed to give priority to the acquisition of new scenes for parts of Cameroon where the cover was either non-existent or mostly cloud-obscured, only one new scene for central Cameroon was in fact obtained.

It was apparent from the outset that much of the available Landsat imagery was of rather poor photographic quality and evident that its interpretation would be greatly facilitated and be more detailed and accurate if the imagery could be enhanced by improving contrast, detail and colour rendering and eliminating the striping effect. However, investigations showed that there were no facilities able to carry out enhancement on an operational basis at the time (mid-1976) (see 3.3.).

Existing Aerial Photography

Benin and Togo north of 8°30' were covered by 1:80 000 black and white infrared and panchromatic photography taken by Kenting in December 1974 to February 1975. A copy of this cover on both emulsions was purchased for the project before the start of operations in the field, since it could be used for checking the interpretation of the Landsat imagery as well as for the investigation of change in critical areas.

The whole of Benin and Togo and a large part of Cameroon were covered by 1:50 000 black and white panchromatic aerial photography taken between 1949 and about 1952 by the Institut Géographique National (IGN). For Benin and Togo portions of this cover were purchased as required directly from IGN in Paris. Delivery took two to three months and each order had to be accompanied by an authorization from the Government. To avoid repeated delays the project obtained a blanket authorization from these two Governments, of which a copy could be attached to an order.

For Cameroon aerial photography had to be purchased through the Centre Géographique National in Yaoundé, which either transmitted an order to IGN in Paris, or provided prints directly if these were available in Yaoundé. Delivery times were consequently very variable, from weeks to months, and some orders were never fulfilled. The situation was somewhat complicated by the fact that the negative archives were in process of being transferred from Paris to Yaoundé during the period of the project. However, the Centre Géographique National was very cooperative in permitting access to its air photo archives.

In Togo there was also 1:50 000 aerial photography available for the main forest areas taken in 1969. This was held by the Office de développement et d'exploitation des ressources forestières (ODEF) and made freely available to the project. During the 1976/77 and 1977/78 flying seasons IGN was producing new aerial photography at 1:30 000 for the whole of Togo. A portion of this covering one of the study areas was acquired by the project. Special arrangements were made with IGN to obtain this cover for another of the study areas where it was essential for the assessment of major recent changes, but this did not become available.

New Aerial Photography

New aerial photography would have been useful for the southern part of Benin not covered by the Kenting photography. The cost for the whole of this area would have exceeded the provisions of the project budget and although the possibility of photographing selected areas as an adjunct to their mission in Togo was taken up with IGN, the premature termination of this mission did not permit this.

In the absence of recent aerial photography for the forest areas of Cameroon the project's programme in relation to investigating changes in the forest cover over time was entirely dependent on obtaining new aerial photography of selected study areas. The steps taken to obtain this, described in section 4.1, all proved abortive mainly due to abnormally unfavourable weather conditions. As a result no systematic analysis of change, as made in Benin and Togo, could be undertaken in Cameroon.

Topographic Maps

All three countries had virtually complete map cover at 1:200 000 made by IGN from the aerial photography of the 1949-52 period, which was purchased locally. These showed vegetation boundaries usually with high accuracy, but in rather general categories. Detailed comparison with Landsat imagery revealed some errors, particularly in the mapping of rivers among dense vegetation, which is understandable.

The IGN 1:50 000 map cover was very partial in all three countries and the project had to produce the base maps at this scale for most of the study areas (4.2) by photographic enlargement of the maps at 1:200 000.

The 1:500 000 map cover was complete and copies of the original films without the vegetation sheet were obtained from IGN to serve as a base for the vegetation mapping in Benin and Togo. For Cameroon these were photographically reduced to 1:1 million as no accurate map at this scale was available.

2.3 PROJECT STAFFING

The pilot project was formulated on the assumption that the vegetation cover of Togo and Benin on the one hand and of Cameroon on the other would each be mapped mainly from the interpretation of Landsat imagery by one person in well under twelve months.

The necessary technical qualifications for the field staff therefore had to include experience of interpreting Landsat imagery and aerial photographs for tropical vegetation survey; some experience of plant ecology and of West African forest and savanna vegetation; experience in the compilation of vegetation maps, including mapping from satellite imagery and aerial photographs. The experts also had to be French speaking to a level that would permit work with francophone counterpart staff and all reports to be produced in that language.

By the third quarter of 1976 when the assignment of field staff, originally scheduled for April 1976, was becoming urgent only two available candidates with some of the necessary qualifications had been located. They were consequently recruited, as of November 1976, in the expectation that the relative lack of experience in the use of Landsat imagery would be made good in the course of the work, since this was essential to achieve the project's major objectives.

In the case of one of the experts this expectation was borne out, in the case of the other it was not. The former was initially assigned to work in Benin and Togo and was assigned to Togo on a full-time basis from August 1977. He was able to complete the interpretation and essential field work by the end of March 1978. The latter worked in Cameroon from November 1976 to November 1977, but made little progress with realising the project's main objectives.

Intensive efforts made to recruit suitable replacements for Benin and for Cameroon were without avail and the project would have been in a very difficult position had it not become possible to obtain the services of a consultant in September 1977. The latter was a forestry photo-interpretation specialist with some thirty years experience of geodetic surveying, forest surveys, photo-interpretation, and mapping in the tropics, including the project countries, and some experience of using Landsat imagery.

In the course of two missions in Benin, each of two months, he was able to complete the vegetation mapping, initiate and supervise work on the two study areas and conduct training of counterpart staff, as well as drafting a technical report.

The work for Cameroon, including the vegetation mapping, the selection of study areas and the interpretation of the available aerial photographs, training counterpart staff and preparing subsequent work programmes, and preparing technical reports, was carried out in three missions respectively of two months, two weeks and one month, plus three weeks of Landsat interpretation in Europe. As the consultant was not available on a continuing basis, these missions were carried out when his other commitments allowed.

In Togo, due to lack of personnel, no full-time technical counterpart staff was assigned by the Government to work with the project expert. In Benin there was a full time co-director (lecturer in geography at the University of Benin, Cotonou), and two forestry technicians with some experience of forest inventory on another FAO project. From September 1977 five geography students in their last year also spent varying amounts of time working with the project.

In Cameroon there was also a full-time co-director seconded from the Forest Service (Ingénieur des Travaux) and at first three and later two forestry technicians without prior experience in photo-interpretation.

The two co-directors organized and conducted field surveys, but did not generally participate in the day to day technical activities, being occupied with the administrative and logistic aspects of project operation.

By the end of the project several of the technicians and geography students had become competent in some aspects of the work, but none had mastered all the operations to a level where they could work without guidance. For those with the necessary aptitude, continuing practice and further training are therefore indicated. The project itself was in a position to award three fellowships for a total of seventeen man-months.

One of the aspects of coordinating the project's work was to ensure that the results produced in the three countries were not only compatible but as uniform as possible. Nevertheless, the bias introduced by the contrasing specializations and experience of the consultant and the expert working in Togo remains perceptible.

The work in Togo was done by a field ecologist with relatively little previous experience in the application of remote sensing. The interpretation and mapping for Togo are on the whole less detailed than for Benin and Cameroon, and the report provides a very full ecological description of the country and its vegetation, with less weight given to the application of remote sensing.

In Benin and Cameroon the work was done by a specialist photo-interpreter with a fair knowledge of the vegetation but no ecological training. The maps were consequently rather more detailed and the reports provided very full accounts of the remote sensing aspects of the work, but less detail concerning the vegetation and its ecology. This difference in emphasis does not detract from the overall validity of the results; rather it may be considered an added advantage in that, within the project as a whole, both the ecological and remote sensing aspects have been treated very fully.

The experience of the project indicates that the limited availability of people who combine fairly common qualifications in tropical forest survey or plant ecology with adequate experience in the use of satellite data for the production of vegetation maps in the tropics could present a problem for large scale activities in tropical forest cover monitoring.

Until now the major source of people trained or experienced in satellite remote sensing remains North America (National Research Council, 1977, p.135) and these tend to be mostly anglophone and without tropical experience. The fewer qualified people available in Europe, although more commonly multi-lingual and acquainted with the tropics, are in such demand that they are rarely available for the fixed term assignments offered by U.N. projects. In the short term, therefore, the recruitment of field staff with the necessary qualifications is likely to remain a problem, particularly for work in non-anglophone areas. The solution will be to train staff from developing countries, as emphasized in the recommendations of the three technical reports. While the project has made some contribution to this, it will require a large and sustained programme before the need for such specialists is fully met.

2.4 TRAINING

At an early stage of the project's field operations a training course in photointerpretation and mapping was organized. This was held in Yaoundé from 31 January to 26 February 1977. It was conducted by the same consultant who subsequently executed the bulk of the project's field work in Benin and Cameroon.

The course was conducted at the practical level, with most of the time spent on laboratory and field exercises. The course was attended by personnel from Cameroon consisting of the project co-director, two forestry technicians assigned to the project and three geography students from the University of Yaoundé. From Benin the course was attended by the two forestry technicians assigned to the project. These worked with the project throughout its duration. Of the two technicians from Cameroon one stayed with the project throughout, the other left the project within the year.

No personnel from Togo attended this course as arrangements had been made for the two counterpart technical officers to attend a six weeks course being held about the same time by IGN in Lomé. For administrative reasons their attendance at this course was only partial. The consultant provided a detailed report on the course in Yaoundé, including an evaluation of the students' performance on the basis of weekly tests and considered this to be very satisfactory.

In Benin and Cameroon where counterpart personnel constituted the main element of the project staff, on the job training was intensively conducted by the consultant during the course of his missions in those countries (1.4). This included all aspects of the project's activities. However, as pointed out in the consultant's report referred to above, practice and experience are the main basis for competence in these activities, to which periodic refresher courses may usefully be added. At the end of project's field activities the photointerpretation technicians in Benin and Cameroon had not reached a level which would permit them to work without guidance, or to enable them to train other staff.

From an early stage the Governments of Benin and Cameroon insisted on the necessity of the adequate training of the national staff to enable project activities to be pursued on the termination of UNEP/FAO assistance. The original allocation for training in the project budget was increased to permit the financing of a four-month fellowship in satellite remote sensing for two of the geography students who had formed part of the counterpart team in Benin, and of a nine-month fellowship in forest surveys and remote sensing for the co-director in Cameroon. The two former fellowships were implemented from October 1978 to January 1979, the latter will be undertaken from January to September 1979.

2.5 EQUIPMENT

Equipment of a wide range of sophistication - from zoom stereoscopes through colour additive viewers to electronic density slicers with digital storage - has been and continues to be developed for the visual interpretation and mapping of Landsat imagery. While such instruments undoubtedly have their uses, they require skilled operators and can be troublesome to maintain. As the project was foreseen to have access to such instruments at the Federal Department of Forestry in Nigeria, it was decided to acquire only simple mechanical instruments which would entail no risk of breakdown and so avoid any compromise of the project's very tight programme.

The adequacy of such elementary instrumentation for the detailed and rapid interpretation and mapping of Landsat imagery constitutes one of the project's most significant findings. It demonstrates that, at least in the first phase of developing a capability for the application of remote sensing data, the emphasis can be placed on training staff in the characteristics of the data and of the resources to be managed, rather than on complex instrumentation.

As described in 3.5 the basic interpretation was carried out on imagery in the form of diapositives. These were placed on a light table and examined under an ordinary mirror stereoscope. These two items formed the core of the essential equipment. The mirror stereoscopes also served for aerial photointerpretation, of which the results were transferred to a map base using a sketchmaster.

Ancillary items included pocket stereoscopes for use in the field; hand lenses for examining fine detail on the imagery; an overhead projector for projecting the imagery diapositives onto a topographic map or an assembly of aerial photographs; planimeters and dot grids for area measurements and a pantograph for transferring detail between documents of different scales.

Other than this, only the usual range of draughting materials was used. In this connection it was found that draughting film less than 0.05 mm thick tended to be very unstable in tropical conditions.

For field work the normal range of equipment was used, including cameras, binoculars, cassette recorder (for aerial survey), compass, altimeter and measuring tapes.

2.6. COLLABORATION WITH NIGERIA

The project document states (3.01) "Actual monitoring will be carried out in the three francophone countries (Benin, Cameroon and Togo) and close collaboration will be secured with the forest monitoring activities of the Nigeria project."

Although no formal Agreement was signed by Nigeria and FAO as foreseen (1.1), the Nigerial authorities - the Director, Federal Department of Forestry and his staff - and the staff of the UNDP/FAO NIR/71/546 Forest Development project in Ibadan were at all times very cooperative.

The Federal Department of Forestry had complete Side Looking Airborne Radar (SLAR) cover of Nigeria flown in 1976-77. The interpretation of the SLAR cover and preparation of vegetation and landuse maps at 1:250 000 for the whole of Nigeria was sub-contracted to a firm in the U.K. The project coordinator maintained close contact with the firm, in particular over the vegetation classification being developed for the SLAR mapping, since both sides agreed on the desirability of using a common classification as far as possible. Initially the pilot project's classification (2.1) formed the basis for that being used for Nigeria, but subsequently this was abandoned and the classification developed for the new Unesco sponsored 1:5 million vegetation map of Africa was adopted, which departed considerably from the classic 'Yangambi' terminology. The pilot project's and the Nigerian classification are consequently substantially different as regards the naming of many of the classes (and the Nigerian maps at 1:250 000 have rather more classes than the project's smaller scale maps), but the correspondence between the two can be readily established.

Of the 69 map sheets covering Nigeria about half had been printed by the end of 1978. Among those which could be examined was one which adjoined the pilot project's map for northern Benin. Allowing for the different scales the maps display a good match.

Early in the project it had been contemplated to conduct preliminary interpretation of the Landsat imagery using the instrumentation at Ibadan. A colour additive viewer was available there and a density slicer was due to be installed. There were also excellent photographic facilities. The Nigerian authorities were agreeable in principle to such an arrangement. However, apart from a very small amount of work, this could not be pursued partly because of chronic difficulties in operating the instruments due to problems of power supply and procurement of spare parts (and a long delay in the installation of the density slicer), partly due to the delays experienced with the project's programme in the early stages.

It had initially been envisaged that the remote sensing activities of the Nigerian Forest Development project would include analysis of the change in vegetation cover in a number of representative regions, analogous to the pilot project's study areas and that the latter would participate in these. Although this did not prove to be possible, one study was carried out in Nigeria, in six sample areas in the extreme north between Sokoto and Maiduguri. These used aerial photography from 1950 and Landsat imagery from 1976 to compare changes in the area of cultivation between these two dates.

The vegetation maps produced from the SLAR cover of Nigeria can be used in the same way as those prepared by the pilot project to determine critical areas as a basis for monitoring activities (5.2.2). When the printing of the Nigerian maps has been completed it will also be possible to prepare a consolidated vegetation cover map, at an appropriate scale, which could serve to record the present state and subsequent changes of forest cover over the combined area of the four countries.

CHAPTER 3

VEGETATION MAPPING USING LANDSAT IMAGERY

3.1 INTRODUCTION

From the title of the project and its objectives (1.1) it was to be understood that the formations to be mapped were not only the forests but also those with an element of woody vegetation - woodland and tree and shrub savannas. The concept was evidently not limited to forest as such, given that for example in Benin there were only some 63 000 ha of forest, less than 1% of the total area of the country. It was equally clear that no detailed work would be undertaken on areas without woody vegetation, although such areas were identified and delimited on the maps in order not to leave unidentified blanks and to indicate the conditions on the boundaries of areas of direct interest. The latter has particular relevance to the identification of critical areas to be monitored (see 5.2.2).

The project document was adapted in many respects from UNEP/FAO project 0202-73-005 "Formulation of a Tropical Forest Cover Monitoring Project" (FAO, 1975), where it was stated that the term 'forest' was to include "all woody vegetation types down to shrublands .."(2.1).

The 'Formulation' also states (4.4.1.): "It is proposed to use as a main source of information satellite imagery ...". This was also implicit in the formulation of the pilot project, in that 25 man/months of field experts were allocated to map the vegetation of Togo, Benin and Cameroon, whose aggregate area was given in the project document (3.01) as 644 000 km^2, and carry out the 'back-look' studies.

3.2 ASSESSMENT OF LANDSAT IMAGERY FOR MAPPING TROPICAL FOREST COVER[1/]

The detailed vegetation cover maps of Togo, Benin and southern Cameroon prepared by the project, in each case comprising the first such maps produced for these areas at this scale, indicate the considerable possibilities of the application of Landsat data to this type of work. Despite the shortcomings described below, the Landsat imagery which was available generally permitted the relatively rapid and accurate delimitation of the major vegetation classes of interest. In certain instances, notably class 14 on the Togo map (see Appendix 3), a rather wide range of physiognomic types could not be distinguished with sufficient certainty or consistency to permit their separation. But this did not detract from the general validity of the method.

1/ As the terms 'scene' and 'image' are frequently employed it will be useful to define them. The continuous 185 km wide strip of the earth's surface recorded by the satellite is divided into units 185 km long before the data is processed and disseminated. The data corresponding to such a frame of 185 km on a side constitutes a scene. A scene is therefore defined by its geographic coordinates and date. The coordinates vary only by a few seconds or minutes at different dates. The numerical data comprising a scene is in most cases transformed into photographic negatives for each spectral band and their colour combinations. These negatives are used to generate a range of photographic products which constitute the images of each scene (generic:imagery).

Whereas aerial photography displays an optical image of the ground, albeit from an unaccustomed (vertical) viewpoint, Landsat multispectral imagery displays a rather complex and degraded analogue representation of features on the earth's surface. (The complexity arises mainly from the variable mixture of elements on the ground (e.g. soil, grass, trees) within the limits of resolution; the degradation from the numerous processes in the production of a photographic image from the original numerical data). Consequently Landsat imagery requires rather more elaborate decoding than an aerial photograph, quite apart from considerations of scale and resolution.

For mapping vegetation over large areas at scales of 1:500 000 or 1:1 million, the small scale of the standard Landsat photographic products (normally 1:250 000 to 1:1 million) and the degree of integration due to the limited resolution of these images (very variable but rarely better than 200 m in a given direction) are useful characteristics. The difference of scale and detail between the map to be compiled and the imagery is thus far smaller than would be the case with conventional aerial phtography, at scales generally not smaller than 1:80 000 and displaying detail down to a few metres in size. To this must be added the fact that a Landsat scene covers 185 x 185 km (34 225 km^2), requiring about 800 aerial photographs at 1:50 000 (with the usual overlap) to cover the same area. From a purely logistic aspect it is therefore much more convenient to work with Landsat imagery than with conventional aerial photography when mapping extensive areas. This is not to say that Landsat imagery can or should entirely replace aerial photography for working at these scales; but it does permit its use to be reduced to the absolute minimum required as a key to interpreting specific features on the imagery. Such interpretation, obtained from a restricted number of aerial phtographs, can frequently be extrapolated over large areas of a Landsat scene and so yield considerable savings in cost and time.

Another major advantage of Landsat imagery is that it exhibits very little distortion in relation to a geodetic map of the same area (Mott and Chismon, 1975; Wong, 1975). The process of transferring the boundaries of vegetation classes from an image to a map base can therefore usually be accomplished by more or less direct tracing from one document to the other (3.7). With aerial photographs, especially when the photos and map are of widely different scales and the terrain is not flat, the process is laborious and costly and usually requires the use of a photogrammetric instrument, even if of a low order.

A corollary to the dimensions of a Landsat scene is that the coherent (synoptic) view of a very large area which this provides may itself generate some information not otherwise obtainable. The distribution and juxtaposition of features and the transitions between them, over several tens of thousands of square kilometres, is inevitably instructive and the patterns which emerge often suggest a first level of interpretation.

Subsequent levels are then attained by the process described in 3.5. To what extent all the stages of this process have to be applied and over what length of time will depend partly on the complexity of the vegetation and of its spatial distribution, partly on the quality of the imagery available (see below), and largely on the familiarity of the interpreter with the area or with similar conditions - metaphorically, on whether it is a case of picking up a dialect, or of learning a new language.

Once the interpreter has become sufficiently familiar with the main features of the natural vegetation and land use (which is an inseparable boundary feature), the detailed interpretation, including checking with ancillary information such as air photos, topographic maps and other documents, can proceed fairly rapidly. The project's experienced photointerpreter in Benin and Cameroon was able to complete the detailed interpretation of an image in about five days. A lot of additional work is of course required before this results in the compilation of a map. Nevertheless, it is a rate of progress which compares very favourably with the time which would be required to interpret several hundred aerial photographs for a compilation at the same scale.

A comparison between the 1:500 000 vegetation maps produced by the project for Togo and Benin with a vegetation map of Ivory Coast at the same scale (ORSTOM, 1971), made by the conventional procedure of aerial photograph interpretation, shows that the detail and the range of physiognomic types mapped are very similar. This provides some indication that the use of Landsat imagery, with the attendant advantages in terms of time and cost, does not necessarily imply any loss of detail at the scales used by the project and under the conditions encountered.

It is worth pointing out, however, that the imagery had certain shortcomings which, if remedied in whole or in part, would result in a significant improvement of the efficiency of its use in terms of time and cost, and in many instances increase the detail and accuracy of the maps produced.

The major problem in this respect was the absence of Landsat cover for parts of the project area. This was either because no image had been recorded (e.g. southern Cameroon) due to persistent cloud cover, or the recorded images were obscured by cloud (the coastal areas and southern Cameroon). This resulted in approximately 25% of the area mapped in the three countries being without Landsat cover, mostly in Cameroon. The technique used to overcome this problem there is described in 3.5.4. In Togo and Benin only the coastal, mainly agricultural areas were seriously affected and these were therefore mapped in less detail (Togo), or with more intensive ground survey (Benin).

When several images with extensive cloud cover have been recorded for a scene, since the gaps in the cloud will generally be in different places at different dates, such scenes can be used in combination to obtain a 'cumulative' image of the area. However, this would not work when the cloud is diffused over the whole scene and the gaps are therefore very small, which was the case with some scenes.

In southern Cameroon where this problem was most severe some virtually cloud-free scenes had been recorded, whereas adjacent scenes were unrecorded or almost totally cloud obscured. This seems to indicate that for the latter it should also be possible to obtain cloud-free imagery, although this would require a deliberate campaign of data acquisition on the part of NASA. In 1977 such a campaign for this area was in fact arranged with NASA, to take advantage of the launch of Landsat-3. But this resulted in only one new image for a scene somewhat to the north, for which good imagery was already available (2.2).

Among the major advantages cited for Landsat data, particularly for vegetation mapping, is the possibility of obtaining contemporary cover for very large areas and for a range of seasons. Even more important is the ability to select imagery recorded during the most favourable period for the purpose in view. The very real advantages represented by these factors were not available to the project and are in fact rarely met with in the tropics outside the areas covered by Landsat receiving stations.

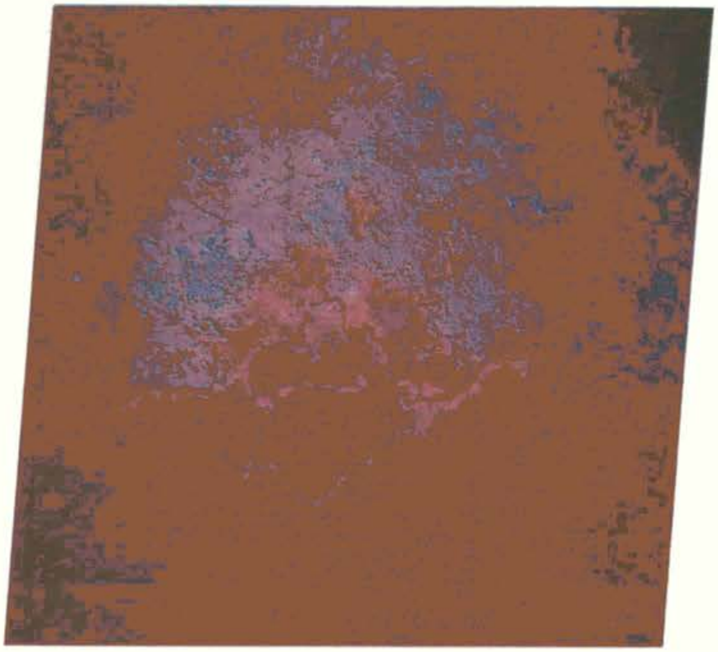


Figure 1. Scene 1478-08454, 13 November 1973. The light fleck in the centre is the town of Batouri in Southern Cameroon. The forest-savanna boundary appears very distinctly, as do areas of degraded forest (lighter red), forest outliers, galleries and areas of burnt savanna (blue). One of the few cloudless scenes over the forest zone.

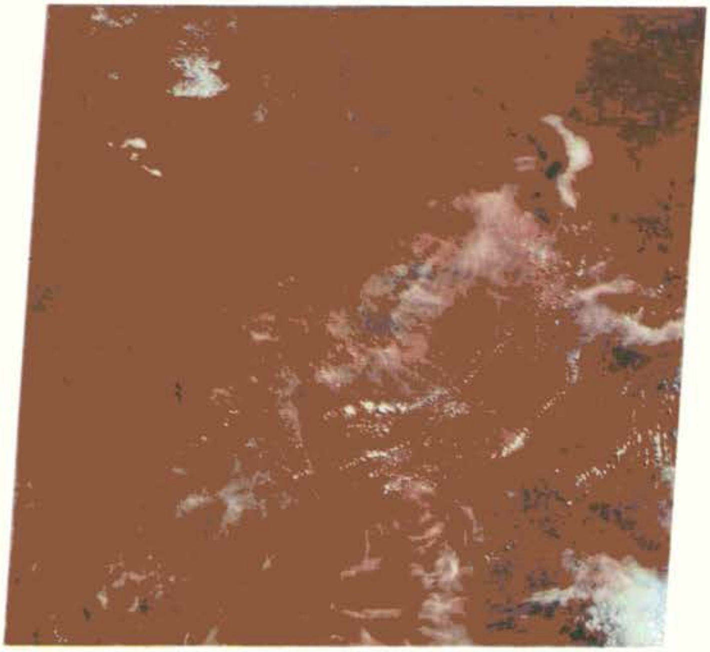


Figure 2. Scene 2134-08470, 5 June 1975. Except for the extreme southern part the area lies to the north of that mapped in Cameroon. The overwhelming spectral response of the new grass cover early in the rainy season is well illustrated, as well as the incidence of cloud.

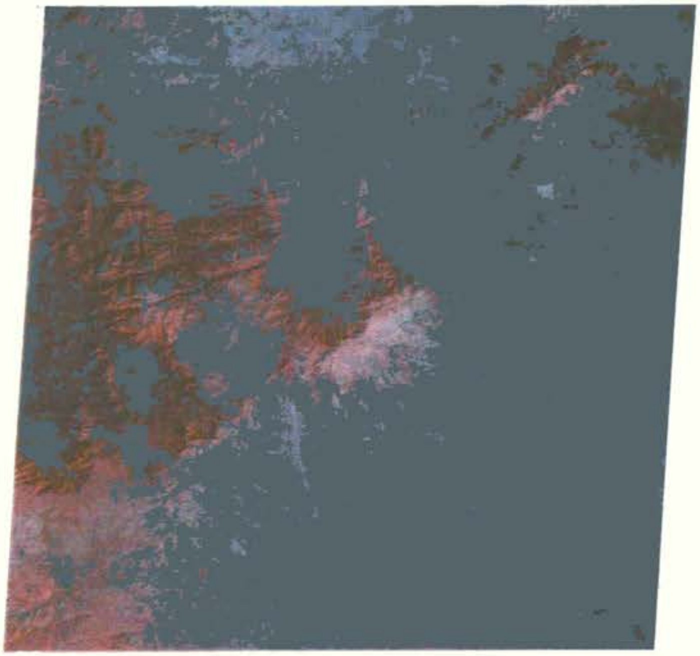


Figure 3. Scene 2332-08445, 20 December 1975. The same area as figure 2, in the dry season, showing the extensive burning of the grass cover (blue).

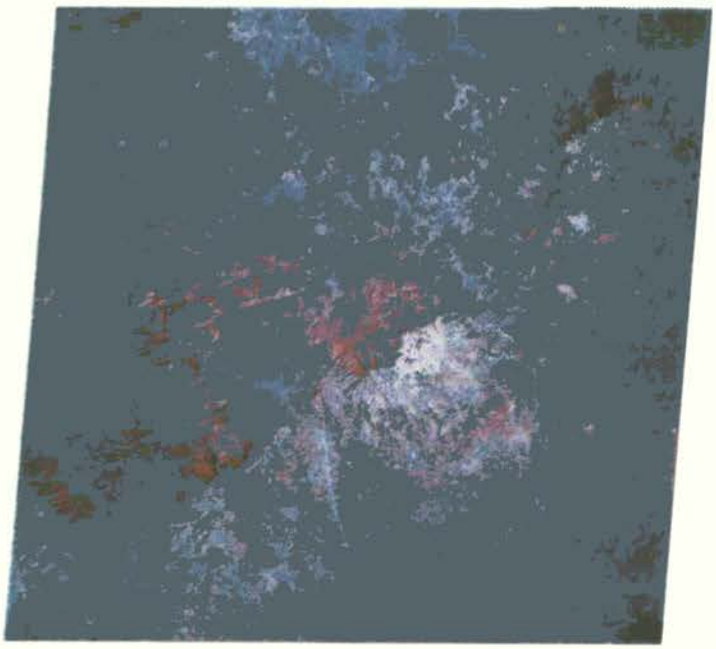


Figure 4. Scene 1210-08590, 18 February 1973. The same area as figures 1 and 2, later in the dry season of a different year. The shift and spread of the burnt areas is striking, especially in the south west corner.

The two main reasons for this are the limitations on the frequency with which scenes can be recorded outside the direct range of the existing receiving stations (at the time limited to North America, Italy and Brazil), and the monsoonal climate of most of the tropics, characterised by an extended rainy season with abundant cloud cover, particularly at the time of the Landsat pass at about 09.40 hours at the equator.

As a result of this situation about 75% of the project area was covered only by dry season imagery, on which the predominant features (outside the high forest zone) were areas where the grass layer had been burnt. No direct interpretation of the vegetation, other than grass, present on these areas was possible, although inferences about other formations could be made. The few scenes for which imagery of more than one season was available clearly indicated that such cover could greatly facilitate interpretation, especially when the dry season imagery was extensively obscured due to burning. In addition to the relative sparseness of Landsat cover for the project area, the useable images had been recorded in various months during the dry season of years ranging from 1972 to 1976. This chronological disparity inevitably affected the accuracy of the vegetation mapping, controlled from air and ground surveys conducted in 1977/78.

A third factor militating against obtaining optimum results from the imagery was the mediocre quality of a large proportion of the standard photographic products delivered by the EROS Data Centre (EDC) and even more so by the USDA Western Aerial Photography Laboratory which was used at one time because both its prices and delivery time were lower than those for the EDC. The film products (diapositives) were often very dense so that even on a light table little could be seen. The colour products were extremely variable in colour rendering, both in space and time and the colour prints were often not particularly sharp and tended to have a uniform tint.

In recognition of this problem the EDC established a completely new production system (EROS Digital Image Processing System - EDIPS) in February 1979 by which both digital enhancement and improved colour processing is routinely applied to standard products. The resultant images will therefore be more readily interpretable than those which were available at the time of the project.

3.3 IMAGE ENHANCEMENT

As pointed out in 3.2 the quality of the Landsat imagery available to the project was generally mediocre and it was evident that interpretation could be more detailed and accurate using enhanced imagery. Production of the latter involves processing the data constituting a scene in its digital form on a computer compatible tape. This enables the banding effect to be eliminated and the introduction of better contrast, thus improving resolution and edge detection. It would also have allowed optimum photographic processing for sharpness and colour rendering. The possibility of obtaining computer enhanced imagery was therefore investigated at an early stage of the project. It was found, however, that at the time (mid-1976) there were no operational facilities in existence which could perform the enhancement of some 30 scenes at a reasonable cost and in a reasonable time. The EROS Data Centre, main source of Landsat imagery, is due to produce enhanced imagery on a routine basis starting in 1979, but this has come too late to benefit the project.

Colour additive viewing of the Landsat imagery was used only on an experimental scale. Originally the possibility was considered of letting the two field experts spend some time examining the Landsat imagery on a colour additive viewer, before going into the field, but in the event the scheduling of the work programme did not permit this. Nor was it subsequently possible to use the colour additive viewer in Ibadan (Nigeria) due to the problems of power supply there and the exigencies of the experts' programme. The density slicer being installed at Ibadan is becoming operational over a year after the date originally scheduled and was therefore not available (2.7).

This is not considered to have affected the ability to interpret the imagery. The use of a colour additive viewer can be helpful for the preliminary evaluation of certain image characteristics, but is only useful for interpretation in proportion to the information available about the area concerned. Once the experts were in the field, with the possibility of making ground and air surveys, the use of a colour additive viewer or density slicer was no longer necessary.

The experimental colour additive procedure which was used consisted of having controlled diazochrome colour composites made for part of one scene of Cameroon and one of Togo. None was made for Benin as there was no staff in the field there at the time.

The diazochrome products were made by the Department of Natural Resources of Cornell University (Dr. J.E. Skaley) where a computer model has been developed for evaluating the several variables involved in making diazo composites to obtain maximum contrast between specified grey levels on the original imagery (Skaley et al., 1977).

The diazochrome composites were made from the 70 mm transparencies and covered some 3 800 km^2 at a scale of about 1:275 000. The balanced colour rendering greatly enhanced the contrast between various features on the imagery and highlighted very subtle differences (figure 5). Due to the generally poor quality of the Landsat colour imagery (diffuse and variable colour rendering, lack of contrast and sharpness) the enhanced diazo products would have greatly facilitated interpretation and mapping of vegetation, had it been possible to make these for the entire Landsat cover being used. Unfortunately, this was not something the laboratory concerned could undertake.1/

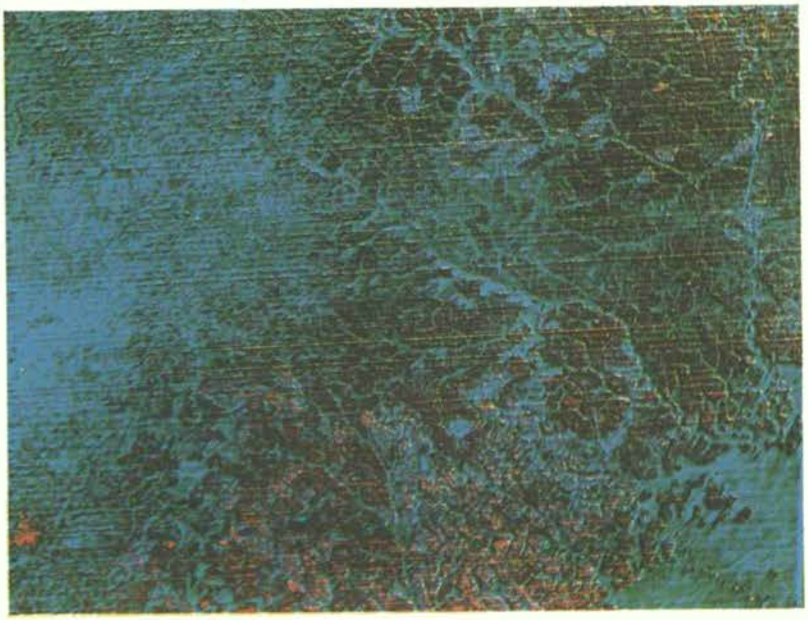
The work of the project was therefore carried out with the routine products available. While these were adequate for the purpose, part of the information recorded by the satellite was degraded and not available from these products. To have maximum access to the information content of Landsat imagery for vegetation mapping the use of imagery enhanced by whatever procedure is most appropriate is strongly to be recommended, although the relative costs and benefits must also be taken into account.

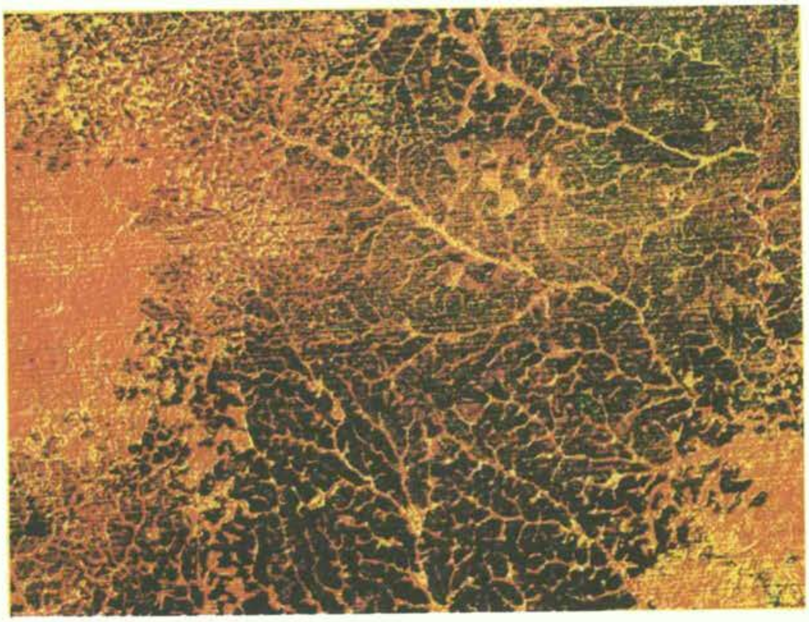
1/ Although there appear to be no commercial facilities which can readily produce diazo diapositives in large format and for numerous scenes, an increasing number of remote sensing institutions are undertaking such work on a routine basis for their own purposes and could probably handle a limited number of scenes for outside interests.

Figure 5a (opposite). A diazo false colour composite of a portion of the scene reproduced in figure 1 (1478-08454), depicting an area in the south of Cameroon. The illustration has been reproduced from a 35 mm slide of the original, which has a scale of about 1:140 000. The diazo copy is composed of band 5 (positive) in cyan, band 7 (negative) in yellow, band 5 (negative) in magenta. Green is undisturbed forest; light blue is degraded forest and in the galleries includes inundated or swamp forest and other riparian vegetation. Burnt grassland, mainly at the bottom centre, appears as a mixture of red and blue and unburnt savanna with varying proportions of trees and shrubs as a mixture of red and green. The red patch at bottom left is the town of Bertoua. The effect of the striping in the origninal image is evident.

Figure 5b (opposite). Diazo false colour composite as 5a, but composed of band 5(negative) in cyan, band 7 (negative) in yellow, band 7 (positive) in magenta. Undisturbed forest is yellow, degraded forest magenta and very subtle variations in the forest canopy appear to be depicted. The burnt areas are strongly contrasted.

The colours of the original diazo copies have been somewhat modified during the various stages of their reproduction here.





3.4 SELECTION OF MAP SCALE

Standard Landsat imagery is commonly available at scales of about 1:3.4 million, 1:1 million, 1:500 000 and 1:250 000. The entire range of products (black and white and colour prints and film transparencies) is routinely available only at the scale of 1:1 million. This and the 1:500 000 (for which only the colour transparency is not produced) are also the best scales for interpreting vegetation, since 1:3.4 million is too small and at 1:250 000 the placing of linear boundaries around vegetation and land use classes which do not exhibit well defined boundaries, either because there are transitions on the ground, or because the imagery is not of good quality, becomes increasingly difficult.

It was clear, therefore, that the interpretation would be done either at 1:1 million or 1:500 000. For Togo and Benin the larger of these scales was selected for the mapping as this would permit showing all detail of interest, but still be practicable as relatively few scenes were involved and in that one map sheet would suffice for Togo and two for Benin. This also kept the actual map drawing work to a reasonable level, given the limited time and staff available to the project. Furthermore the Governments preferred the use of this scale.

In Cameroon, from cartographic considerations alone, it would also have been preferable to map at 1:500 000, to be able to show fine detail which could be interpreted in certain areas. However, the whole of Cameroon is covered by about 16 sheets at this scale, whose production would have faced the project with an unmanageable task. Even when it was decided to map only the southern portion of the country these considerations were still valid, since time and manpower were then even more critical, so that the scale of 1:1 million was retained.

The scales of 1:500 000 and 1:1 million used for the vegetation maps, though selected pragmatically, are the same as those recommended in the 'Formulation' (4.4.1).

3.5 IMAGE INTERPRETATION

Whereas on an aerial photograph it is generally possible to identify such features as trees, shrubs, grassland, bare soil, urban areas, etc. directly, this is not the case with Landsat imagery. Although the images are produced on photographic paper, or film, by the usual developing and printing of negatives, the tones and textures on the latter are derived from electronic signals corresponding to a range of integrated levels of reflectance from areas of about 0.4 ha (ca 1 acre) on the ground recorded by the Landsat multispectral scanner. Consequently there is no photographic image of the kind obtained when a film is exposed through a lens on which the features are more or less immediately recognisable by the human eye.

The recognition of features on a Landsat image, i.e. its interpretation, is therefore somewhat analogous to learning a code and is best approached by a series of steps directed at establishing the correspondence between tones of grey, or colours, and textures on the image and the features on the ground whose reflectance gave rise to them.

If an area is well known and can be located on a Landsat image then the matching of the distribution of tones and textures on the image with the known features on the ground is fairly readily accomplished, at least in theory. In practice, relatively small variations of ground features such as density of the vegetation cover or of soil colour, which can be ignored for purposes of classification when making observations on the ground, may cause considerable variation of appearance on satellite imagery. Conversely, some variations readily observed on the ground and possibly on aerial photographs, such as species composition of a forest, may be completely undetectable on a Landsat image.

The essential procedure for interpreting Landsat imagery in terms of vegetation cover is therefore to obtain as much relevant information as possible about the area concerned, matching this information with the imagery and progressively refining the detail with which this is done, and then extrapolating the resultant interpretation key as extensively as possible.

3.5.1 Familiarisation

The readily available literature on the vegetation, geology, soils, land-use and climate, including thematic and topographic maps, was examined in conjunction with the imagery. At this stage it was usually most instructive to examine mainly the colour composite images (1:500 000) rather than individual spectral bands printed only in black and white.

Certain features, such as the larger rivers and lakes, urban agglomerations and areas of pronounced relief could for the most part be readily identified on the imagery at a first look. By reference to topographic maps the location of such features could be established and, by extrapolation, the location of areas whose appearance on the image gave no direct clue to their nature.

At this stage it was useful to delimit areas of broadly homogeneous appearance on the image and then compare these with topographic and thematic maps to establish any relationships between image and ground features which might emerge. If aerial photo mosaics had been available these would have been the most informative documents to use because of their high information content in a form readily matched with Landsat imagery and the relatively large area they cover. However, mosaics were not available and quotations for their production from the available photo cover were prohibitively expensive.

In practice major geologic and/or soil boundaries, boundaries of predominantly cultivated and non-cultivated land and of areas with a more or less closed vegetation cover (but only if in a green state, since the chlorophyll pigments give rise to the characteristic spectral reflectance of vegetation) could generally be identified at this stage.

The season at which the image being examined was recorded must be taken into account, as this strongly influences a range of factors such as the state of the vegetation, the annual land use cycle (particularly the presence of burnt areas) and variations in soil moisture, which can all have a pronounced effect on the appearance of an image (figures 2, 3, 4). Preliminary information on such factors was obtained, where necessary, from the relevant literature.

Further insight into the way in which given features are represented on an image was obtained by noting smaller areas of homogeneous and well defined appearance and locating these on a map, or on recent aerial photographs when available, to determine what they represented on the ground. A useful technique for matching imagery and maps, or rough assemblies of aerial photographs, was to fix the latter on a wall and use an overhead projector to project the 1:1 million colour transparecy of an image, matching the scales by moving the projector to the appropriate distance. The latter is facilitated by joining some of the geographical coordinate tick marks on the image, on a thin film overlay, and the same coordinates on the map and moving the projector until the lines coincide. Doing this for a range of locations led to the progressive construction of an interpretation key, at least for a given image, since absolute colour or grey level values tended to vary from one image to another. But by virtue of increasing familiarity with an area and the corresponding Landsat cover, such variations posed progressively less of an obstacle to interpretation.

At a point in this procedure when the interpreter had an adequate idea of the nature and range of features to be encountered on the ground and was sufficiently familiar with the imagery to perform fairly ready matching between image and ground, it became most useful to take the images into the field for a first direct checking and interpretation.

This may also be preceded by a broad reconnaissance of the area prior to any interpretation, particularly if the available maps and literature are inadequate and/or the interpreter is unfamiliar with the region.

3.5.2 Aerial Surveys

Such reconnaissance surveys are best done from the air when this is possible. For mapping whole countries it enables the extensive areas involved to be surveyed more efficiently than from the ground. Features required for orientation on the imagery can usually be readily located from the air and the synoptic vertical view of vegetation physiognomy, particularly crown closure, and of the spatial distribution corresponds more closely to the appearance on the imagery than that obtained from ground traverses.

The most useful aircraft is a helicopter of the four seater type (e.g. Alouette 2 used in Togo) where the cabin is mostly of clear plastic giving a good field of view. The manoeuvering and hovering capabilities are also useful, permitting a closer and more prolonged look at given features. A slow flying speed of ca 130 km/hr can also be readily maintained. If light aircraft are used they should have analogous characteristics, i.e. high wings not obstructing the view and the ability to maintain a relatively low flying speed. The single-engine Cessna 206 and twin-engine Partenavia used in Cameroon and flying at ca 200 km/hr were found very suitable, whereas the Antonov single-engine biplane used in Benin was less so. The most suitable flying height was found to be between 200 m and 300 m, although this can vary with several factors, including the terrain and the variability of the vegetation units being examined.

As aircraft rental is costly (Cessna 206 $100/hr; Partenavia $240/hr, $360/hr from June 1978) and planes are not necessarily available at short notice, it is essential to plan flights carefully in advance. The pilots were usually given flight plans drawn on a 1:500 000 map. Ideally the observer would occupy the co-pilot's seat, both for the view and to check bearing and speed from the instruments. Observations recorded at regular, e.g. two minute, intervals could then subsequently be plotted in terms of distance on the flight plans. When sufficient personnel is available it is most efficient to have one observer for each side of the flight line and a third to take photographs.

It was also useful, particularly in the early stages of the work, to make direct comparisons between the satellite imagery and the ground, using the 1:500 000 colour composites overlaid with clear film on which major roads, rivers and towns were marked to facilitate positioning during the flight and the annotation of the images.

The use of cassette recorders was tried for recording observations, but was found unsatisfactory because of the considerable time required to transcribe the recording and the difficulty of doing this due to the high noise level in the small aircraft used. A detailed account of the procedure adopted for aerial reconnaissance and recording the observations is provided in an appendix to the Benin and Cameroon reports of the project.

3.5.3 Ground Surveys

Ground surveys were also made at various stages, both for initial reconnaissance purposes and later to obtain information on the structure of the vegetation (height, grass, shrub and tree layers present), the species composition and relevant ecological factors, and to check interpretation of the imagery and aerial photographs.

In Togo species composition was sampled by enumerating the trees and shrubs on rectangular plots 20 m x 100 m. In Cameroon circular plots of 100 m diameter were enumerated and in Benin observations were made without marking out plots. In all cases the observations or plots were located subjectively at characteristic sites. Detailed field sheets were completed in each case and subsequently analysed to yield the floristic and other data used in describing the vegetation classes mapped.

3.5.4 Interpretation

Having acquired adequate familiarity with the vegetation to be encountered in the field and its appearance on the imagery, and taking into account what could be inferred about the spectral properties of various types and states of vegetation and related features in terms of the Landsat spectral bands, the next step was the detailed interpretation of the imagery in the laboratory.

While varying in sequence and in the emphasis placed on various procedures according to circumstances, the interpretation was carried out using the following techniques.

Direct interpretation of the 1:500 000 colour composite prints. This could be done readily for galleries and other isolated areas of forest for example, appearing in red against a background of other colours, and to some extent for savanna types and cultivated areas.

Interpretation of the 1:1 million transparencies over a light table. Except when the transparencies were very dense, which was sometimes the case, their examination with a x10 hand lens enabled very fine detail to be observed, although with a very restricted field of view. It was found that the transparencies were best viewed with a mirror stereoscope. This gave some enlargement while viewing a large portion of a scene. More significant, however, was the possibility which this gave of viewing two spectral bands at the same time, or the colour composite together with one spectral band in black and white. This was consequently a versatile method permitting a systematic examination of all the possible band combinations and selection of the combination most useful for the interpretation of a given area or type of vegetation.

When mapping was at 1:1 million, as for Cameroon, interpretation was carried out directly under the stereoscope (as with air photos), a clear film overlay on one of the transparencies being marked up with the boundaries. For mapping at 1:500 000, the results of examining the 1:1 million transparencies were used to refine the interpretation made directly on overlays of the colour composite prints at that scale. Considerable use was also made of the aerial photographs in the course of interpreting the Landsat imagery, to provide a key to the less obvious features appearing on the latter.

Effectively, therefore, a multiphase interpretation procedure was implemented, extrapolating from relatively costly and time consuming low-intensity surveys (in terms of the area covered) from the ground and the air, via air photo interpretation - intermediate in cost, time per area interpreted and the extent used - to intensive interpretation of large areas on satellite imagery.

In Cameroon where no recent aerial photography was available and the area to be mapped was also much larger than in Togo and Benin the relative amount of ground survey was very low, whereas a considerable amount of survey from the air was undertaken. The latter was particularly necessary to complete the map in those areas where no cloud-free Landsat imagery was available, amounting to about 20% of the area mapped. The procedure adopted for these areas, which in the south-east were mostly covered by virtually unbroken high forest, was to make survey flights to observe and map changes in the forest cover from that represented on the 1:200 000 topographic maps. These maps were made from aerial photographs taken around 1950 and depicted forest boundaries very accurately. After the 1:200 000 maps had been updated from the observations made on these flights, a pantograph was used to transfer the forest and other vegetation boundaries to the 1:1 million vegetation map.

3.6 DEVELOPMENT OF THE MAP LEGENDS AND THE ECO-FLORISTIC ZONATION (see Appendix 3 and 4)

Each of the vegetation maps displays a legend consisting of vegetation classes grouped by eco-floristic zones. The establishment of these legends was very much a progressive procedure and a complex undertaking in so far that the legends for the three countries had to be mutually consistent and at the same time capable of adaptation to other parts of Africa and eventually to other geographic regions in the context of global tropical forest cover assessment and monitoring.

These requirements were specified when an initial classification was commissioned (see 2.1), as well as that it should be a physiognomic classification, i.e. based on the height, crown closure and structure of the plant communities, and be compatible with the Unesco (1973) and Yangambi (Trochain, 1957) classifications.

In essence the classification used corresponds to that of Yangambi. Especially among anglophone workers, there has been a tendency to abandon the Yangambi classification, particularly for mixed formations (grasses and trees or shrubs) for some time. This is evident from the classification proposed for East Africa by Pratt et al (1966) and F. White's new vegetation map of Africa (as yet unpublished) at 1:5 million. Following the latter the 1:250 000 vegetation and land use map of Nigeria prepared in 1978 has also largely departed from Yangambi (2.6). Nevertheless, the adherence to Yangambi of the project's classification is considered appropriate because the terminology is still the most familiar in the francophone countries concerned and so most readily conveys an image of the vegetation which is actually present. To do this was considered an important objective in constructing the legends, given that the maps would be put to practical use rather than constitute only scientific documents.

For this reason also the spatially dominant physiognomic type was indicated when it was necessary to include more than one of these in a class. In the case of the more variable vegetation types, e.g. the savanna formations, the naming of a class could only indicate the dominant component(s) in any case and the presence of variants must be expected, e.g. the occurrence of grass savanna in extensive areas of tree and shrub savanna, or the presence of the latter in areas of woodland savanna.

It must of course be borne in mind that linear boundaries placed on a map to delimit complex natural phenomena such as the spatial distribution of climatic and topographic variables and of the vegetation itself can rarely be more than a generalized indication of the situation on the ground, reflecting the map compiler's best judgement.

The actual vegetation classes for each legend were developed progressively according to the vegetation which was found to be present, the relative importance of the different types and the possibility of consistently separating the various physiognomic types on the Landsat imagery.

In Benin the main tree crop plantations areas (oil palm, coconut palm) in the coastal zone were also mapped, at the request of the Government. This was done mainly from reconnaissance flights and an existing map, as the Landsat imagery for this area was mostly obscured by cloud.

Over the geographical extent and altitudinal range of the project area, and due to the human impact on much of the vegetation, a given physiognomic type could represent climax or non-climax vegetation and have very different floristic and dynamic characteristics. To reduce the variation of the ecological status of the physiognomic classes the project area was stratified by division into broad eco-floristic zones. The definition and delimitation of eco-floristic zones also constitutes a stratification of the vegetation cover into more homogeneous groupings and as such can facilitate interpretation of Landsat images and aerial photographs by limiting the types to be expected at a given location or, conversely, can permit the presence of a given vegetation type to be inferred on ecological grounds when it is not directly identifiable on photographs or images, as described below.

The eco-floristic zonation was originally made at 1:5 million for the whole project areas as part of the initial classification commissioned by the project (2.1) and then refined in the course of the vegetation mapping of each of the three countries.

The eco-floristic zones were defined primarily on the basis of altitude and rainfall. In this connection it is important to note that in the project countries altitude becomes progressively less significant, in terms of inducing rainfall, with increasing latitude (equated with distance from the coast in the case of Togo and Benin). Thus some areas in Togo (the Dapaong scarp) and Benin (the Atakora range) were included in the low-altitude zones although exceeding the altitudinal criteria for these since, due to their northerly location, they exhibited the same rainfall (and floristic composition) as the surrounding lower areas.

Taking the eco-floristic zones of the commissioned classification as a starting point the available rainfall data was mapped and the significant altitudinal limits determined in relation to the distribution of the vegetation. These two factors thus gave a first approximation to the location of the eco-floristic zones, which was then refined with reference to soil maps and predominantly, of course, to the distribution of the vegetation classes on the ground and their floristic composition. The latter was obtained from extensive sampling in Benin and Togo and from the detailed descriptions of Letouzey (1968) for Cameroon. The general procedure used to define the zones is shown in Appendix 7.

Particularly in the low rainfall conditions at the lower altitudes in Togo and Benin soils were found to have a determinant role in the distribution of areas of true forest. In such a case the spatial distribution of an eco-floristic zone characterised by forest which is soil dependent (e.g. Togo, class 1) will reflect the distribution of the soils, or soil/topography complex, concerned. Isolated areas of high relief will have the same effect and both cases are well illustrated on the Togo vegetation map (class 12). Consequently an eco-floristic zone is not necessarily a coherent unit within a single boundary.

The location of the eco-floristic zones can be expected to be broadly continuous across the frontier between Benin and Togo and the maps show this to be the case (see Appendix 4 and the vegetation maps).

In the south the boundary between zones I and II has been rather arbitrarily made to meet on the frontier. From the work in both countries if appeared that this boundary could be placed equally well somewhat to the south, at the northern boundary of the Terre de Barre. This is a typical case confronting map compilers, where an arbitrary line has to be drawn when on the ground there is only a gradual transition from one set of conditions to another.

Zone V in Togo which reaches to the frontier between the two countries does in fact not extend to any significant degree into Benin where the relatively high altitudes characterising this zone and the related vegetation are not encountered, or very much less marked.

That the boundary between zones I and III in Benin and Togo does not meet on the frontier is due to the influence of the Oti valley in north-east Togo, which extends zone I to the northern frontier. Its northward extension as the valley of the Pendjari on the frontier between Upper Volta and Benin must be assigned to zone III in Benin. The apparent anomaly is removed if the boundary of zone III in Togo is considered to run eastwards along the Togo-Upper Volta frontier until it joins the same boundary in Benin, roughly where the three countries meet.

Examination of the rainfall criteria used for the three low-altitude eco-floristic zones in Togo and Benin also reveals slight differences. These are due to the peculiarities of the rainfall regime in south-west Togo - the minimum for the West African coast - and to the fact that Benin extends more than 2 degrees further north than Togo.

In the southern part of Cameroon conditions are considerably different from those in Togo and Benin - rainfall is much higher, with an equatorial regime, and the range of altitude is also much greater - and this is reflected in the criteria for the eco-floristic zones. The zones at medium and high altitude could be well defined, using the appropriate contour levels on the topographic maps as a guide. The boundaries of the coastal zone are also fairly reliable, particularly as regards the mangrove areas, since these are usually readily discernable on the imagery (when not obscured by cloud).

However, the boundaries between the lowland forest zones (I,II, III) are only indicative, since no well defined boundaries exist on the ground. Even beyond the transition zones between them the evergreen, semi-deciduous and mixed evergreen and semi-deciduous forest are not distinguishable on aerial photographs or Landsat imagery. Letouzey (1968), from extensive floristic surveys, has established the climatic conditions under which the three types usually occur. Climatic data for southern Cameroon was analysed in detail (Cameroon report, Annexe 2) and this permitted the boundaries of the climatic zones corresponding to the three major forest formations to be drawn on the map where they appear as the limits between these classes. Wherever possible these limits were made to coincide with major rivers or physiographic features; elsewhere they are shown as broken lines.1/ This demonstrates how ancillary data may be used to complement the information directly obtainable from the Landsat images (i.e. the boundary of the moist forest without phenological distinction) and thus amplify the detail which can be presented on the final map, and the application of ecological stratification to the interpretation of Landsat images.

The boundaries of eco-floristic zones are for the most part even less amenable to representation by a line placed on a map than the boundaries of vegetation classes and were therefore not shown on the vegetation maps, where the occurrence of these zones is to be inferred from the location of the classes assigned to them in the legend. However, very small scale maps to indicate the general distribution of the eco-floristic zones were prepared for each country and are shown in Appendix 4.

For each of the three legends (Appendix 3) the eco-floristic zones constitute the first level of classification and in consequence the title 'Ecological map' has been used, in conformity with resolution No. 3 of the International Colloquium on Vegetation Mapping as cited by Küchler (1967, p.127).

In designing the three vegetation maps each eco-floristic zone was assigned its own suite of colours. Among these colours consistent ecological values were maintained, as far as technical constraints permitted. Green to represent forest conditions was taken as the point of departure, with yellow to represent drier conditions, red for higher temperatures

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1/ On the northern sheet of the vegetation map of Benin it would also have been preferable to present the western part of the boundary between classes 3 and 21 as a broken line since the transition between these classes is very gradual and its positioning there is evidently arbitrary.

and blue increasing wetness or lower temperatures. Browns or olives were generally used to represent cultivation. However, the number of basic colours employed had to be limited, mainly for reasons of cost, and so there are inevitably some departures from this scheme, especially with the map of Cameroon where a large number of classes was involved.

3.7 MAP COMPILATION AND PRODUCTION

3.7.1 Map Compilation

By map compilation is understood the procedure whereby a document from which the final map can be prepared for printing is produced from the interpretation of the imagery. The interpretation of a Landsat image at the final map scale was drawn on a clear film overlay on which the coordinate tick marks from the image were also traced. The first step was to check that the boundaries and classes at the edges of each scene matched those of the adjacent scenes.

For Cameroon, in the absence of an accurate base map at 1:1 million, an attempt was made to trace the individual interpretation films on to a single sheet using the scene edge and centre coordinates as a guide to their relative positioning. The result, however, did not correspond to the base map which was subsequently produced by photographic reduction and assembly of the 1:500 000 map sheets, because the scale of the images is always somewhat variable and the coordinate ticks are not very accurate.

The procedure which proved most effective was to superimpose a base map (at the scale of the interpretation and of the final map and preferably in the form of transparent film - more stable than paper)[1/] an interpretation film (corresponding to one scene), and the film on which the compilation was to be drawn. The interpretation film was then adjusted to the base map so that the main features coincided (for example gallery forest with the corresponding rivers) and the interpretation was traced on to the compilation film. The procedure was repeated for each scene.

When discrepancies arose between vegetation boundaries and map features, mainly due to scale variation of the imagery and errors on the maps (rivers, roads, coast lines, etc. often appear more accurately on Landsat images than on maps which are inevitably generalised to some extent) the usually minor adjustments to the vegetation boundaries on the interpretation films could be made without introducing any gross errors. The errors introduced by this procedure, of the order of two or three kilometres on the ground at most, could be distributed over a scene by sub-dividing the latter and working systematically from one sub-division to the next, with each requiring only very limited adjustment between the interpretation film and the base map. Since Landsat images are good approximations to geodetic maps the transfer of detail from them on to existing maps usually poses no serious problems and can be done by eye.

1/ As the mapping for Benin and Togo was at 1:500 000 the original films of the IGN maps at that scale were obtained, except the vegetation sheet, and combined into a single transparent base map on stable film.

The resultant film, showing the boundaries of all the vegetation classes positioned in conformity with the detail on the base map, was the master compilation from which all further documents for making the printing plates were derived. This film was also used to measure the area of classes which had been mapped.

For Benin and Togo the vegetation maps were printed over a monochrome half-tone print of the base map (IGN 1:500 000 series). Only certain planimetric and other features were traced from the base map for incorporation in the final map of Cameroon, where the base map had to be reduced to 1:1 million from originals at 1:500 000 and the resultant crowding of all features did not constitute a suitable base for combining with the thematic map.

Once the compilation film was completed, Ozalid copies (on paper) were made and used to develop the colour scheme and the layout of the legends and other text, after which the map could be given to the printer.

3.7.2 Alternative form for the small-scale vegetation maps

The project's vegetation maps at 1:500 000 and 1:1 million have been produced as conventional printed line maps with a colour assigned to each class of the legend. This procedure involves numerous processes after the completion of the compilation film, which are technically very exacting and therefore time consuming and costly. Furthermore, they necessitate a varying degree of generalisation of the original interpretation and the final vegetation map constitutes a symbolic representation, in this case not only of the vegetation and its distribution on the ground, but also of its appearance on the Landsat imagery.

For the map scales used by the project Landsat imagery constitutes a map base of good planimetric accuracy (Mott and Chismon, 1975; Borgeson, 1979). It would be possible to produce a vegetation map by preparing a mosaic of the Landsat images which have been interpreted, superimposing the compilation film on this and printing the combined documents in black and white, or colour. This would preserve the detail of the Landsat interpretation and has a number of other advantages, and some possible disadvantages.

To produce such a 'Landsat map' it is necessary to assemble all the images covering the area being mapped, generally using prints of the colour composites, although a single spectral band in black and white can also be used. For the Landsat cover used by the project this would have meant using images of a range of dates; of varying photographic and radiometric quality; of very variable colour rendering and with some areas covered by cloud. Moreover for some areas there would have been no imagery at all, e.g. parts of southern Cameroon. Most of these factors would result only in cosmetic defects and even these could usefully indicate the varying accuracy of the interpretation possible over different parts of the area. In future this type of defect will in any case largely disappear due to the routine enhancement of imagery and other improvements in its production which are being introduced (3.2).

The presence of cloud and complete lack of cover pose more serious problems, but can be met by much the same approach used to map the vegetation in such ares. This used the existing map cover (1:200 000, 1:500 000) to draw vegetation boundaries observed during reconnaissance flights made for the purpose. It would be equally possible to insert portions of the topographic map cover to fill gaps in the Landsat cover. While this would again detract from the appearance of the resultant document, it would show the real conditions under which the work was done. This is in contrast to the production of conventional maps, where there is usually a conscious effort to make the printed document as uniform and visually attractive as possible, partly because given the labour and expense involved it would be perverse not to, partly to reinforce the communication function of the map.

One of the main advantages of a Landsat map is precisely in this last respect, because the information is displayed in the same way as it was used to make the interpretation. Consequently most of the details, transitions and nuances which are lost when producing a conventional map are preserved. From a purely practical point of view a Landsat map is ready for printing virtually as soon as the interpretation is completed. For the project's conventionally produced maps several months elapsed between the completion of the interpretation and the printing. At each stage of the preparatory work there is also the possibility of introducing errors, particularly in the case of such a detailed small-scale map as that of Cameroon. As a result of these factors the production of a Landsat map is also much less costly. This and the relatively simple procedures involved also permit the up-dating of such maps, for example by the addition of detail when new imagery with additional phenological information becomes available, or for areas previously cloud covered.

Taking into account the various practical advantages, as well as the consideration that monitoring implies an essentially dynamic situation for which maps easy to revise would be an advantage, the production of such Landsat maps may often be more appropriate than that of the conventional thematic line maps.

3.8 MEASUREMENT OF AREAS

Information about the relative and absolute areas of the vegetation and land cover classes which had been mapped was obtained to provide an overview of the present status and probable dynamics of the forest cover as a whole, in each country.[1/] The resulting area tables are shown in Appendix 5.

Areas were measured by the use of a dot grid with 5 mm spacing. The grid was reproduced on stable plastic film and measurements were made by overlaying this on the compilation film (3.7), or on an ozalid copy of this film which was freshly made to avoid changes in its dimensions due to variations in the ambient temperature and humidity.

The use of dot grids to measure areas on maps and aerial photographs is generally preferred over other methods (Spurr, 1960; FAO, 1973) because it is simple, rapid and requires no precision instruments whose use can give rise to undetectable errors and whose maintenance under tropical conditions may be troublesome.

The use of a dot grid also has the advantage that the statistical error which this introduces can be readily calculated. Each dot constitutes a sample of the area it represents, this area being the square of which the dot is the centre. If a dot lies near a boundary line the latter may not include (or exclude) the entire square and this gives rise to the error of the area estimate obtained from a dot count. It also follows that

1/ Chapter 4 of the country reports.

the greater the proportion of dots occurring next to the boundary (i.e. the smaller the area being measured and/or the more irregular the shape of the boundry), the greater the probability of error.

As the dots of a grid are systematically arranged the use of the statistical formulae assuming random distribution of samples gives an overestimate of the error which in this case can be very large. There are, however, empirical formulae which have been developed to obtain a good approximation of the error arising from the use of a dot grid and a convenient one is that shown in the Manual of Forest Inventory (FAO, 1973, p.83), slightly modified. This takes into account both the size of the area measured and the shape and regularity of the boundary and has the form:

$$e\% = 52 \frac{\sqrt{k}}{n^{3/4}}$$

where e% is the percentage error of the measured area at the 95% probability level;

n is the numbe: of dots counted within the measured area;

k is a factor which depends upon the shape of the area and the regularity of the boundary. For shapes which are not particularly elongated, with a fairly regular boundary (i.e. without numerous indentations) k may be given a value of 5 to 7, increasing with the elongation and/or irregularity of the boundary.

For classes of very small area, such as the Woodland (class 11) in northern Togo, whose area of 1250 ha corresponds to only 2 dots of a 5 mm grid at a scale of 1:500 000, the measurement error is inevitably large (± 69% when k = 5), but of correspondingly small significance for the accuracy of the relative extent of all the classes since it only covers 0.022% of the country.

For areas about 20 times larger (e.g. Togo class 1, semi-deciduous and deciduous forest, 24 375 ha), the error only amounts to ± 0.26% (k = 16) and for most of the classes it is negligible.

CHAPTER 4

INVESTIGATION OF PAST CHANGES IN THE FOREST COVER

4.1 SELECTION OF STUDY AREAS

The investigation of past changes in the vegetation cover was undertaken to obtain information about the general nature of such changes and more particularly about the dimensions of the areas concerned as well as the rates of change involved, as a guide to the scope and frequency required for periodic observations, i.e. monitoring, in the future.

The project document (3.01) mentioned the selection of two study areas in Cameroon and a combined one for Benin and Togo. The latter was not possible due to the differences in the progress with the programme of work in the two countries and the factors involved in the selection of the areas, as described below.

The approach in the project document was derived from the proposals for this work contained in the "Formulation" (4.4.2) where a sampling of units of 11 000 km^2 had been envisaged when working at a global scale. In Togo some preliminary work was done towards investigating changes in the vegetation cover over a substantial part of the country by a sampling procedure, but this was not implemented for lack of time to carry out the considerable amount of aerial photo interpretation which this required.

The application of a statistical sampling procedure for tropical forest cover monitoring is considered in section 5.2.3. In the context of the pilot project the method envisaged for the investigation of the study areas was to interpret at least two sets of aerial photographs, taken at an interval which sufficed to display significant change in the vegetation cover; to map the interpretation at each date and analyse the differences between these maps (Baltaxe and Lanly, 1976). The observation of change of forest cover on Landsat images was not investigated due to the absence of suitable multidate cover.

In the programme of work established for the experts it was stated that the selection of the pilot areas would be based on the following activities and considerations:

- Determination of the available aerial photographic cover for the country, at various dates.

- Identification and review of any past and current studies of the vegetation cover.

- Preliminary evaluation of the change in the vegetation cover of any potential study areas.

- Preliminary evaluation of the relative socio-economic importance of any potential study areas.

- Consideration of logistic factors affecting the investigation of potential study areas.

From preliminary discussions with representatives of the Government agencies concerned and with technical assistance personnel working in the countries it seemed as if the main task would be to make a selection among suitable study areas, rather than their identification. In practice, however, the main problem turned out to be the location of areas where significant changes had occurred and were displayed on available aerial photography.

The problem was approached somewhat differently in each of the three countries. In Togo the initial ground and air reconnaissance surveys and a report of earlier surveys (see 1.3) indicated that at the lower fringes of the upland forest (class 12 on the vegetation map) conversion to agricultural land was occurring, after a period of underplanting with coffee and cocoa which inhibited natural regeneration. Observation in the field and from the air also revealed that large portions of the forest in the area of Togodo (class 5) had been converted to agriculture in recent years.

The selection of these areas was discussed with the Government authorities, who proposed that a study area should also be selected among the forests in the region of Abdoulaye (class 1), where a commercial exploitation project was to be implemented. Study areas were therefore established in the Togodo and Abdoulaye areas, leaving the upland forests for later, if time permitted.

Aerial photographic cover from 1949 was available for the whole country, from 1969 for the forest areas, and new cover for the whole country was in the process of being completed in 1977, so this aspect imposed no restriction on the choice of areas, or so it appeared at the time. Unexpectedly the new cover for the Togodo area could not be completed in 1977/78, which greatly reduced the significance of the quantitative results from this area.

In Benin circumstances did not permit extensive field or aerial surveys during the early stages of the project. At a meeting of the project coordinating committee in June 1977 four regions were indicated to the project for the location of study areas. On the strength of this the 1949 aerial photographic cover of these regions, available in the offices of a UNDP/FAO project, was examined to locate areas with vegetation cover of some interest at that time. As long as these areas were situated north of 8°30 they would also be covered by the 1974/75 photography, from which any changes in the vegetation cover could be ascertained. The final choice of two study areas was made by the co-director in September 1977, on the arrival of the consultant who was to initiate the photointerpretation and mapping.

In Cameroon the situation was considerably more complex. Aerial photographic cover from 1949 to 1954 existed for most of the country. Later cover, mostly from the early 1960's, was very fragmentary and virtually confined to the savanna, as opposed to the high forest areas. Analysis of change in the vegetation cover in the latter, using aerial photography of two well-separated dates, therefore required obtaining new photography for the areas selected.

The main area of interest in Cameroon lay between 2° and 6°N, with weather conditions which make it notoriously difficult to obtain aerial photography. This is the reason why no recent photography of any extent existed.[1/] The most favourable season for aerial photography is normally from mid-December to mid-January.

The project expert arrived in Cameroon in late November 1976 and five possible study areas, in which it was considered highly probable that changes in the vegetation cover had occurred since the date of the earlier photography, were selected in consultation with the Director of the Forest Service by January 1977. Invitations to tender for an aerial photography contract had been sent out by FAO in December 1976 and a contract was signed in February 1977. Weather during the earlier part of the dry season had in any case been unfavourable for photography and information from Cameroon indicated better prospects for the end of the dry season. In the event, conditions during the entire period were unfavourable and as far as is known no aerial photography was taken in southern Cameroon in the 1976/77 season. Measures adopted to obtain new aerial photography later in the year were again unsuccessful due to unfavourable weather.

In the meantime, the vegetation cover on the earlier aerial photography which was by then available and on the satellite imagery (as far as cloud cover permitted) was compared in the selected areas, i.e. at an interval of over twenty years. This revealed that, contrary to expectations, little if any change was observable. In September 1977 Professor Letouzey, on the basis of his extensive studies of the vegetation of Cameroon, was therefore asked whether he could suggest any areas where changes in the vegetation cover had occurred and indicated ten localities which he considered might be examined.

The old aerial photographs were ordered for eight of these areas (one being very remote and two others rather similar). At the beginning of February 1978, the start of the consultant's first mission, the photographs (1950) of seven of these areas had been delivered. After a preliminary examination of the aerial photographs and reconnaissance flights over all these areas, two were selected as suitable for the study of changes in the vegetation cover, and two other promising areas had been located during the flights.

The old photography for the last two areas was ordered and the possibility of obtaining new aerial photography was investigated with a local air survey firm. This firm was due to have aircraft stationed in Cameroon and could, therefore, take advantage of brief periods of suitable weather, especially as each of the areas could be flown in a few hours. However, both for administrative reasons and because the aircraft arrived later than foreseen, no new photography for the four areas could be obtained. The project's experience in Togo and Cameroon underlines the inherent difficulties posed by weather conditions in the tropics for obtaining aerial photography at a given time. The implications of this for monitoring activities are considered in 5.3.2 below.

4.2 ASSESSMENT OF CHANGE IN THE STUDY AREAS

The basic method used to assess changes undergone by the vegetation cover in the study areas was to interpret the vegetation classes on aerial photography of different dates, transfer the results for each date to a map and from this measure the area of each class at

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1/ The relatively complete 1949/50 cover for mapping purposes had apparently been obtained by an intensive campaign during which survey aircraft working in adjacent countries had been called in over a series of radio links whenever cloud-free areas appeared.

each date. By noting the class present at a given point (i.e. at the dots of the dot grid used to measure areas) at different dates, the qualitative trend of the changes could also be described. This application of multi-date dot grid measurements and the establishment of contingency tables such as 4.3 and 4.5 is also used for the analysis of landscape dynamics in other fields (Zeimetz et al, 1976 and various studies cited there).

For the areas selected in Benin and Togo only two sets of photographic cover, taken 20 or 25 years apart, were available. Cover at more frequent intervals would have been useful, to provide more reliable data on the past rate of change of the vegetation as a guide to the most appropriate monitoring interval for the future.

As mentioned above, no aerial photography at a second date was obtained for the four areas selected in Cameroon. For a total of seven areas for which the old aerial photography was obtained by the project, this was compared with observations noted during reconnaissance flights made for the purpose of selecting the study areas. The comparative descriptions have been included in the project's report on Cameroon (chapter 5). For two of the four areas selected the vegetation cover at one date was interpreted from the old photography and mapped, in the expectation that new air photo cover would eventually become available and as a training exercise for the counterpart staff.

After a study area had been selected its boundaries were traced on a topographic map at 1:50 000 if available, otherwise at 1:200 000. The corresponding aerial photographs were then interpreted under a mirror stereoscope. Ground control was undertaken either before or after the interpretation which in the latter case was adjusted as necessary.

The classes used for this interpretation varied according to the vegetation present, but were generally more detailed than those used for the vegetation maps at 1:500 000 or 1:1 million. In this connection it is worth noting a point made in the project's report on Togo (5.1) where it was shown that the breakdown of the vegetation into very detailed classes could lead to considerable errors when the same aerial photographs of an area were interpreted at an interval of several years, due to the inherent difficulty of interpreting fine differences consistently. The classes used should, therefore, be adequate to reflect the significant physiognomic and other differences in the vegetation present without seeking to distinguish every last detail.

The sequence of procedures for transferring the boundaries of vegetation classes drawn on the aerial photographs on to a map base varied according to circumstances and to the instruments available. The standard technique using a Sketchmaster had been envisaged and such an instrument was available in Cameroon, so that transfer between aerial photographs and maps, each of a range of scales, could be executed without difficulty. For Togo and Benin the Sketchmaster provided was not available. The techniques improvised as a substitute will be of interest for other situations where the appropriate instrumentation is lacking.

In Togo 1:50 000 topographic maps of the study areas were available. The 1949 photography was also at approximately 1:50 000; the 1969 photography was at 1:30 000. The expert had a standard photographic enlarger and used the following procedure:

- The interpreted aerial photographs (23 x 23 cm) were given to a commercial photographer who produced a 6 x 6 cm diapositive of each annotated photograph.

- The diapositive was placed in the enlarger and projected on to be 1:50 000 map.

- The map was mounted on a tilt-board moveable about the two horizontal axes, permitting some adjustment of the projected image to allow for variations in altitude over a given photograph.

- When the projected image and the map had been matched (mainly by correspondence of hydrographic features) the vegetation class boundaries from the diapositive was drawn on to the map.

In Benin the only instruments available were the mirror stereoscopes used for the photo-interpretation. The scale of the available maps was 1:200 000. The aerial photographs were at 1:50 000 for 1949/50 and at about 1:80 000 for 1974/75. For the latter, requiring the most steps, the procedure adopted was as follows:

- The portion of the 1:200 000 map covering the study area was enlarged to 1:80 000 by a commercial photographer (better and more accurate results would be obtained using a large copy-camera in a photographic laboratory, when available).

- A semi-matte film (e.g. Kodatrace) was superimposed on the resultant 1:80 000 map and coordinate markings were traced from the map on to the film.

- On a given photograph at least four points, also identifiable on the map (river junctions, cross roads, etc.) were marked.

- The photograph and the corresponding portion of the map were placed under a mirror stereoscope and the common points brought to coincide. (When the scale of the map and photo are slightly different and/or there are displacements due to changes in altitude, the control points must be selected close to each other, possibly using only part of a photograph at a time).

- The boundaries from the interpreted aerial photograph were then traced onto the film overlay of the map under the stereoscope.

- The completed interpretation film at 1:80 000 was photographically enlarged to 1:50 000.

- The portion of the 1:200 000 map covering the study area was photographically enlarged to 1:50 000.

- The major map features were traced from this enlargement on to a clear film overlay.

- All the boundaries from the interpretation film at 1:50 000 were also traced on to this overlay, resulting in a compilation on film at 1:50 000 showing some map features and the boundaries of the vegetation classes. Ozalid copies of this film were then produced for the subsequent analysis.

The method described below for the quantitative analysis of the qualitative changes represented on the vegetation cover maps of two dates was applied to the data obtained in Togo. The method was also introduced to the project staff in Benin but had not been implemented by the end of the present project.

A rectangular dot grid with a spacing of 5 mm was used to estimate the area of each vegetation class on the map of a given date. At the same time a matrix was constructed with the number of rows and columns corresponding to the points on the dot grid covering the entire study area. Each point on the grid, therefore, had a unique address (row/column coordinate) in the matrix.

The dot grid was placed over the map of the first date and the class into which each dot fell was recorded by a corresponding symbol in the matrix. The procedure was then repeated with the map of the second date, the class symbol for each dot being recorded in the matrix below that of the first date.

The resultant matrix thus showed the vegetation class present at each position at the two dates. From this, tabular statements of the areas of each class at each date could be derived (1 dot representing 6.25 ha at a scale of 1:50 000) as well as the nature of the change, if any, at each point and in total (Table 4.3 and 4.5). The figures in the compartments of Table 4.3 and 4.5 represent the area of the class on the left derived from the class at the top. A few of the figures are anomalous, due to the dot grid which was used (1 dot = 6.25 ha), or slight inconsistencies of interpretation. Thus in Table 4.3 the 6 ha of Gallery forest derived from Degraded semi-deciduous forest may be due to either of these causes.

In addition to the map showing the vegetation cover for a given area at each date it was intended to produce a composite map showing the changes which had occurred. This would have been a simple matter had each vegetation class, or parts thereof, changed only into one other class, e.g. forest to cultivation. In this case the area under cultivation gained from forest could be clearly shown. In practice, the changes which were observed occurred in so many directions - forest to degraded forest, to tree and shrub savanna, to cultivation; tree and shrub savanna to forest, to degraded forest, to cultivation, to villages, etc. - that it would have been far more confusing than informative to depict these changes in cartographic form.

TABLE 4.1

STUDY AREAS

AVERAGE ANNUAL RATES OF REDUCTION OF AREAS ORIGINALLY PRESENT

	FOREST	DEGRADED FOREST	GALLERY FOREST	WOODLAND SAVANNA	TREE SAVANNA
TOGO					
TOGODO					
1949-1969					
Area 1949 ha	9 537			1 675	5 400
Annual loss %	0.6			1.0	1.5
Annual loss ha	57			17	81
TSAGBA					
1949-1969					
Area 1949 ha	6 237	681	194		9 775 1/
Annual loss %	4.8	2.0	3.5		1.0
Annual loss ha	300	14	7		92
BENIN					
DJOUGOU					
1949-1975					
Area 1949 ha	306	4 450	4 125	17 734	
Annual loss %	1.0	3.8	2.4	3.2	
Annual loss ha	3	165	100	567	
MALANVILLE					
1950-1975					
Area 1950 ha				2 481	26 197
Annual loss %				3.9	3.5
Annual loss ha				97	919

1/ Tree and shrub savanna.

4.3 RESULTS AND CONCLUSIONS

4.3.1 Rates of change

Quantitative results were obtained for four study areas, two in Benin and two in Togo, and are shown in tables 4.2 through 4.7. Based on these, table 4.1 shows the major negative changes in each of the four areas (i.e. consisting of a loss of tree cover). The compensatory expansion of shrub savanna, cultivation, etc. can be seen in the original tables and maps (maps in pocket). The rates of change shown in table 4.1 were obtained by dividing the difference in the area of a given vegetation class at the two dates by the number of years separating the latter and expressing the resultant average area lost annually as a percentage of the area at the earlier date.

Before considering the quantitative aspects of table 4.1 it should be noted that the results presented there may be biased, for two reasons. In the first place, it has been assumed that the changes in the area of the vegetation classes took place over the entire interval between the dates of the two sets of aerial photography which were available. The results, therefore, represent the lowest estimate of the average annual rate of change; if the changes observed were initiated some years after the date of the earlier photography, then the average annual rate would be correspondingly greater.

The placing of the boundaries of a study area, in relation to locations where changes are occurring, can also have a considerable effect on the calculation of the average annual rate of change. This is most readily illustrated by considering the effect of including the Togodo and Tsagba study areas, which are only about 10 km distant from each other, within a single boundary. In this case the apparent rate would have been somewhere between the values obtained for these two areas. Where such spatial variation in the rate of change exists the results from numerous small areas are likely to be more reliable than those from fewer, larger areas, since the latter are more likely to contain some locations where no change has occurred.

The most striking changes observed do not appear in table 4.1. These occurred in the Togodo area, which was selected because the disappearance of the bulk of the forest present on the 1969 aerial photographs had been observed during reconnaissance flights in 1977 and confirmed on the ground. In 1977/78 new 1:30 000 aerial photography for the whole of Togo was being flown. The only area not covered by March 1978 was a strip including the Togodo area. Consequently no quantitative analysis of the changes which had occurred since 1969 could be made. However, from the observations made from the air and on the ground it was estimated that over 80% of the forest present in 1969 had been removed by 1977. The average rate of loss was thus at least about 10% annually, if reckoned to have been initiated in 1969.

Apart from this instance the extreme cases presented in table 4.1 are the Togodo area up to 1969, with less than 100 ha of forest and savanna formations being lost annually; the Tsagba area where an average of 300 ha of forest was cleared or degraded per year, and the annual lose of over 500 ha of woodland savanna in the Malanville area. The last two represent average annual rates of 3.9 and 4.8% of the original area, at which the latter would disappear in a period of about 26 to 30 years. As tables 4.4, 4.6 and 4.7 show, in the interval between the two sets of air photo cover the disappearance of 96% of the forest in the Tsagba area, of 99% of the degraded forest and 83% of the woodland savanna in the Djougou area, and of 97% of the woodland savanna in the Malanville area had occurred.

TABLE 4.2

TSAGBA STUDY AREA

AREA OF VEGETATION CLASSES IN 1949 AND 1969

	1949		1969	
	ha	%	ha	%
Semi-deciduous forest	6 237	37	238	1
Degraded semi-deciduous forest	681	4	406	2
Gallery forest	194	1	56	-
Tree and shrub savanna	9 775	50	7 931	41
Cultivation and bush fallow	1 838	9	10 263	53
Settlements	6	-	100	-
Unclassified areas	794	4	531	3
TOTAL	19 525	100	19 525	100

TABLE 4.3

TSAGBA STUDY AREA

TRANSFORMATION OF THE VEGETATION COVER BETWEEN 1949 AND 1969

Area in hectares

CLASSES 1949 / CLASSES 1969	Semi-deciduous forest	Degraded semi-deciduous forest	Gallery forest	Tree and shrub savanna	Cultivation and bush fallow	Settlements	Unclassified areas	Totals 1969
	in 1969 TRANSFORMED INTO							
Semi-deciduous forest	181	25	-	13	-	-	19	238
Degraded semi-deciduous forest	162	75	19	62	44	-	44	406
Gallery forest	-	6	31	19	-	-	-	56
Tree and shrub savanna	237	119	88	6 787	494	-	206	7 931
Cultivation and bush fallow	5 557	444	56	2 550	1 181	6	469	10 263
Settlements	-	-	-	44	50	-	6	100
Unclassified areas	100	12	-	300	69	-	50	531
Totals 1949	6 237	681	194	9 775	1 838	6	794	19 525

TABLE 4.4

TOGODO STUDY AREA

AREA OF VEGETATION CLASSES IN 1949 AND 1969

	1949		1969	
	ha	%	ha	%
Semi-deciduous forest	9 537	40.9	8 400	36. 0
Forest regrowth	1 225	5.2	1 362	5.8
Woodland savanna	1 675	7.2	1 337	5.7
Tree savanna	5 400	23.2	3 781	16.2
Shrub savanna	5 181	22.2	8 275	35.6
Cultivation and bush fallow	281	1.3	144	0.7
TOTAL	23 300	100	23 300	100

TABLE 4.5

TOGODO STUDY AREA

TRANSFORMATION OF THE VEGETATION COVER BETWEEN 1949 AND 1969

Area in hectares

CLASSES 1949 / CLASSES 1969	Tree savanna	Shrub savanna	Woodland savanna	Semi-deciduous forest	Forest regrowth	Cultivation and bush fallow	Totals 1969
	IN 1969 TRANSFORMED INTO						
Tree savanna	1 031	1 937	394	375	44	-	3 781
Shrub savanna	3 587	2 937	458	812	269	212	8 275
Woodland savanna	425	150	488	175	94	6	1 338
Semi-deciduous forest	232	94	230	7 456	356	32	8 400
Forest regrowth	94	56	81	644	456	31	1 362
Cultivation and bush fallow	31	7	25	75	6	-	144
Total 1949	5 400	5 181	1 676	9 537	1 225	281	23 300

TABLE 4.6

DJOUGOU STUDY AREA

AREA OF VEGETATION CLASSES IN 1949 AND 1969

	1949		1975	
	ha	%	ha	%
Semi-deciduous forest	306	0.4	225	0.3
Degraded semi-deciduous forest	4 450	5.8	62	0.1
Woodland savanna	17 734	23.0	2 991	3.9
Tree and shrub savanna	10 419	13.5	14 772	19.1
Grass savanna	844	1.1	-	-
Gallery forest	4 125	5.4	1 534	2.0
Saxicolous formation	103	0.1	737	1.0
Bare soil	200	0.2	41	-
Cultivation and settlements	38 937	50.5	56 806	73.6
TOTAL	77 118	100	77 118	100

TABLE 4.7

MALANVILLE STUDY AREA

AREA OF VEGETATION CLASSES IN 1950 AND 1975

	1950		1975	
	ha	%	ha	%
Woodland savanna	2 481	6.20	53	0.13
Tree savanna	26 197	65.52	3 234	8.09
Shrub savanna	59	0.14	23 306	58.30
Gallery forest	643	1.60	641	1.60
Saxicolous formation	147	0.36	434	1.08
Area subject to flooding	6 509	16.28	4 929	12.33
Cultivation and settlements	2 600	6.50	6 806	17.02
Bare soil	66	0.16	56	0.14
Water	584	1.46	522	1.31
Total	39 981	100	39 981	100

Although these figures may not be entirely accurate due to the possible errors introduced at various stages of the assessment of the changes (errors of photo-interpretation, including inconsistencies in the interpretation of a time-series of photographs; errors of mapping; errors of area measurement), it remains evident that the cumulative loss of tree cover in these areas has been considerable.

4.3.2 FREQUENCY OF MONITORING

The frequency of monitoring will partly depend on the ability to detect and measure the changes which have occurred between consecutive observations. It is therefore necessary to consider the absolute areas likely to be affected at the rates of change discussed above. The factors predominantly responsible for the changes which have been observed are the clearing of land for cultivation by the bush fallow system and the harvesting of wood. The annual burning of the grass cover also has some effect on the degradation of the more open formations, but this varies greatly according to local conditions.

In the countries under consideration the land clearing and wood harvesting operations are conducted extensively - harvesting by clear felling an area is virtually unknown in the context being discussed; cultivation mostly takes place on individual units of a few hectares. Consequently the figures given in table 4.1 for the number of hectares lost annually will almost invariably be the sum of numerous areas of a range of sizes. From the aerial photographs and observations on the ground the size of the fields or contiguous areas cleared for cultivation in a given year ranges from about 2 ha to some 50 ha, the former being much more frequent. Even the smallest of these areas can be readily detected from the air and on medium-scale aerial photography (1:60 000 or larger), so that from this aspect monitoring at yearly intervals using aerial photography would be feasible, though costly and laborious.

An examination of tables 4.2, 4.4, 4.6 and 4.7 shows that there is not only a conversion of forest and savanna formations to areas of cultivation and fallow and to settlements, but also a transition from formations with denser tree cover to more open formations, as well as the reverse. The former mainly reflects the results of selective cutting in the various savanna formations. Where there is an apparent conversion of forest to savanna types this is most likely due to clearing of the forest and subsequent reconstitution of shrub and tree cover, as occurs in the changes from the more open to the denser savanna formations. The effects of such changes will generally be very gradual and detectable only at relatively long intervals. The results from the study areas show that such changes can be interpreted and mapped after twenty years, but provide no direct indication of the minimum interval after which the transformation from one class to another (of those established for the study areas) is detectable. This interval will certainly vary with the intensity of wood harvesting in a given locality, which will in turn depend on such factors as population density and the demand for wood. Thus the transformation of virtually the entire area of woodland and tree savanna, in the Malanville area, into shrub savanna and cultivation (table 4.7) is partly attributable to the ready market for wood in the neighbouting countries. To ascertain the minimum interval at which changes from one type of tree cover to another can be detected with reasonable certainty evidently requires further investigation, by monitoring suitable areas at diminishing intervals, adjusting these according to the findings at each observation.

However, as the results from the Tsagba and Djougou areas show, as well as the observations in the Togodo area between 1969 and 1977 and of certain areas in Cameroon, the major factor inducing change is the clearing of tree cover for cultivation. It will, therefore, be reasonable to base a first approach to the determination of appropriate intervals for monitoring on the data concerning such clearing, particularly as these will tend to be shorter than those relevant to the results of wood harvesting activities alone.

The instances, in table 4.1, of an annual loss of less than 20 ha, even when this constitutes a high rate because the initial extent of the class concerned was small (e.g. gallery forest in the Tsagba area) are evidently of little interest in considering the frequency of monitoring.

For situations where the rate of loss and the annual area involved is relatively high, as for forest in the Tsagba area (4.8%, 300 ha), degraded forest in the Djougou area (3.8%, 165 ha) and woodland savanna (3.2%, 567 ha), it becomes a matter of arriving at a compromise between the shortest practical interval at which to repeat observations and the proportion of the originally existing tree cover which can afford to be lost before some intervention is made to halt, or at least diminish, the process.

In the three situations cited, from 16% to 24% of the original area of the classes concerned would be lost after an interval of 5 years. It must also be taken into account that there is likely to be a lag of several years between an observation that tree cover is being lost at a significant rate at a given location and some effective intervention. The actual area lost with a 5-year monitoring interval would therefore be more than the figures quoted above and could well range from 20% to 35% or more, for the rates being considered.

In the case of Togo and Benin where little forest remains and considerable portions of the denser savanna formations are also under pressure from cultivation, such losses can hardly be acceptable. Consequently for many areas a monitoring interval of less than 5 years would be appropriate.

In other cases, comparable to the instances in table 4.1 where the rate of loss is less than 3% annually, a five year interval could be considered appropriate. But it must also be borne in mind that in the Togodo area it was observed that whereas for 20 years forest was being lost at an average annual rate of only 0.6%, this rose abruptly to about 10% after 1969. In some situations, therefore, monitoring intervals of 1 to 2 years would be required if the disappearance of some of the last stands of high forest in certain areas is to be prevented.

4.3.3 SCALE OF MONITORING

In view of the relatively small contiguous areas by which forest clearing for cultivation mostly takes place in the regions observed - areas ranging from approximately 2 to 50 ha as described above - the most suitable scale for mapping and measuring the resultant changes will usually be 1:50 000, as adopted by the project. This enables areas of only a few hectares to be represented[1/] and quite a number of countries in Africa have map cover at this scale, although it may still be in process of completion. A further advantage is that much of the early aerial photography for francophone Africa is also at 1:50 000 which would facilitate mapping at this scale for studies of past changes. However, for areas of any extent such a relatively large scale involves the use of numerous map sheets and generally multiplies the laboriousness of the various stages of mapping and area assessment. This reflects the fact that the selection of any map scale involves a compromise between detail and accuracy on the one hand and the level of inputs (in terms of time and cost) on the other.

For some situations a scale of 1:100 000 would be adequate, but such map cover is not commonly available. It can be produced from existing 1:50 000 or 1:200 000 maps by photographically changing the scale of the original films of the maps at these scales, though this also involves additional time and cost. In certain situations, where forest cover is being cleared at the rate of several hundred hectares annually at one location this could be monitored using maps at 1:200 000, of which most of the francophone countries in Africa at least have virtually complete cover.

Evidently the actual scale at which to record observations from monitoring will depend on a combination of the various factors referred to above, although the main consideration must remain the ability to map and measure the changes in the area of individual stands with sufficient accuracy to enable the rates of change to be assessed.

As mentioned in Appendix 2, under certain conditions monitoring can also be carried out by computer analysis of Landsat data, although this would require specialized staff and facilities. But the loss of tropical forest cover may also be detected from the interpretation of sequential Landsat images when these are available. Such images must be of good quality (and preferably enhanced) and the formations concerned must display high contrast in relation to their background, e.g. a forest stand in a savanna area, or burnt clearings within the forest. Given these conditions areas of less than ten hectares may readily be detected on Landsat imagery at a scale of 1:1 million, so that this can be used to observe the location of the loss of forest cover. However, area measurements would not be very accurate unless the areas concerned were sufficiently large and homogeneous and any more detailed analysis would require a multistage procedure with the subsequent use of aerial photographs.

1/ At 1:50 000 a rectangle of 4 mm^2 represents 1 ha
At 1:100 000 a rectangle of 4 mm^2 represents 4 ha
At 1:200 000 a rectangle of 4 mm^2 represents 16 ha

CHAPTER 5

FOREST COVER MONITORING

5.1 INTRODUCTION

The pilot project did not execute all stages of monitoring, since this mainly consists of periodic observations of the forest cover over a more or less extended period. However, the vegetation mapping and back-look studies conducted by the project provided data and experience from which to derive methods for periodic observations of change, i.e. monitoring in the strict sense, which forms the subject of this chapter.

Monitoring is considered here as having the objective of providing early warning that deleterious change in the forest cover is taking place so that appropriate intervention can be made. This implies that the rate and nature of the changes should be respectively measured and assessed, as done for the study areas. In practice simpler situations may also be encountered, as when the transition is directly from forest to cleared land instead of to progressively less dense formations. Then it will suffice to measure the rate of clearing.

Other phenomena can also usefully be observed by monitoring, such as the natural or man-made reconstitution of the forest cover. The main point of reference, however, (given the concerns which led to the formulation and execution of the pilot project), will be the degradation or loss of the forest cover. The details of the method to be applied for the conduct of monitoring will depend on the phenomenon to be observed and it will therefore lead to greater efficiency if this is defined as closely as possible at the outset.

The difficulties encountered by the project in locating study areas where significant changes in the forest cover had occurred are discussed in 4.1. This may be considered a specific instance of the general situation that it will be necessary either to identify locations where monitoring is necessary, or to assign priorities among areas to be monitored (or both) unless this is a political decision based mainly on socio-economic considerations. The identification of such 'critical areas' is therefore the first topic considered.

5.2 IDENTIFICATION OF AREAS TO MONITOR

5.2.1 Direct identification

Areas where monitoring is required can be considered under two broad categories: those where significant change of the forest cover has taken place,[1/] and those where little or no change has occurred up to the present but where the probability of the initiation of change due to human intervention is high. For the first category there is the possibility of identifying the areas in question from documents on which they are depicted at different dates, or by direct observation (generally from the air) of disturbance in progress. The

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1/ The interval over which change is being considered in this context is of the order of one to three decades, as for the study areas, and the 'present' is the latest year for which an observation is available. One reason for monitoring where past change has occurred is to ascertain whether it is continuing.

second category may be identified by an analysis of the stability of different elements of the vegetation cover, as a function of the presence and magnitude of factors influencing their disturbance by human intervention.

The project's experience with the visual interpretation of Landsat imagery demonstrated that forest, in the strict sense of stands of trees with at least 80% crown closure, can under most circumstances be readily identified. Although the detection of features on Landsat imagery depends considerably on the conditions of contrast, very small areas of forest and of clearings within the forest can usually be detected, of the order of 5 to 10 ha. Galleries no more than 200 m wide can be readily identified and the distinction between forest and degraded forest is usually also very clear (figure 1). Consequently as far as forest in the strict sense is concerned the characteristics of the imagery would normally permit a first determination of the location of changes from a comparison of images of a succession of dates. Such images should preferably be recorded at roughly the same calendar date and certainly in the same season.

Landsat imagery is particularly suitable for this application because it permits the examination of very large areas much more rapidly than is possible by any other means. In passing, it may be mentioned that digital Landsat data can be analysed in such a way that a map of areas which are different at two dates is produced directly, although this would usually be too costly for the application being considered here. However, the versatility and cheapness with which diazochrome colour composites of Landsat imagery can be produced to enhance specific features (Moore, 1979) would lend itself particularly well to the detection of change in forest cover. While it would therefore be appropriate to use Landsat data as far as possible to locate areas of change, the possibility will be limited by the relative paucity of cloud-free cover for many tropical forest areas, particularly at two dates, and the fact that much of the latter is by now several years out of date.

However, the availability of Landsat cover at only one date does not exclude its use for detecting change. For a part of the scene illustrated in figure 1 the same pattern of forest and galleries appears distinctly on aerial photographs at 1:50 000 taken in 1951/52, on the 1:200 000 maps made from these photographs, and on the 1973 Landsat images (and particularly on the diazochrome enhancement of part of the area, figure 5). Had any change occurred in this area it would therefore have been detectable from a comparison of the Landsat images with the aerial photographs or maps.

In the complete absence of Landsat cover, due to cloud, the comparison of aerial photographs and/or maps of different dates may be resorted to for locating area where change is in progress. But this will generally not be practicable for large areas corresponding to a number of Landsat scenes (given that one Landsat scene is covered by about 800 aerial photographs of 23 x 23 cm format at 1:50 000), and the situation then is much the same as that encountered by the project in locating areas for the back-look studies, described in 4.1. As was done by the project, one approach will then be to narrow down the areas to be examined for the presence of significant change by appeal to existing information held by persons with the relevant knowledge. However, this may not always be appropriate (because unsystematic and subjective), or effective, when large-scale long-term monitoring operations are to be implemented. The same applies to the random observation of change in progress in the course of ground or air surveys being conducted for other purposes (e.g. vegetation mapping).

5.2.2 Prediction of stability

When areas where changes in the forest cover are in progress cannot be identified directly, either due to the absence of the requisite documentation, or because they do not exist in the region under consideration, then the identification of areas to be monitored may be approached indirectly by predicting the stability (or instability) of elements of the vegetation cover1/ and monitoring those which are assessed as being least stable (i.e. most at risk). (In some respects such a procedure constitutes a stratification of the vegetation cover into 'stability classes' and as such will also be useful to narrow down the areas to be examined on remote sensing documents of two or more dates for the direct location of past change).

The prediction of stability can be applied to the identification of areas which require monitoring whatever their extent e.g. to determine which countries in a region or areas within a country exhibit a level of instability which would make monitoring advisable, or to decide to which of two elements of a vegetation class in the same locality priority for monitoring should be assigned. Priority implies a temporal dimension and levels of stability are evidently also a guide to the relative interval at which two elements require to be monitored.

Stability, in this context, may be defined as the probability that a given element of the vegetation cover will be cleared, or significantly degraded, by human intervention. Assessment of what constitutes 'significant degradation' must be made in terms of the present level of the productive and/or protective function. For a forest, for example, this may not be materially affected by selective logging at a low level of mechanisation; but it could be seriously threatened in the long term by the underplanting of cocoa and coffee.

Method.

On the basis of the observations made in the course of vegetation mapping, it was shown in the project's report on Togo that priority for monitoring should be given to two of the three classes of high forest. In the Conclusions (Chapter 6) of that report it was also pointed out that it was significant that the area of high forest which displayed a high degree of stability (Class 1) was surrounded by another stable formation, acting as a buffer between the forests of Class 1 and areas of high population density and intensive cultivation. The areas of forest being cleared for cultivation, on the other hand (Class 5 for example), were adjacent to regions of intensive cultivation and relatively high population density.

This indicates an approach which may be used to assess the relative stability of elements of the present vegetation cover whose preservation is of concern, either to identify ares where monitoring is required, or to establish priorities for monitoring among

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1/ 'Elements of the vegetation cover' refers to units such as are placed within a boundary on the vegetation maps; clusters of such units when they are small, and sub-divisions when they are large.

specific elements of the vegetation cover. Essentially this would consist of listing and evaluating the factors which affect the stability of the elements concerned.

If the procedure is to be applied on a large geographical scale to differentiate between major portions of a country, for example, then it would be appropriate to use a technique similar to that applied for the eco-floristic zonation (3.6), namely to prepare a series of transparent maps displaying the distribution of the major factors influencing stability of the vegetation cover, such as population density, land use, slope classes, etc. and to overlay these on a vegetation map. The relative stability of the major zones may then appear quite readily, or a more detailed assessment could be undertaken as described below.

Among the factors to be taken into account the following, based on the experience of the project's work, can be listed:

- the absolute extent of a formation whose stability is to be assessed
- its location in relation to similar formations
- the relative stability of the adjacent formations and their extent
- population density and its spatial distribution
- the major forms of land use
- accessibility
- terrain conformation in relation to land use and to the distribution of the vegetation formations being considered
- the ecological status of the vegetation formations (climax, marginal, successional stage; eco-floristic zone)
- socio-economic factors such as the demand for wood, programmes for population resettlement (e.g. outside national parks, as in Togo) and projected development activities including road construction and commercial forest exploitation.

Calculation of the index.

These factors can be weighted to reflect their relative impact on stability. Thus the fact that a forest massif is adjacent to a densely populated area may be considered to have a greater (negative) influence on its survival than the fact that it occurs on relatively steep slopes difficult to cultivate and constituting some deterrent to its clearing for that purpose. In practice the logical procedure will be to assign the largest weights to the factors having the greatest potential for the destruction of the forest cover. The resultant index will therefore be numerically large when the forest is most at risk and will in effect be an index of instability.

For each of the factors considered (which can be confined to those most critical in a given situation and need therefore not be exhaustive) a ranking order can be based on a linear scale (e.g. from 1 to 10). Each vegetation element being evaluated is then assigned a value on such a scale, based either on some absolute quantity (e.g. population density of the adjacent area), or a relative assessment (e.g. intensity of surrounding land use), although in most cases it will also be possible to quantify such factors, e.g. in terms of distance to a region of intensive cultivation. Care must be taken that the highest rank on a scale is consistently equated with the highest degree of instability (in line with the weights), since some factors may favour stability when they have a high numerical value (e.g. degree of slope), and others when they have a low numerical value (e.g. population density). A linear index of instability will then be obtained for each vegetation element by multiplying weight and rank for each factor and summing these products.

Such an analysis of stability may be undertaken in an exhaustive manner for entire regions by obtaining a linear function of the various factors, for instance by a principal component analysis, from which the index for all, or selected, elements of the vegetation cover is then calculated in accordance with their rank for each factor (as mentioned in the report on the Formulation of a Tropical Forest Cover Monitoring Project, p.30). Or, as mentioned above, it can be used in a more restricted way, for example to assess the relative priority for monitoring between the fragmented easternmost elements of the forest of class 1 and class 12 in Togo (see vegetation map), by a comparison of the selected critical factors based mainly on their presentation on the vegetation map, as illustrated below.

		Class 1		Class 12	
Factors	Weight	Rank	Product	Rank	Product
Distance to region of intensive cultivation	4	4	16	10	40
Population density of adjacent region	4	2	8	7	28
Steepness of forested terrain	2	6	12	2	4
Predominant size of individual forest areas	2	5	10	3	4
Sum of products = Index of instability			46		76

On the result of this analysis there is a higher probability that deforestation will occur among the isolated forest areas of class 12 than among those of class 1, which it is therefore less urgent to monitor. It is important to note that it is the relative magnitude of the index which is significant for evaluating priorities, but that it would generally be difficult to interpret the magnitude of the index in terms of absolute stability.

More complex situations can also be envisaged, such as the case of the Togodo study area. It was mentioned above that the Togodo and Tsagba areas were situated about 10 km apart. By 1969 the extent of forest in the Tsagba area had been reduced to 181 ha, about 90% of the original 6 237 ha having been cleared for cultivation (table 4.4). At this point there was a migration into the adjacent Togodo area, the nearest reserve of good cultivable soil under a forest stand, where clearing for cultivation then proceeded at a high rate. In such situations the introduction of a time factor and relative rates of change in adjacent areas would have to be taken into account for the assessment of stability, requiring a modelling procedure rather than the estimation of a linear index.

In the establishment of the linear index according to the example given above, ranks can usually be assigned objectively for each factor from measurements or other quantitative data, whereas weights can only be assigned to each factor in a more or less subjective manner. The example shows that the index is highly sensitive to the weighting of the factors, which must therefore be based on the best available information.

Additional back-look studies.

One source of such information will be the results of back-look studies of the kind conducted by the project, which provide data on the rates and kinds of change to which the forest cover is being subjected and enable these to be linked to the causal factors concerned. Any monitoring programme established in the project countries would therefore benefit from the investigation of additional study areas.

As appears from 4.1, the selection and location of study areas will usually be a subjective procedure, so that an objective statistical method for determining their frequency in relation to the variability of the conditions which they bring to light is not applicable. However, the principles underlying statistical analysis can also serve for a subjective sampling procedure and the representativeness of subjectively selected study areas can be improved by distributing them among relatively homogeneous strata. Such stratification can be based both on eco-floristic zones, to reduce the variability of the vegetation classes encountered, and on the distribution of factors related to stability, as discussed above, since these are likely to influence the rate of change which is the main variable being sampled. The representativeness of the study areas will also be improved when their frequency within the different strata is proportional to the heterogeneity of the strata. Such heterogeneity can be assessed initially as a function of the number of vegetation classes and the range of factors related to stability present in a given stratum. Taking the vegetation map of south Cameroon as an example, from inspection alone it appears that far fewer study areas would be required in zone III, which is largely dominated by a single vegetation class and has more or less uniformly low population density, than for zone V which contains five vegetation classes of significant extent and exhibits a wider range of population density, topography and land use.

5.3 MONITORING PROCEDURES

5.3.1 Introduction

Areas which have been identified as requiring monitoring may be periodically observed and assessed for change either in their entirety, or by a sampling procedure. While the latter can be applied as a matter of choice, the possibility of implementing complete monitoring will usually depend on the extent of the areas concerned and the means available for their periodic observation and assessment. If the means are inadequate then sampling will be mandatory, unless the area to be monitored is deliberately reduced (possibly after a refinement of the assessment of stability) to permit its complete monitoring by the means which can be deployed. In certain situations statistical sampling may also be preferred on theoretical grounds, because the procedure enables the precision of the quantitative results to be calculated. There are consequently no hard and fast rules for selecting one or other of these procedures, although in any given situation logistic considerations will tend to influence the choice. The main difference between the two procedures consists of the way in which the observations are distributed and the results are analysed, whereas the methods for making the observations and measuring change in the forest cover are common to both.

5.3.2 Methods of periodic observation

Periodic observation of the forest cover to ascertain whether changes are occurring are best made by remote sensing, the state of the forest cover at a given time being recorded on Landsat data, on conventional aerial photographs, on 35 or 70 mm photographs of fixed plots from light aircraft, or by visual observations from a light aircraft or helicopter. Although the detection and measurement of change will generally be easier and more reliable when the recording method is the same at successive dates, when different methods are unavoidable this does not necessarily invalidate the use of the resultant data, as mentioned in 5.2.1. Remote sensing permits extensive areas to be observed in a limited time and, more significantly, the near vertical view of the forest cover which it provides allows an immediate appreciation of the size, distribution and nature of gaps in a stand and a clear view of stand margins. This is difficult to obtain from the ground and will often be the key to ascertaining whether change is occurring. In most cases stand physiognomy can also be recognised and its modifications therefore observed, although when change is confined to physiognomic modification some ground control will usually be necessary as well.

Observation on Landsat data.

The use of Landsat data for monitoring will depend upon its availability and the scale at which the changes are occurring (4.3.3). Only the presence of a Landsat receiving station covering the area to be monitored would provide sufficient assurance that data will become available for observations at an interval of two to three years at most if the area is very cloud-prone. In 1980 Africa remains the only continent without a Landsat receiving station so that for the present monitoring south of the Sahara with Landsat data should not be contemplated at intervals of less than three or four years, during which time new cloud-free imagery could be expected to become available, especially if the necessary arrangements with NASA were made.

If change of the forest cover is to be observed and analysed at a scale of 1:50 000, as done by the project (4.2), then this could only be done by the computer processing of the digital Landsat data (Appendix 2). On imagery at 1:250 000 it is possible to interpret and map areas of two to three millimetres square, i.e. areas of 25 to 60 ha, although this will depend very much on the quality of the images and the nature and contrast of the areas concerned. The possibility of using Landsat images for monitoring as a function of their scale is therefore dependent on a range of factors, including the rate of change and the monitoring interval, which determine the size of the area to be periodically mapped and/or measured, and of the pattern of deforestation. If individual areas of deforestation become larger between observations (rather than only more abundant), then they will also become progressively easier to interpret and map on Landsat images; but if change is mainly due to the removal of individual trees and shrubs (as in the Malanville area of Benin for example) to supply fuel wood and poles, then this could be detected on Landsat imagery only at rather long intervals (4.3.2).

When an evaluation of the factors discussed above indicates that Landsat data can be used for monitoring in a given situation then there is every incentive to do so since, compared to any other form of remote sensing data, its cost is negligible and its procurement simple. Its geodetic accuracy is generally good (3.2) and it therefore lends itself well to mapping for the measurement of areas, which may at times also be carried out directly on the imagery.

Observation on aerial photographs.

Conventional modern aerial photography of good quality has virtually no technical constraints as far as its interpretation for monitoring tropical forest cover is concerned, and can provide cover of consistent scale and overlap flown in straight lines, all of which facilitates interpretation and mapping. Except in flat terrain the preparation of maps directly from interpreted aerial photographs can be troublesome (4.2) due to image distortion and is necessary because for the same reason they do not lend themselves to the direct measurement of areas.

There are, however, several factors which limit the use of conventional aerial photography for the periodic observation of forest cover in the tropics. As discussed in 4.1 obtaining aerial photography in the tropics can often be frustrated by unfavourable weather conditions. The need to programme photographic missions by commercial firms usually several months in advance of their execution makes it difficult to take advantage of short periods of good flying weather. The cost of conventional aerial photography is also extremely high and since many of the costs are fixed the cost of photography per unit area is much greater for small areas. This will therefore generally preclude repeated aerial photography at intervals of a few years, unless this can be executed by a Government agency at nominal cost.

Observation with light aircraft photography.

Light aircraft photography is relatively cheap, costing little more than the rental, or operation, of the aircraft. An overwhelming advantage for tropical forest cover monitoring is that it can be carried out at a few hours notice and so use the short periods of favourable weather which generally occur, to ensure obtaining the photography required. The disadvantages are the small photographic format; the difficulty of maintaining the camera's optical axis vertical and of precise navigation (e.g. in crosswinds). Precise navigation for light aircraft can be attained by installing global navigation systems which function on low frequency signals transmitted from ground stations. When such navigation aids are not available it would be particularly difficult to produce photography with constant side-lap and under such circumstances an area would normally be photographed by a series of more or less parallel but discrete line transects. By making these sufficiently dense over the area in question a comparison of the state of the vegetation cover at successive times could be made. Another possibility would be to establish permanent sample transects, if conditions permitted their repeated location with certainty.

The two main elements required for 35 or 70 mm aerial photography are a light aircraft and a mount with its various accessories for the camera, or cameras. Until recently the need to have the mount custom built posed considerable problems for this type of photography and since it meant making long term arrangements for the availability of a particular light aircraft prevented its use by the project.

It has now been reported from the United States (Meyer and Grumstrup, 1978) that a firm there will produce such a camera mount to order. A national forest cover monitoring unit could, therefore, obtain this and mount it on its own aircraft, or on one locally available at short notice. With these two elements assured the execution of 35 or 70 mm aerial photography to meet the needs of a monitoring programme can be undertaken. The publication referred to above gives comprehensive information on many aspects of 35 mm aerial photography, permitting such a system to be orgnized. Some aerial survey companies and other institutions also use mounts, usually for a bank of four 70 mm cameras, for attaching outside the door of light aircraft of various types and could furnish the specifications for having these custom made.

Once a system for obtaining repeated aerial photography of areas to be monitored has been established the basic procedure for the assessment of change will be essentially the same as used by the project for the study areas, described in section 4.2. By carefully establishing the scale of the light aircraft photography it will be possible to map the vegetation by close reference to a map of the area made from the latest available metric aerial photography. In certain cases mapping may not be necessary, as when the annotation and comparison of photographs of succeeding dates displays any change, or its absence, sufficiently clearly for the objective in view.

Visual inspection.

If circumstances do not permit the use of Landsat data or aerial photography for monitoring, for example at the outset of a monitoring programme or at some juncture when the necessary facilities are not available, recourse may be had to aerial inspection of the areas to be observed. Such inspection may also be carried out to confirm the identification of areas to be monitored. The procedure should aim to provide a comparison of the present state of the vegetation cover with its depiction at an earlier date on Landsat images, aerial photographs, or maps. Whatever documents are available should be systematically studied and annotated and used to plan the aerial reconnaissance.

During the inspection systematic observations of present conditions will need to be made in a manner which will permit comparison with earlier conditions as displayed on the documents being used. This may be facilitated by using a grid overlay, particularly when it is necessary to sketch present boundaries of vegetation classes from an aircraft. This is best done while hovering in a helicopter. With a light aircraft lines may have to be flown repeatedly until the sketching is satisfactorily accomplished. While this will not permit any precise measurements, it will enable the occurrence of change to be established and indicate its nature and magnitude, and in some instances this may suffice.

Monitoring objective.

It is evident that the methods used to make periodic observations will also depend on the information which these are designed to supply and the formulation of the objective of monitoring a given area or region should form an essential step in the overall design of a monitoring programme. The information which is required may range from the simple confirmation that modification of the forest cover is taking place, through data on absolute areas and rates of deforestation, to an analysis of the nature of changes of the vegetation cover taking place over time.

Even if only the confirmation that change is taking place is of interest, this is usually best supported by measurement of the areas of forest at different dates. As mentioned above, except in flat terrain this requires the prior transfer of areas delimited on Landsat images or aerial photographs to a topographic map, as described in 4.2 The actual measurement of areas on a map is usually best carried out using a dot grid, as discussed in 3.8.

As mentioned in 5.3.1, the methods of observation and measurement discussed apply equally whether observations are made for entire areas or only for samples. In the former case the analysis of the measurements obtained can be conducted as for the study areas, described in 4.2. For sample observations a different approach is required, as described in the next section.

5.3.3. Methods of sampling change

The project's commitment to the production of vegetation maps and studies of change, coupled with constraints of time and of the availability of staff, did not permit the implementation of a sampling method, although its application in trial form for Togo was given some consideration and is referred to below.

As mentioned in 5.3.1, the incentives for monitoring by observing and taking measurements on only a sample of the total area being monitored will either be to reduce the amount of observation when very large areas are being monitored and to extrapolate the sample values to the entire area, or to obtain an objective estimate of the error of the quantitative results even when the areas being monitored are quite small. In either case the desired result requires that the procedures conform to statistical sampling theory. This is expounded in many general and specialised texts (e.g. Manual of Forest Inventory, FAO, 1973) and will not be elaborated on here except in so far that it is relevant to the exposition of the procedures described.

The population.

As a first step in designing a sampling procedure the population to be sampled must be defined. The population cannot be defined as all those areas where change has occurred, or is occurring, because this requires that all such areas are known and mapped since, to be statistically valid, samples must be selected from the entire population. If the only parameter of interest is the progressive loss of forest area then the population can be defined as the area of forest at a given period within some geographically defined limits (e.g. an eco-floristic zone, a country, or a group of countries), providing that information on the location of the forest is available.

If the latter is not the case, or if the parameter of interest is the rate of change between various classes of woody vegetation cover (as analysed in the project's study areas) then it will be necessary to regard the vegetation cover over the entire geographical area being monitored as the population to be sampled. This demonstrates the interest of first identifying areas where monitoring is required as closely as possible (i.e. a first level of stratification), to reduce the incidence of samples where no change is taking place.

It is also possible arbitrarily to define much smaller areas where change is known to be taking place, such as one of the project's study areas of less than 100 000 ha, where again the population to be sampled would be the vegetation cover over the entire area.

Size of sampling units.

Another prerequisite for the implementation of a sampling procedure will be the determination of the size of the sampling units. In a study of the reduction of the forest area in the Ivory Coast Lanly (1969) assessed the area of forest at two dates by using the effective area of selected aerial photographs at 1:40 000 as sampling units, each of which had an area of 1 500 ha. From practical considerations this has much to recommend it and from what has been said in 4.3.2 about the size of the areas cleared annually in the project countries, such a sampling unit would be adequate and could even be reduced in size (e.g. by selecting plots distributed within the effective area of an aerial photograph) if monitoring was carried out at intervals of only a few years.

However, when considering the size of sampling units for monitoring change in the forest cover it must be taken into account that the area of deforestation, at a given location, may expand over time. When this occurs it will sooner or later lead to the repeated observation of zero change in some, or all, of the sampling units and make the sample as a whole progressively less representative of the parameter being sampled. For a given rate of deforestation and monitoring interval this will tend to occur the sooner, the smaller the sampling units are. Although the sampling error will usually be lower when (for a given sampling intensity) a larger number of small sampling units is used, the determination of the size of the sampling units will usually require a compromise between considerations of precision and representativeness of the sample.

The size of the sampling units will also be influenced by the method of observation. It has already been mentioned that the effective area of an aerial photograph makes a convenient sampling unit. If Landsat images are used to make the periodic observations then the size of the sampling units must clearly be large enough to be readily detected and interpreted. As mentioned in 5.3.2 monitoring in the tropics is most likely to depend on light aircraft photography and without special navigation aids this is best suited to the photography of discrete areas such as sampling units, which may then take the form of relatively short lines of (preferably) 70 mm photography. In this case it may also be necessary to mark sampling units on the ground, for repeated identification.

When absolute area is being sampled (e.g. the amount of forest depletion), for the sample mean to be extrapolated over the entire area of the population it is necessary to know the precise area which has been sampled (which is given by the product of the area of a sampling unit and the total number of sampling units) as a proportion of the total area covered by the population.

Sampling intensity.

The magnitude of the sampling error (or the precision of the sample mean, which may be expressed as the percentage sampling error at a given level of probability), is a function of the number of sampling units and of the variability of the population parameter being sampled. Since making monitoring observations is exacting and often costly and the means for their acquisition will tend to be limited there is, as in most applications of sampling, an incentive to reach an optimum compromise between the size of the sampling error and the number of samples. Of the three variables involved, the allowable sampling error must be predetermined, the variability of the population parameter estimated or sampled, and the corresponding number of samples calculated from the first two variables.

The variability of the parameter, expressed as the variance of the mean of a number of sample values (e.g. of the percentage reduction in forest area between two dates, or of the average annual rate of change), may be estimated from available records, or some samples measured on the aerial photos or Landsat cover available, or from back-look studies, or any combination of these.

In broad biological studies as represented by forest cover monitoring a precision of ± 10% at a 95% probability level can be considered very satisfactory. If this results in the calculation of a number of samples which is considered too large, then the allowable error must be increased (i.e. the acceptable precision reduced) until a practicable compromise between these two variables is attained. The actual sampling error of the results will of course depend on the variance of the mean of all the samples measured.

It is evident that the variability of the parameters of change will be very high when considered over the entire area of a country such as Togo, or any other large area with a similar range of ecological and socio-economic factors. Thus both on statistical grounds and to be able to relate the results to more specific geographical and ecological units, it will always be preferable to stratify extensive areas into more homogeneous and restricted areas (or, strictly speaking, populations). The two major criteria for stratification will be the eco-floristic conditions and the distribution of the factors which most commonly have a significant influence on the rates of change, as discussed in 5.2.1. The boundaries of the strata should be depicted on a map, so that sampling units can be assigned to the appropriate stratum. The calculation of the number of sampling units, as described above, must then be made separately for each stratum.

Sampling design.

A major consideration in any sampling procedure is the selection of the sampling units, i.e. the sampling design. To conform to statistical theory the selection should be random, and with replacement, i.e. every unit should have an equal probability of being selected each time a selection is made. This latter condition can be ignored if the proportion of sampling units is small compared to the total number of such units comprising the population being sampled (FAO, 1973 p.23), which will usually be the case. As is commonly done for tropical forest inventory, for greater ease of execution and reduction of cost (e.g. of periodic light aircraft photography), it will generally be preferable to distribute sampling units systematically, although this may result in some (unknown) overestimation of the sampling error.

If there is no existing data, i.e. aerial photographs, Landsat images, vegetation maps, on which the 'initial' extent of the forest cover, or of various vegetation classes can be measured, then the simplest procedure will be to lay a grid over a map of the various strata and distribute the calculated number of sampling units systematically within each stratum, using the grid intersections to locate the centre point of a sampling unit to be photographed from light aircraft.

If in Togo, for example, it was decided to use the 1949 aerial photo cover to represent the 'base line' situation and the 1977/78 cover to make the first measurements of change, and that a sampling unit would be equal to one aerial photograph (or only its effective area), then for each stratum the number of photographs corresponding to the calculated number of sampling units can be systematically selected. This may be done by reference to the photo-index for the mission and the map of the strata, and selecting each nth photograph in every ith line to obtain a systematic distribution over the area of each stratum.

For the next set of observations, say in 1982, no new aerial photography may be available. For the conditions encountered in Togo Landsat imagery would not permit sufficiently detailed interpretation to observe all the changes of interest. Digital Landsat data could not be readily used to observe changes other than the clearing of high forest. It would therefore be necessary to have recourse to light aircraft photography of the sampling units. Whatever subsequent method of observation is used, this will be facilitated by preparing a map at the outset which shows the location of all the sampling units in each stratum. When different vegetation classes are being mapped and measured at each observation some ground control will also be required, at an intensity dictated by the circumstances.

A number of variations on these procedures are possible, e.g. first selecting areas on Landsat images or selecting grid squares on a vegetation map (primary sampling units), and then within these selecting aerial photographs, or sampling units to be photographed from light aircraft (secondary sampling units). But for the examples cited, the statistical design will be either a one-stage or two-stage stratified systematic sampling, for which the estimate of the population mean, its variance and precision may be calculated from the sample value of these parameters according to standard statistical procedures and formulae as applied, for example, to tropical forest inventory.

The analogy between forest cover monitoring by a sampling procedure and forest inventory is particularly pertinent when continuous forest inventory is considered, which also involves a process of periodic sampling. Various types of continuous forest inventory are possible, according to whether the same sampling units are always remeasured, or are replaced to varying degrees at successive measurement times.

For monitoring change from one vegetation class to another it would be advantageous to use the procedure of successive sampling with partial replacement (see FAO, 1973 p.183 ff.) because the location of the sampling units progressively changes and this will ensure obtaining a more representative sample of change in conditions where shifting cultivation in the strict sense is practiced and cleared areas tend to multiply rather than to expand. It will also avoid that in conditions where cleared areas expand over time an increasing number of sampling units will cease to manifest change because they have reached the ultimate stage of the removal of the entire woody vegetation cover ("0" sampling units). This approach was also recommended in the 'Formulation' report (1.1) because it tends to result in a lower sampling error than using all the same sampling units for successive observations.

Such a procedure can be implemented, for example, if Landsat imagery can be used to make the periodic observations and new Landsat cover is regularly available. As mentioned earlier, complete conventional aerial photographic cover at likely monitoring intervals for extensive areas will rarely be available. But photography from light aircraft could also serve, since new sampling units can be selected as originally, centred on the intersections of a grid which can be located on a map and photographed as required.

In the application to continuous forest inventory of sampling with some degree of replacement, a proportion of the sampling units is measured only once and the relationship between the value of a parameter at successive inventories is calculated from the regression of its estimated mean value at the later time on that at the previous time. This is not applicable to monitoring rates of transition between classes of the vegetation cover as done in the study areas (although appropriate for sampling the reduction of the forest cover as a proportion of the original extent over a given region), because the conditions of change at each location are unique (e.g. the absolute area of change between two dates, as opposed to the dimensionless average annual rate of change derived from this). However, as long as at least two successive measurements are taken for each sampling unit then the data will be in the form of rates of change at specific locations and may be analysed accordingly.

A further consideration which arises in using a sampling procedure to monitor change is that the results would provide estimates of mean rates of change over an entire stratum, but would not necessarily identify all areas where harmful change was occurring at a given time when such a stratum covers a large area (e.g. an entire eco-floristic zone). Significant changes requiring intervention could, therefore, escape notice and so vitiate the system as a means of giving adequate early warning of the degradation of the forest cover. However, this could to some extent be overcome by noting areas where change was occurring on a high proportion of the sampling units and undertaking a systematic survey of such areas. Observations made on photographic flights between sampling units could be acted on in the same way.

Finally, it may be mentioned that the first time observations are made of the areas of different vegetation classes in each sampling unit this constitutes a sample estimate of the total area of each of the vegetation classes over the entire area being sampled. While the usefulness of the 'base-line' vegetation maps of the kind made by the project has frequently been referred to in this chapter, and their applications also go beyond this, there could well be situations where making such maps would not be practicable and the assessment of the initial state of the vegetation cover could be obtained by the application of a systematic sampling strategy of suitable design. Although the representation of the spatial distribution of the vegetation classes would be rudimentary (obtained for example by extension from sampling units over the entire grid), the area of each vegetation class would be objectively estimated, and the confidence limits of the estimate known. Such an approach could also serve, for example, to establish priorities for a subsequent programme of conventional vegetation mapping.

5.4 PRESENTATION OF MONITORING DATA

Monitoring the forest cover will produce data about the absolute and relative extent of areas and on rates of change, at successive times. Such data can be presented in various ways, depending partly on the use to be made of it.

Absolute areas, at one or more dates, can be presented in tables such as are shown in Appendix 5. The same may be done for relative areas, e.g. the area of high forest at different dates as a percentage of the area at the earliest date, or of the total land area of an administrative of other unit. Tabular statements also lend themselves to aggregation for successively larger units of area, whether administrative or geographic.

Such data can also be displayed in the form of maps, from which it will usually be derived. An example is the maps of the Tsagba study area (Togo) in 1949 and 1969 attached to this report. For a situation of complex change as displayed there a new map is best produced for each date of observation and the time series compared. In simpler situations, when only the regression of one cover class is mapped (or all cover classes regress to a common class, e.g. cultivated land, but not into each other), then the areas at successive dates may be shown on the same map, in a series of different colours, for example, to provide a striking display of change over time.

If rates of change are expressed as percentages, in the form used for the study areas (4.3.1), or as any other ratio, the resultant numerical values can also be tabulated (e.g. table 4.1). Within tables they may be grouped by the vegetation classes between which change has occurred, and by location, and when dealing with a large amount of data the numerical values themselves may be grouped into classes, e.g. up to 3%, 3 to 6%, etc. The absolute areas present at different dates can be presented in the form of contingency tables (e.g. table 4.3) for dates 1 and 2, 2 and 3, etc. Such tables are particularly useful for the display of the qualitative trends and magnitude of change between two observations, which need not be consecutive. Thus, in addition to contingency tables for the two most recent observations it may also be of interest to prepare such a table comparing the earliest and latest situation.

Contingency tables can also be aggregated for increasingly larger units of area. It is also possible to envisage the preparation of maps on which classes (i.e. levels) of rates of change at different locations, or in different zones, are represented by symbols or colours.

By overlaying any of the maps discussed above on to thematic maps at the same scale - vegetation cover, land use, soils, climatic data, population density, etc. - maps synthesizing such thematic information with the data derived from forest cover monitoring can be prepared and used as an aid to analyzing the relationship between the factors involved, as a guide to the inventory and management of the forest cover, for land use planning, etc.

The manipulation of a range of thematic data to obtain such a synthesis may also be done by using computerized or manually operated geographic data systems. In this case all the data is referred to a system of spatial coordinates. The implications for forest cover monitoring will be mainly the need to record and organise the data obtained periodically so that it is compatible with the data management system being used, for example concerning the size of the recording areas and the format of the data records.

For tropical forest cover monitoring the frequency at which new data is obtained will usually be low - once a year at the most. But the number of observations at a given time may be very great when the areas being monitored are very extensive. If this is the case the use of a computer facility to handle the data derived from monitoring could be contemplated, especially as existing computer programmes could be used for most of the computations required. If such a method is adopted it would also lend itself to the production of computer printout maps for the display of the results, as discussed above, although this might require the preparation of some special programmes.

CHAPTER 6

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

6.1 GENERAL

The methods adopted by the project for mapping vegetation cover at the country level and for investigating past changes in the vegetation cover in selected areas of limited extent, with the results obtained and the observations made in the course of these activities, have been set out in detail in the report on each of the three participating countries 1/ and in the preceding chapters of the present report, which has also dealt at some length (chapter 5) with the implications of the project's activities and findings for the continuous monitoring of the forest cover. The present chapter therefore only presents the main conclusions, and the recommendations to which these lead, to provide a summary overview of how tropical forest cover monitoring may be approached and conducted, on the basis of the project's pilot activities in this field.

These also lead to some more general conclusions and recommendations. The vegetation cover maps confirm (because the observation is not new) that the loss of forest cover is related to population density. This applies whether the three countries are compared in terms of overall population density and area of forest remaining (illustrating the historical trend), or whether specific localities are considered as may be done on the map of south Cameroon where the distribution of areas of degraded forest more or less reflects the distribution of access routes - roads and rivers - along which the population is concentrated. Consequently any intervention to halt or moderate the loss of the forest cover should be undertaken not only in consideration of the forest, but primarily in the light of the needs of the population and how their satisfaction may be brought into equilibrium with the maintenance of adequate forest cover.

To be in a position to undertake the management of the forest cover under such complex terms will require sound knowledge of the specific causes and processes of deforestation (or degradation), and of the effects on the factors of the environment and on the dynamics of the forest itself, for example its potential for reconstituting itself under protection or fallow. A starting point for such investigations could be the results obtained from the project's study areas, although eventually they should be distributed over the range of significantly different ecological and socio-economic conditions which may be identified as described at the end of 5.2.

In all three of the participating countries the forest cover, in the broadest sense, is being reduced albeit at very different rates and under widely different circumstances. From what has been said above about the connection with population pressure, this reduction can be expected to expand its occurrence and increase its rate. Consequently it was recommended in all the country reports that monitoring of the forest cover should be undertaken and monitoring units for this purpose set up.

1/ Bénin, Cameroon, Togo: Cartographie du couvert végétal et étude de ses modifications.

Specific conclusions and recommendations concerning this and vegetation mapping are given in the next two sections. Proposals for extending multilateral assistance to other countries and regions for the inception of tropical forest cover monitoring are set out in Appendix 1.

6.2 TROPICAL FOREST COVER MONITORING

6.2.1 Planning of a monitoring programme

The implementation of a programme of tropical forest cover monitoring involves the planning and design of a series of mostly inter-related technical activities, which in turn will depend on considerations of policy and administration, and of the physical and socio-economic conditions influencing the forest cover and its dynamics. The inception of a monitoring programme will therefore require the systematic consideration of various aspects which may include all, or some, of the following:

- the institutional location and administrative level of a monitoring unit. These may be influenced by considerations of the input and output of information, as well as of access to documentation such as aerial photographs and maps, when access to these is restricted.

- the initial scale and rate of expansion of the programme, in terms of staff and the consequent needs for training, and in terms of facilities and equipment.

- the major objectives of the programme, in terms of the kind and scope of the information to be produced, e.g. data on the loss of forest cover at the country level, or data relevant to the dynamics of the fuelwood supply situation in the vicinity of major urban centres.

- the identification of the areas to be monitored and the assignment of priority among these.

- the monitoring scale/s and interval/s to be applied.

- the method/s to be used for periodic observations and for their evaluation and analysis.

- the form/s in which the results are to be presented and whether these are to be integrated into a natural resources data management system.

- the detailed programme specifying which locations will be observed at a given time.

Decisions about some of these aspects, such as the identification of areas to be monitored (when this is necessary) and the selection of the scale and interval to be used, will require preliminary work of the kind undertaken by the pilot project, namely vegetation cover mapping and back-look studies, unless the necessary information is already available. A decision to implement tropical forest cover monitoring should therefore also allow for this to be undertaken in successive phases which will progressively provide the information required to launch a systematic programme of periodic observations.

6.2.2 Monitoring Units: Staff and information flow.

The availability of staff with the appropriate qualifications and experience to conduct the project's work was the main constraint encountered in its execution. In all the project's country reports it has been recommended that a sufficient number of staff at various levels should be trained to make the execution of forest cover monitoring possible. Such training should permit an appreciation of the ecology of the vegetation cover and the application of remote sensing techniques to study this.

Personnel of forest cover monitoring units should endeavour to keep abreast of new information about the vegetation cover and new remote sensing documents becoming available for their area of operation. The setting up of procedures and lines of communication to ensure this (rather than leaving it to chance) would form a useful component of any monitoring unit's activities, as would the dissemination of such information when it originates from a monitoring unit.

The importance of the input to monitoring units of information on developments with implications for the stability of the forest cover was emphasized in the conclusions of the country reports, as was the output of information by a monitoring unit concerning the results of its observations, so that these could constitute an effective early warning of the depletion or degradation of the forest cover for those authorities in a position to take appropriate action.

6.2.3 Monitoring methodology.

Although monitoring in the strict sense of making a series of observations at successive times was not undertaken by the project, the results and experience derived from the vegetation mapping and back-look studies indicated that tropical forest cover monitoring can be conducted by a multi-phase methodology based mainly on remote sensing data from satellite images and aerial photography. This permits observing the minimum area on the ground (i.e. minimising the most costly procedure - per unit area observed), and progressively larger areas by progressively less costly procedures, i.e. aerial reconnaissance, aerial photo-interpretation, Landsat image interpretation.

Periodic observation of the extent of the tropical forest cover can be made on Landsat data. Using the digital data enables changes over the area of a few pixels (say 2 to 3 ha) to be observed under some circumstances (Appendix 2). Using imagery, changes over areas with a dimension of a few hundred metres can be observed under favourable conditions. Landsat data should be used at all stages of monitoring to the maximum extent which its availability and resolution allows, because the data it provides can usually not be obtained more efficiently by other means. But given the constraints on the availability and resolution of Landsat data, the most suitable technique for making periodic observations in the tropics is likely to be photography taken from light aircraft. This will usually be more successful, in terms of obtaining photographs from which areas can be mapped and measured, for relatively small fixed plots than for extensive areas. Consequently monitoring by a sampling procedure, in which only relatively small sampling units need to be observed periodically, will tend to be the most efficient approach. At the same time the photographic operation should be made as efficient as the available funds allow, by using the most suitable aircraft, photographic equipment and aids to navigation.

The data from a time-series of observations obtained by monitoring can be analysed and presented in various ways (4.3, 5.4). The construction of contingency tables of the absolute areas of vegetation classes at two dates permits both the quantitative and qualitative analysis of change and is therefore particularly relevant for relating this to its causes and effects. When change in the area of vegetation classes is not too complex (4.2, 5.4) it can be presented on maps depicting the extent of a class, or classes, at different dates. For the synthesis of such data with related environmental and socio-economic factors the use of a geographic data management system should be considered.

6.3 VEGETATION MAPPING

6.3.1 Use and preparation of the vegetation maps

Apart from their application for a range of planning functions and as a representation of the vegetation cover at a given time, it was shown (5.2.2) that the vegetation maps can constitute an important source of information for the identification of 'critical' areas, where monitoring of the forest cover is required either as a precautionary measure to obtain early warning of the onset of forest clearing or degradation, or as a matter of urgency because modification of the forest cover is already in progress. For the orientation of a monitoring programme it will therefore be useful to produce such maps as a first step, if they are not already available, especially as they will also have applications for the stratification of the vegetation cover into eco-floristic zones, and for the location of sampling units and areas in which to conduct back-look studies (5.3, 5.2). While such maps may be produced in the form adopted by the project, i.e. line maps covering an entire country, or the entire forest zone in the case of Cameroon, they can also be produced in a simpler form directly on Landsat images (3.7.2) and limited to the general areas of main interest for monitoring, in so far that these can be identified on the Landsat images and/or from other sources.

The density of the vegetation (degree of crown closure, or of ground cover) and the relative height of the constituent elements (trees, shrubs, grasses) are the two features most readily observed by remote sensing, whether on Landsat imagery, aerial photographs, or during survey flights. These two features, with the vertical and horizontal pattern of their distribution, constitute the physiognomy of the vegetation cover. While the actual physiognomic classes which exist are limited, they can be sub-divided to almost any required degree by using a range of additional criteria, such as floristic composition or edaphic situation. Consequently a physiognomic classification as used by the project will be most suitable for mapping vegetation cover either at small scales, or at larger scales for monitoring, when the observations on which the mapping is based are mainly made by remote sensing.

The eco-floristic zoning applied to the vegetation maps can be used to increase their information content in a number of ways (3.6) and by constituting a degree of stratification also enhances the application of the maps as a basis for the identification of critical areas, the distribution of sampling units and the selection of areas for investigations related to the conditions of change. Eco-floristic zoning should therefore normally be applied when mapping of the vegetation cover for monitoring purposes is undertaken.

6.3.2 Use of Landsat data

The project found that Landsat imagery served well as the primary source of data for mapping vegetation over extensive areas (of the order of tens of thousands of square kilometres or more), the main reasons being that:

- It permits the interpretation of detail compatible with scales appropriate for mapping large areas (1:500 000 or 1:1 million).

- It permits the interpretation of a wide range of physiognomic classes and of edaphic sub-classes either directly, or indirectly (i.e. by inference from collateral data).

- It constitutes a map base of good planimetric accuracy.

- It facilitates mapping large areas rapidly, and therefore at low cost, because it permits the considerable spatial extrapolation of data from aerial photographs, air and ground surveys of representative areas of limited extent.

- It can be used even when of less than optimum quality and when the cover of the area concerned is incomplete.

- It can be interpreted and the results mapped with simple equipment and materials.

Although the project's use of Landsat imagery enhanced by diazochrome processing consisted only of a limited trial, it is possible to achieve a considerable degree of enhancement, even without enlargement, particularly for the fime distinction of vegetation classes (figure 5). Simple techniques involving the use of a densitometer permit the elimination of trial and error in the production of diazo colour composites and the combination of negative and positive images enables band ratios, and therefore vegetation indices (Appendix 2), to be simulated. Since diazo processing is cheap and versatile its use is recommended as a standard technique when Landsat data is applied to vegetation mapping or monitoring.

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APPENDIX 1

Proposals for Follow-up Activities

In agreement with UNEP the third objective of the pilot project "to prepare the extension of the tropical forest cover monitoring project to the whole African tropical and sub-tropical region and to the Latin American and Asian regions" was postponed so that results of the pilot project could be available and evaluated before action in this respect was taken. The matter was, however, given some consideration and a draft project proposal was submitted to UNEP late in 1977. While the concept adopted for that project has broadly been maintained, aspects of its implementation have been modified, as a result of experience with the pilot project and other factors, in the proposal presented below.

Although administratively a single project, the implementation of the pilot project in three countries involved three distinct sets of project activities. An Agreement for the conduct of the project was negotiated with each country, separate teams of counterpart and international staff were established with their own work programmes, equipment and operating facilities. This was imposed both by the geographical locations and by the different institutional situations in the three countries. If this mode of implementation were to be adopted as a model, it would imply the setting up and execution of a very large number of *de facto* projects, given the number of countries with tropical forest cover (especially in the broad sense applied by the pilot project). In such a situation the negotiation of an Agreement with each country alone would become a major task and other aspects such as recruiting sufficient staff and the level of funding required would become impracticable.

An alternative to this approach is therefore proposed, consisting of the establishment of a number of regional, or more likely sub-regional, units to function as focal points for the initiation of tropical forest cover monitoring in a group of countries. Such units would pursue essentially the same objectives as the pilot project, namely the assessment of the present forest cover and the study of change in critical areas preliminary to initiating continuous monitoring.

But instead of executing these activities on a country by country basis through a series of individual projects, the role of the units would be to promote their execution by the countries concerned. To achieve this the units would engage in activities along the following broad lines:

- Publicising and demonstrating the methods employed by the pilot project and other methods discussed in this report, by establishing appropriate contacts, holding workshops and seminars and providing consulting services, and by conducting trials to assist countries in adapting these methods for the range of conditions encountered.

- Training and demonstration, by conducting practical courses and field exercises and by acting as a clearing house for placing trainees at appropriate institutions.

- Coordinating certain activities and ensuring the flow of technical information among the countries concerned and into the region or sub-region from outside. Technical aspects calling for some coordination include the establishment of vegetation classifications, criteria for ecological zonation, matching maps of adjoining countries, statistical methods for sampling procedures, aggregating results from different countries to produce a regional synthesis. Maintaining close contact with the technical developments, both within the region and in the world at large, in the range of activities of which monitoring is comprised and assisting countries in terms of information and consultations to adopt the new techniques most suited to their conditions. This will require participating in certain technical meetings and the establishment of a collection of the most important literature.

The implementation of these activities would be greatly facilitated by attaching the regional monitoring units to existing institutions which are engaged in related activities, such as the Regional Remote Sensing Training Centres in Ouagadougou (Upper Volta) and Nairobi (Kenya). These are engaged in training personnel from countries in the region in the application of remote sensing techniques and therefore offer many of the facilities required for the activities of the proposed regional forest monitoring units. Such an arrangement would greatly reduce the time required to make the latter operational and could also reduce the inputs required for their establishment and functioning.

The establishment of a new regional remote sensing training centre is being actively pursued in Asia in connection with the Asian Institute of Technology near Bangkok (Thailand) and although less advanced, two such centres are also envisaged for Latin America. Both these regions already have national centres in various countries engaged in the advanced application of remote sensing for resources surveys, which could also be considered as hosts for a tropical forest cover monitoring unit covering several countries.

A further advantage of this approach is the likelihood that in due course the monitoring unit would be absorbed by the host centre and thus not constitute an indefinite charge on the agency financing its creation.

Although it is not possible to specify the detailed inputs for the establishment of regional forest monitoring centres at this stage the major requirements would be for staff and for funds to finance group training activities (including publications) and individual fellowships. A staff of two - a specialist in the field of tropical forest monitoring and a specialist in training activities related to this - supported by consultants, adequate travel funds and preferably an associate expert would suffice at least in the earlier stages. According to circumstances a certain amount of transport, equipment and supplies and the usual operating costs would also have to be provided.

Once a decision to finance one or more such regional forest monitoring units in principle has been taken, the next step would be to negotiate their attachment to an existing centre for remote sensing training and/or applications from which the subsequent details for the formulation of a project will emerge. This may not differ substantially from the project proposal submitted to UNEP earlier. In any event, the implementation of a follow-up project should be envisaged with a preliminary phase of 3 to 6 months, depending upon its geographical scope, to conduct negotiations with host institutions and countries and to formulate the subsequent substantive phase.

APPENDIX 2

COMPUTER ANALYSIS OF LANDSAT DATA

1. INTRODUCTION

The formulation report (FAO, 1975, p.35) states "It is deemed most appropriate that this project .... includes a research component on the application of automated interpretation of satellite imagery to the problem of classification and monitoring of the tropical forest". It was therefore decided to carry out some computer analysis, which was undertaken by the project coordinator who had some experience in the subject.

Initially some difficulty was encountered in locating suitable computer facilities, but early in 1978 it was learnt that IBM were installing their Earth Resources Management system (ERMAN) in Rome, which was designed for the analysis of multispectral data. Familiarisation and trial sessions were undertaken at intervals during 1978 while the system was undergoing testing and modification. Finally an investigation was undertaken during four half-day working sessions in November-December 1978.

To map a range of classes comparable to those appearing in the legends of the project's vegetation maps by computer processing over a large area requires lengthy and therefore costly preparatory analysis, for which neither time nor funds were available. Such analysis produces maps on which each pixel is classified, a pixel representing 0.45 ha on the ground. The results are therefore very detailed, the scale of the normal computer printout map being about 1:25 000. Such detail gives rise to a range of problems due to which computer processing is not necessarily a suitable approach for mapping numerous classes over very large areas as was done in the preparation of the project's vegetation maps.

Monitoring change, however, is usually concerned with much smaller areas of the order of thousands or tens of thousands of hectares, where detail at large mapping scales is an advantage. Furthermore, monitoring concerns making comparisons over time, for which the objectivity of an automated process is an inherently valuable factor. It was therefore decided to investigate the application of computer processing of Landsat data to monitoring change in the forest cover (also because relatively little work has been done on this), rather than to conduct an overall vegetation classification, which is a field where much work already exists.

2. OBJECTIVE

The objective was to distinguish closed high forest from any other adjacent class, whatever this might be, and to assess whether the accuracy with which this was achieved would be adequate for monitoring the extent and rates of change which could be expected.

The data available for the study consisted of one computer compatible tape of a scene in Cameroon. This was of good quality and cloud-free, but had not been obtained with this particular work in view. As pointed out in section 3.2 very few scenes of the project area were available at two dates and none of these were both of good quality and over tropical high forest.

Although the observation and measurement of change could not be demonstrated directly using a scene of only one date, if forest and non-forest could be mapped with good accuracy at one date then this could be repeated at a subsequent date. The number and location of the pixels in each class at each date would be automatically computed and represent the area of change and where it had occurred.

In the strictest terms there are certain provisos to this. Data of the same area recorded at different dates is not necessarily constant, due to changes in such factors as sun angle and atmospheric conditions. For such spectrally distinct classes as forest and non-forest this is usually not significant unless terrain shadow is also an important factor. In the present case both the areas were level so that this complication was avoided. But any conclusions are only relevant to such a situation.

3. METHOD

The scene used was no. 1478-08454 of 13 November 1973, covering a part of south Cameroon with high forest in the south and savanna areas in the north (figure 1). The town of Batouri is located slightly north of the centre point.

The investigation was carried out on two areas, one consisting of a zone of degraded forest in a matrix of moist semi-deciduous forest (area 1), the other of a massif of semi-deciduous forest in a matrix of savanna (area 2). These were selected as representing typical cases where change could be expected to occur, in the first case by the expansion of cultivation and settlement in the zone of degraded forest following the line of a road, and by encroachment on a well defined forest massif surrounded by savanna in the second case. Area 1 (ca 3800 ha) is located around the village of Bamekok, 5 km north-east of Bimba. Area 2 (ca 4260 ha) is located on the left (eastern) bank of the Dikombi river some 10 km east of Garoua Sambé and about 20 km north of Batouri. Both areas are on the Batouri sheet (NB-33-III) of the 1:200 000 series of Cameroon.

The colour display of the digital data (figures 6 and 7) showed that the degraded forest in area 1 and the forest in area 2 were spectrally both relatively uniform, whereas the surround was much more variable. To attempt to map all the classes present would therefore have been complicated and costly and, more relevant from a methodological standpoint, difficult to assess in terms of accuracy at the pixel level. For purposes of monitoring change in the area of forest cover this is fortunately not necessary (although possibly desirable to study development trends of the vegetation cover as a whole). All that is needed is to map the boundary of the two classes of interest - forest and non-forest - accurately and it is this which makes monitoring particularly apt for treatment by computer processing of Landsat data.

Although the area had been mapped at 1:1 million by the visual interpretation of Landsat images, in the absence of recent aerial photographic cover there was no possibility of making a direct assessment of the accuracy of the results, especially at the resolution of individual pixels. To obtain some indication of the validity of the results the data was classified both by an unsupervised and a supervised technique on the assumption that if the difference between the two sets of results was small the accuracy of classification was probably high.

4. PROCEDURE

The two areas were viewed as a computer coded colour display of bands 4, 5 and 7 with some prior histogram equalization to enhance contrast (see figure 6 and 7). Using all four bands, spectral signatures were obtained from clustering a number of small training fields of some 100 to 600 pixels each (Fleming et al, 1975; Baltaxe, 1977). The resultant cluster signatures were first used as input (i.e. as given cluster centres) to cluster the entire area. Figure 8 shows the resultant map for area 1 on the colour display, obtained by coding all the classes of degraded forest in one colour (red) and all the other classes (non-degraded forest, villages, etc.) in another (green). Figure 9 shows the result for area 2 obtained by the same procedure (forest green, non-forest red). This constituted the unsupervised classification.

For the supervised procedure the ERMAN maximum likelihood classifier was used. Supervised procedures are normally carried out by determining a priori the classes into which the data is to be partitioned; selecting representative sample areas of each class; computing the mean radiance vector and the covariance matrix for the spectral bands being used from the samples in each class to constitute the spectral signature of the class; applying a mathematical criterion (in this case the Bayesian maximum likelihood function) for deciding to which spectral signature (and therefore class) each pixel radiance vector should be assigned. Because of the difficulties inherent in selecting satisfactory sample areas spectral signatures are frequently derived from an initial clustering of the area to be classified, as described above. Thus for area 2 all the cluster signatures from the preceding step were then used as input to the maximum likelihood classification procedure. The resulting classification was displayed as before and is shown in figure 11b.

For area 1 a slightly modified procedure was followed. Among the 29 cluster signatures obtained for this area, only those considered to be highly characteristic of degraded forest and non-degraded forest were used as input to the maximum likelihood classification. This would improve the probability of accurately classifying these two classes and while it might result in unclassified pixels this would not affect the significance of the results being sought. In fact only 126 out of a total of 8475 pixels were unclassified. The result is illustrated in figure 10b.

5. RESULTS

For area 1 the clustering procedure classified 2117 pixels as degraded forest, whereas the maximum likelihood procedure classified 2313 pixels in this class, a difference of 196 pixels.

For area 2 the corresponding results, for the forest class, were 3059 and 2843, a difference of 216 pixels. Thus the area of the classes of interest varied by about 7 to 9% as a function of the classification procedure used. This would indicate an insufficient degree of classification accuracy for purposes of monitoring, since such differences in total area could represent significant changes.

However, when the graphic displays of the two sets of results for each of the areas were superimposed (which was possible using the output on thin paper instead of on

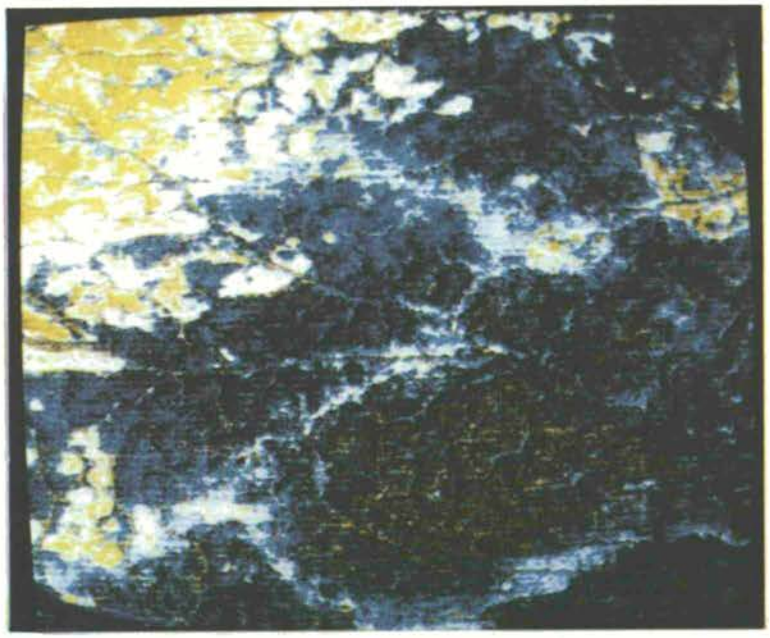


Figure 6. 35 mm photograph of colour display on television screen of portion of the digital data of scene 1478–08454 (see figure 1). Test area 1 is light area at bottom right (cf. figure 8). Display shows range of forest, degraded forest, burnt and unburnt savanna formations. Each pixel is colour coded. Original scale approximately 1:380 000.

Figure 7. As figure 6. Test area 2 is upper portion of blue area in centre (cf. figure 9). Note prominent striping of data.

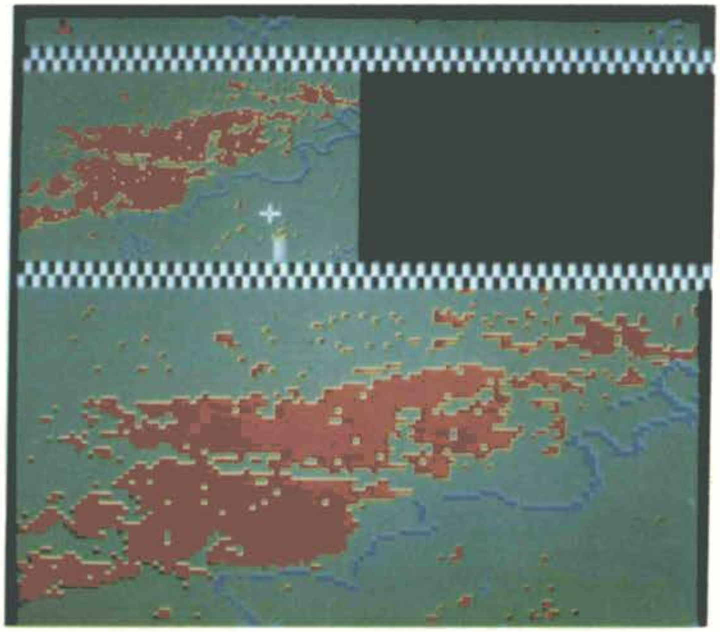


Figure 8. Test area 1. Result of an unsupervised classification (clustering). Degraded forest in red.

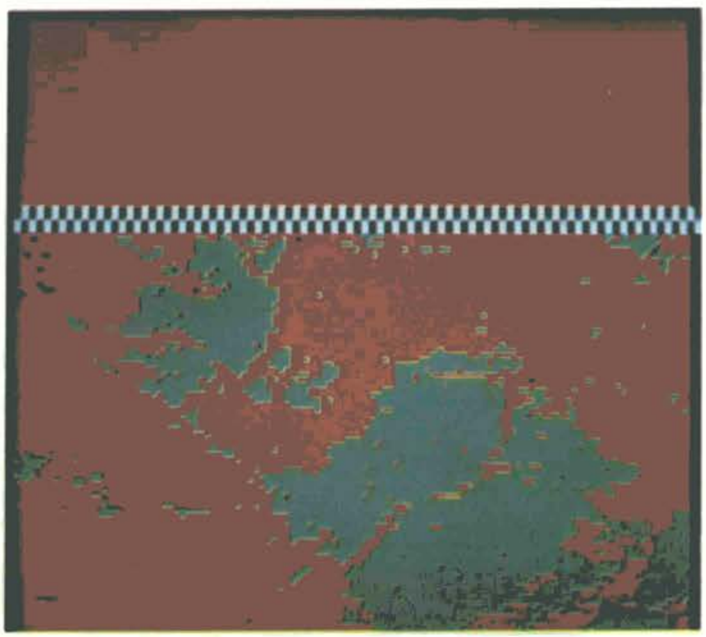


Figure 9. Test area 2. Result of an unsupervised classification (clustering). Forest in green. Black pixels 'unclassified'.

photographic hard copy) it was readily seen that at any given location the difference in the results amounted to mostly one or two pixels for area 1, with up to four pixels at a few locations (figure 10), and that for area 2 the difference consisted mostly of two or three pixels, with up to six at a few locations (figure 11). Thus at a given location the difference between the results of the two classifications ranged from half a hectare to about two and a half hectares. At the mapping scale of 1:50 000 used by the project for monitoring (4.2) one hectare is equal to 4 mm^2, which may be considered the smallest mapping unit at this scale. Consequently the magnitude of the localised differences between the two classification procedures were at about the limit of the differences between two dates which could be mapped at 1:50 000 and at a smaller scale, say 1:100 000, would cease to be significant.

However, the agreement between the two classification procedures is not a direct measure of classification accuracy, but only an indication that valid spectral signatures were being used and that these were giving very similar results although being manipulated by quite different algorithms. In this respect the results may be considered highly positive.

The data used was recorded in 1973 and had characteristically prominent banding whose influence on the results of the classification is clearly visible in the figures. By applying better radiometric correction to the data and eliminating the banding, procedures now routinely carried out on Landsat data produced by the EROS Data Centre (USA), the noise in the data would be considerably reduced and as a result even better consistency of classification could be expected. Closer correspondence between the results of the two classification procedures could probably also have been obtained by additional refinement of the signatures used, but this was not possible within the limited time and means available for this trial.

6. CONCLUSIONS

In the absence of sufficiently detailed ground truth it is not possible to be categorical about the absolute accuracy with which the two classes of interest in the two test areas were classified. The indications are that the accuracy obtained would satisfy the requirements of monitoring and that it could also be improved. It is therefore considered that it would be possible to devise an operational system for monitoring change in tropical forest cover based on the periodic computer analysis of Landsat data on the lines demonstrated here.

Such an operational system could, however, encounter certain problems. Among these is the availability of data at the intervals required. The availability of Landsat data for the tropics has been a serious weakness of the system up to now and there is little prospect that this can be improved except through the establishment of ground receiving stations in the regions concerned.

The comparability of data recorded at different dates depends on several factors and therefore poses a potential problem for monitoring applications. Variations in atmospheric conditions, scene illumination, tree phenology, for example, cause different variations in the spectral reflectance of vegetation and soil, particularly when accompanied by variations

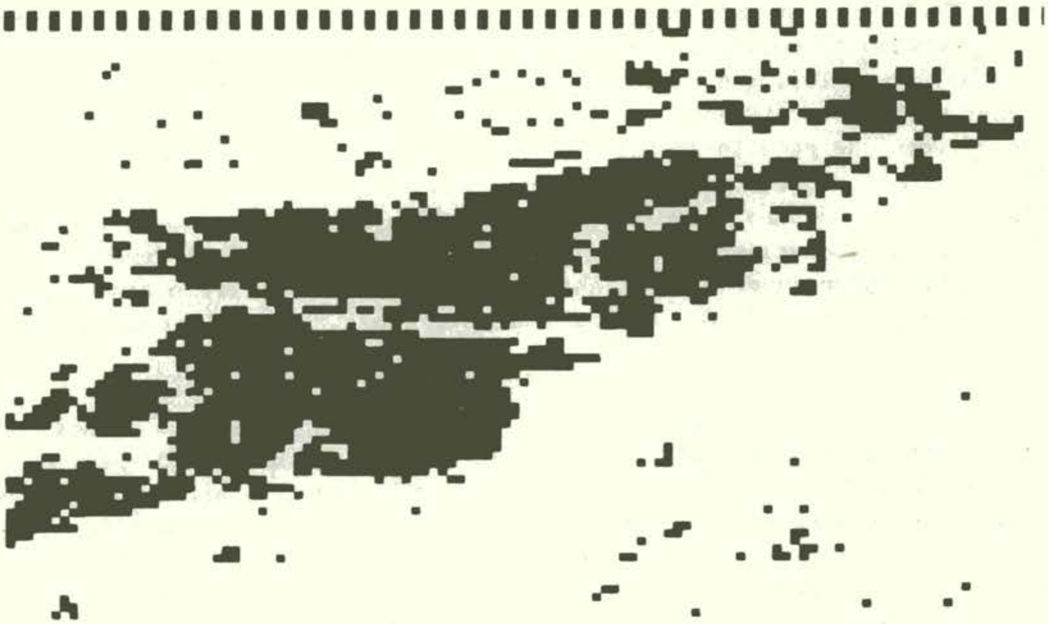


Figure 10a. Test area 1. Final cluster classification. Screen display reproduced directly on paper.

Figure 10b. Test area 1. Final maximum likelihood classification.

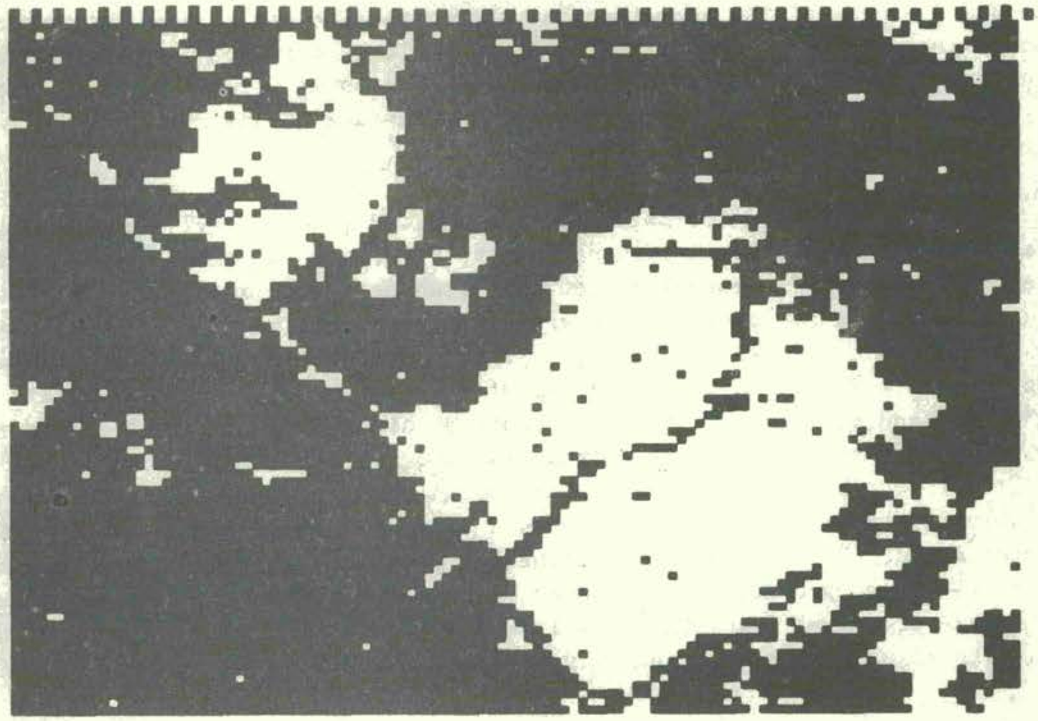


Figure 11a. Test area 2. Final cluster classification.

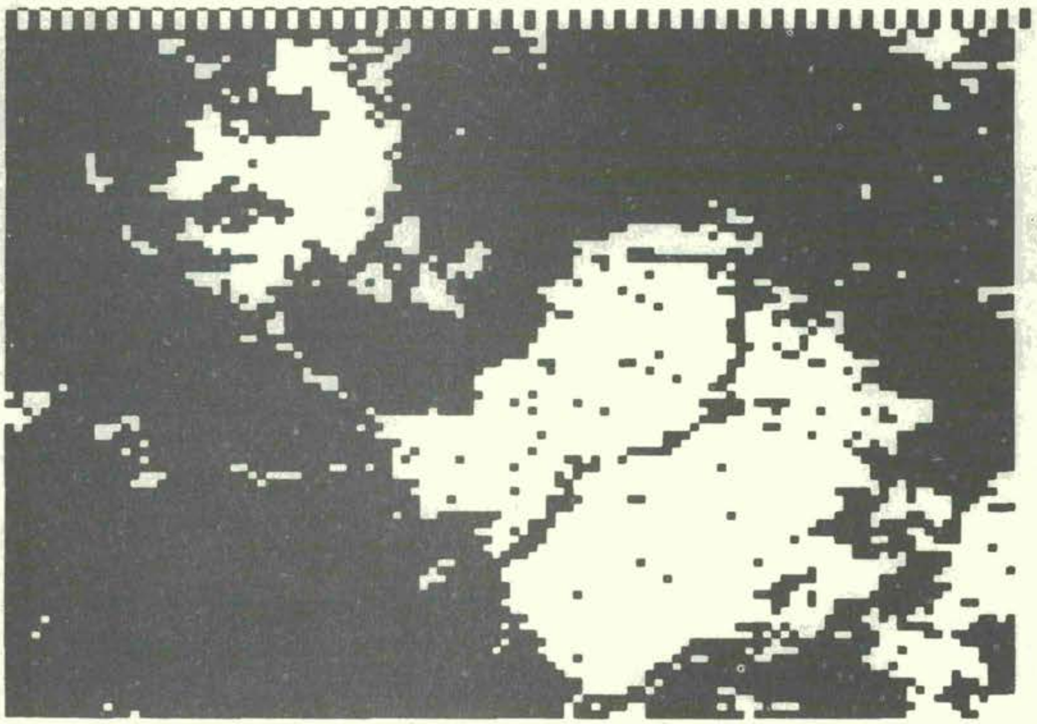


Figure 11b. Test area 2. Final maximum likelihood classification.

in the slope and aspect of the terrain. But there are also techniques for overcoming these effects to a large extent. Correction for atmospheric haze is now a standard enhancement for data produced at the EROS Data Centre and differences in illumination and shadow effects can be significantly reduced by techniques such as the use of the ratio of the values in two spectral bands instead of the original values.

Such ratios can also be used as vegetation indices (Tucker, 1979) whose application would repay further investigation with particular reference to forest cover monitoring. The dimensionless ratio of spectral values can often be a more stable and characteristic index of a given vegetation class on the ground than the radiance vector composed of the original spectral values (Hielkema, 1980). It is therefore quite possible that a display of the appropriate ratio would provide a map of the classes of interest adequate for assessing change and so eliminate both the costs of classification and the distortions, however minor, which this inevitably introduces into the results. Such a procedure would also lend itself to a high degree of automation, an aspect of some interest when the amount of data involved in monitoring forest cover and other phenomena over a large part of the globe is considered. But even when the technical possibility of monitoring changes in tropical forest cover by computer processing of Landsat data has been fully demonstrated, its economic and practical feasibility will depend on many different factors and must be assessed in the light of these for any given situation.

Appendix 3

VEGETATION MAP LEGENDS

BENIN - LEGEND

ECO-FLORISTIC ZONES AT LOW ALTITUDE (Generally below 500 m; to 600 m in the Atakora)

I. Dry continental zone (1 000-1 400 mm, 4-5 dry months)

1. Semi-deciduous forest and deciduous forest, generally degraded (Antiaris africana, Chlorophora excelsa, Cola spp., Khaya senegalensis, Celtis spp.)
2. Woodland and woodland savanna (Anogeissus leiocarpus, Butyrospermum paradoxum, Daniellia oliveri, Isoberlinia doka, Parkia biglobosa)
3. Tree savanna and shrub savanna (Anogeissus leiocarpus, Butyrospermum paradoxum, Daniellia oliveri, Isoberlinia doka, Parkia biglobosa)
4. Tree and shrub savanna with high incidence of cultivation (derived from 2 and 3)
5. Gallery forest (Diospyros mespiliformis, Ficus spp., Khaya senegalensis)
6. Saxicolous tree and shrub savanna (Butyrospermum paradoxum, Combretum spp.)
7. Woodland savanna, tree and shrub savanna seasonally inundated (Terminalia spp., Acacia sieberiana, Mitragyna inermis).

II. Dry coastal zone (850-1 300 mm, 3-4 dry months)

8. Semi-deciduous forest and deciduous forest, generally degraded (Afzelia africana, Chlorophora excelsa, Triplochiton scleroxylon, Ceiba pentandra)
9. Woodland savanna (Ceiba pentandra, Chlorophora excelsa, Daniellia oliveri)
10. Tree savanna and shrub savanna (Daniellia oliveri, Elaeis guineensis, Lophira lanceolata)
11. Mosaic of cultivation and bush fallow (Elaeis guineensis)
12. Mosaic of cultivation and bush fallow with predominantly forest species (Chlorophora excelsa, Antiaris africana, Triplochiton scleroxylon)
13. Mosaic of cultivation and shrub savanna (Lophira lanceolata)
14. Gallery forest (Cola cordifolia, Ceiba pentandra, Vitex doniana, Elaeis guineensis)
15. Riverain formations: relics of semi-deciduous forest in the Mono and Ouémé river valleys (Triplochiton scleroxylon); seasonally inundated grassland with Mitragyna mespiliformis
16. Swamp formations: Raphia gigantea grassland; occasional mangroves on saline sites (Rhizophora racemosa, Avicennia africana)
17. Teak plantations (Tectona grandis)
18. Oil palm plantations (Elaeis guineensis)
19. Coconut palm plantations (Cocos nucifera)

III. Very dry continental zone (800-1 000 mm, 6-7 dry months)

20. Woodland savanna (Anogeissus leiocarpus, Combretum spp.)
21. Tree savanna and shrub savanna (Anogeissus leiocarpus, Combretum spp., Acacia spp., Balanites aegyptiaca, Ziziphus mauritiana)
22. Tree and shrub savanna with high incidence of cultivation (derived from 20 and 21)

23. Gallery forest (<u>Anogeissus</u> <u>leiocarpus</u>, <u>Khaya</u> <u>senegalensis</u>, <u>Ficus</u> spp.)
24. Saxicolous tree and shrub savanna (<u>Adansonia</u> <u>digitata</u>, <u>Combretum</u> spp.)
25. Riverain formations of the Niger and Pendjari: seasonally inundated shrub savanna (<u>Acacia</u> <u>sieberiana</u>, <u>Acacia</u> <u>seyal</u>, <u>Tamarindus</u> <u>indica</u>, <u>Balanites</u> <u>aegyptiaca</u>, <u>Borassus</u> <u>aethiopum</u>)
26. Areas without vegetation

TOGO - LEGEND

ECO-FLORISTIC ZONES AT LOW ALTITUDE (Generally below 300 m)

I. Dry continental zone (1 100 - 1 300 mm, 3-5 dry months).

1. Semi-deciduous forest and deciduous forest (Khaya senegalensis, Anogeissus leiocarpus)
2. Tree savanna (dominant), woodland savanna and shrub savanna (Daniellia oliveri, Butyrospermum paradoxum)
3. Tree and shrub savanna with high incidence of cultivation (derived from 2)
4. Riverain formations: woodland (Diospyros mespiliformis, Anogeissus leiocarpus) palm grassland (Borassus aethiopum), seasonally inundated grassland.

II. Dry coastal zone (800 - 1 100 mm, 3-4 dry months)

5. Degraded semi-deciduous forest (high incidence of cultivation)(Ceiba pentandra, Antiaris africana, Triplochiton scleroxylon)
6. Tree savanna (dominant), woodland savanna and shrub savanna (Butyrospermum paradoxum, Lonchocarpus sericeus)
7. Mosaic of cultivation and fallow derived from semi-deciduous forest
8. Riverain formations: relics of semi-deciduous forest (Chlorophora excelsa, Albizzia spp., Cola spp.), seasonally inundated Mitragyna grassland, swamp grassland

III. Very dry continental zone (900 - 1 100 mm, 5-6 dry months)

9. Saxicolous shrub formations (Anogeissus leiocarpus, Acacia spp.)
10. Tree and shrub savanna with high incidence of cultivation (Combretum spp., Tamarindus indica, Balanites aegyptiaca)
11. Woodland (protected) in a hydromorphic depression (Terminalia macroptera, Khaya senegalensis)

ECO-FLORISTIC ZONES AT MEDIUM ALTITUDE (300 - 900 m)

IV. Sub-humid zone at medium altitude (1 400 - 1 700 mm, 300 - 900 m)

12. Mosaic of semi-deciduous forest (Antiaris africana, Chlorophora excelsa) and deciduous forest (Afzelia africana, Anogeissus leiocarpus), partly degraded.
13. Medium altitude shrub savanna (Lophira verticellata, Piliostigma thonningii)

V. Dry to sub-humid zone at medium altitude (1 200 - 1 500 mm, 300 - 800 m)

14. Complex of woodland (dominant) (Afzelia africana, Anogeissus leiocarpus, Isoberlinia doka), semi-deciduous forest (mainly galleries) Dialium guineense, Antiaris africana, Berlinia grandiflora), medium altitude woodland savanna, tree savanna and shrub savanna (Monotes kerstingii, Isoberlinia doka, Uapaca somon)
15. Tree and shrub savanna with high incidence of cultivation (derived from 14)

CAMEROON - LEGEND

ECO-FLORISTIC ZONES AT LOW AND MEDIUM ALTITUDE (Generally below 1 800 m)

I. Very moist zone at low and medium altitude (Rainfall exceeding 2000 mm, 0-1 dry months)

11. Moist evergreen forest (Cesalpinaceae dominant). Trees less tall and Myristicaceae more abundant at medium altitude (> 800 m)
12. Moist evergreen forest periodically inundated (Mitragyna spp.)
13. Swamp forest dominated by Raphia spp.
14. Degraded evergreen forest (derived from 11)
15. Tree savanna and shrub savanna

II. Moist zone at low and medium altitude (1 500 - 2 000 mm, 0-1 dry months)

21. Moist evergreen and semi-deciduous forest (transition forest) (Baillonella toxisperma, Gilbertiodendron dewevrei). Also on some small mountain areas at medium altitude (> 800 m) mostly to the north and east of Ebolowa.
22. Moist evergreen forest periodically inundated (Guibourtia demeusii, Xylopia spp., Uapaca spp.
23. Moist evergreen swamp forest (Macaranga spp., Raphia spp., locally stands of Sterculia subviolacea)
24. Swamp forest dominated by Raphia spp.
25. Degraded evergreen and semi-deciduous forest (derived from 21) (Musanga cecropioides)
26. Tree savanna and shrub savanna (Terminalia glaucescens)
27. Swamp grassland

III. Sub-humid zone at low and medium altitude (1 500 - 2 000 mm, 1-2 dry months)

31. Moist semi-deciduous forest (Triplochiton scleroxylon, Sterculia spp., Cola spp., Mansonia altissima, Celtis spp., Terminalia superba, Khaya spp.)
311. Complex of moist semi-deciduous forest (slopes and valleys) and grassland (ridges) in the north-west; ridge grassland around Bafia
32. Moist evergreen swamp forest (Uapaca guineensis, Raphia spp.)
33. Gallery forest (forest species, Elaeis guineensis)
34. Degraded semi-deciduous forest (derived from 31) (Musanga cecropioides)
35. Woodland savanna (Burkea africana, Daniellia oliveri) generally with a dense network of gallery forest
36. Tree savanna and shrub savanna (Terminalia glaucescens, Lophira lanceolata, Annona senegalensis) generally with a dense network of gallery forest
37. Grass savanna (Imperata cylindrica, Pennisetum purpureum; scattered Combretum spp.)
38. Mosaic of cultivation and tree and shrub savanna
39. Mosaic of cultivation and grass savanna

IV. Very moist coastal zone on saline sites (0 - 100 m, rainfall exceeding 2 500 mm, no dry months)

41. Moist evergreen forest periodically inundated
42. Mangrove (Avicennia nitida, Rhizophora spp.)

ECO-FLORISTIC ZONES AT MEDIUM AND HIGH ALTITUDE

V. Sub-humid zone at medium altitude (800 - 1 800 m, 1 400 - 1 700 mm)

51. Moist semi-deciduous forest (Afzelia africana, Albizia spp., Chlorophora excelsa)
52. Gallery forest
53. Degraded semi-deciduous forest (derived from 51)
54. Woodland savanna (Burkea africana, Daniellia oliveri, Borassus aethiopum)
55. Tree savanna and shrub savanna (Daniellia oliveri, Lophira lanceolata) generally with a dense network of gallery forest; saxicolous tree savanna on the frontier south-east of Meiganga
56. Grassland

VI. Montane zone (altitude above 1 800 m, rainfall exceeding 1 500 mm)

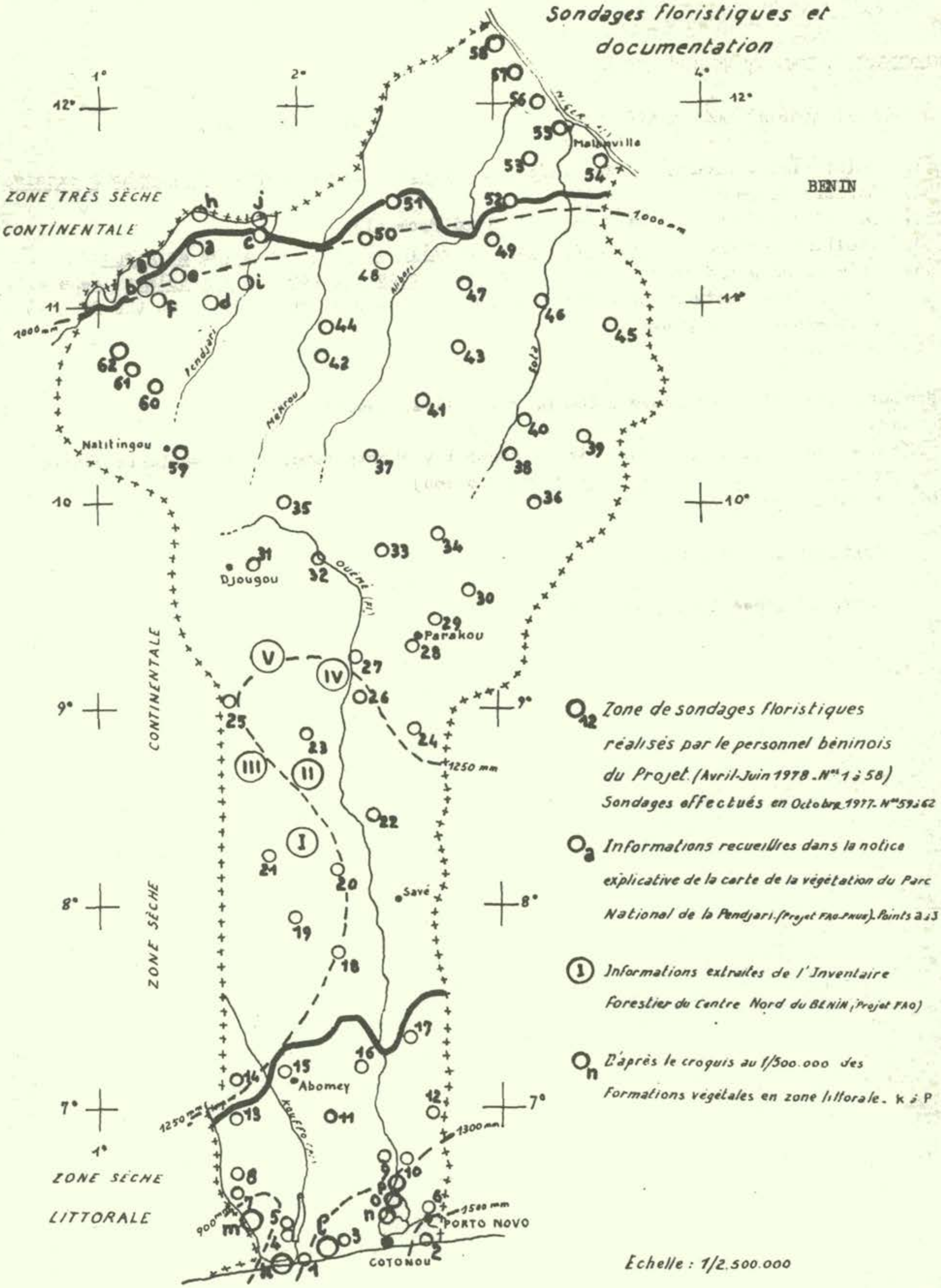
61. Evergreen mountain forest (trees generally short; composition variable according to locality; Podocarpus milanjianus common)
62. Mountain grassland

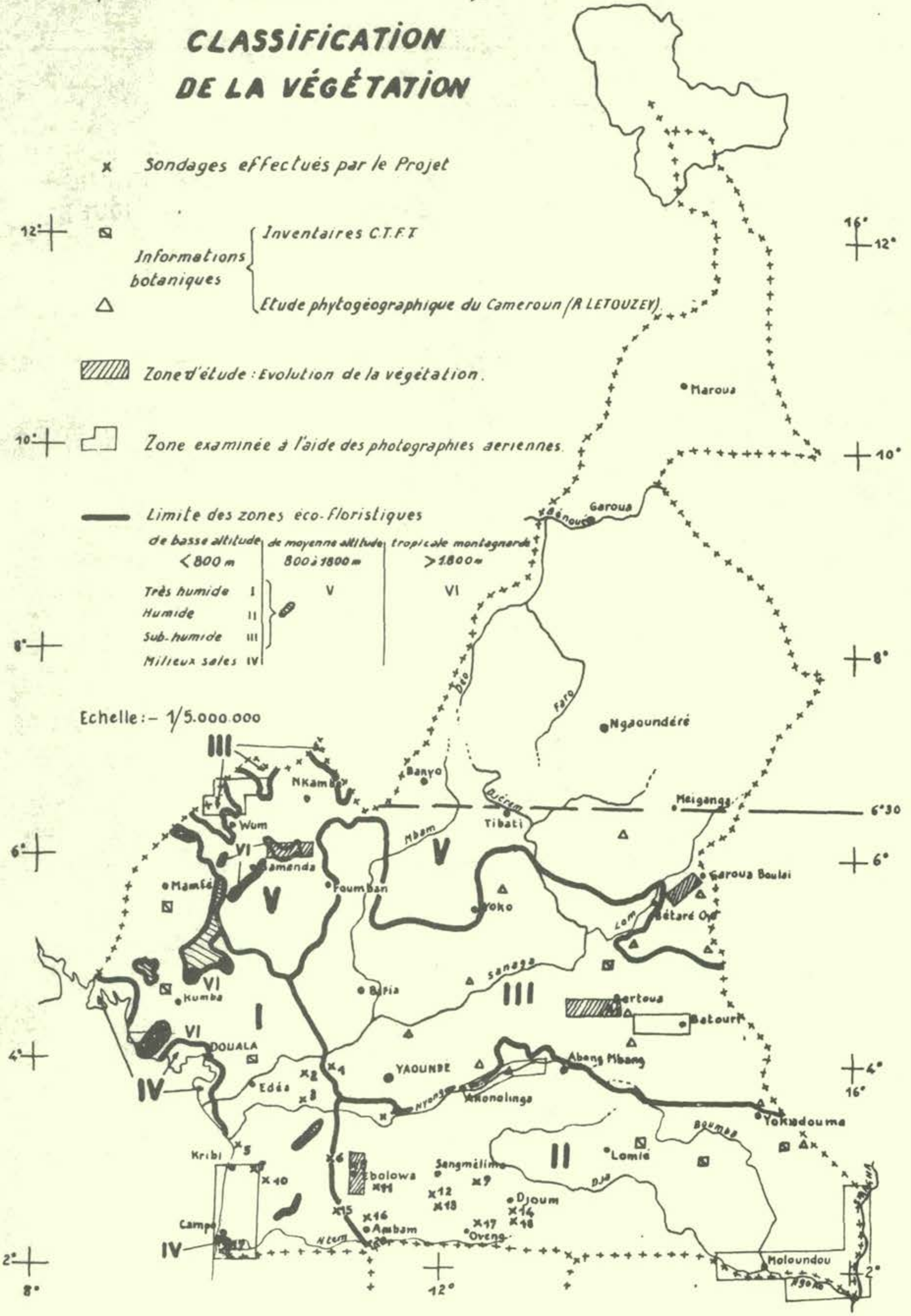
Cultivation (in zones I, III, V, VI)

Parts of zones I, II, III above 800 m.

CLASSIFICATION de la VÉGÉTATION :

Sondages floristiques et documentation




CLASSIFICATION
DE LA VÉGÉTATION
Sondages effectués par le Projet
Informations botaniques
Inventaires C.T.F.T.
Etude phytogéographique du Cameroun (R. LETOUZEY)
Zone d'étude : Evolution de la végétation.
Zone examinée à l'aide des photographies aeriennes.
Limite des zones éco-floristiques
de basse altitude < 800 m
de moyenne altitude 800 à 1800 m
tropicale montagnarde > 1800 m
Très humide I
Humide II
Sub-humide III
Milieux salés IV
V
VI
Echelle :- 1/5.000.000
Maroua
Garoua
Bénoué
Ngaoundéré
Faro
Déo
Banyo
NKambé
Wum
Bamenda
Mamfé
Foumban
Mbam
Tibati
Meiganga
Garoua Boulai
Yoko
Bétaré Oya
Lom
Sanaga
Bafia
Kumba
Bertoua
Batouri
DOUALA
Edéa
YAOUNDE
Abong Mbang
Akonolinga
Nyong
Yokadouma
Boumba
Lomié
Dja
Kribi
Ebolowa
Sangmélima
Djoum
Campo
Ambam
Ntem
Oveng
Moloundou
Ngoko
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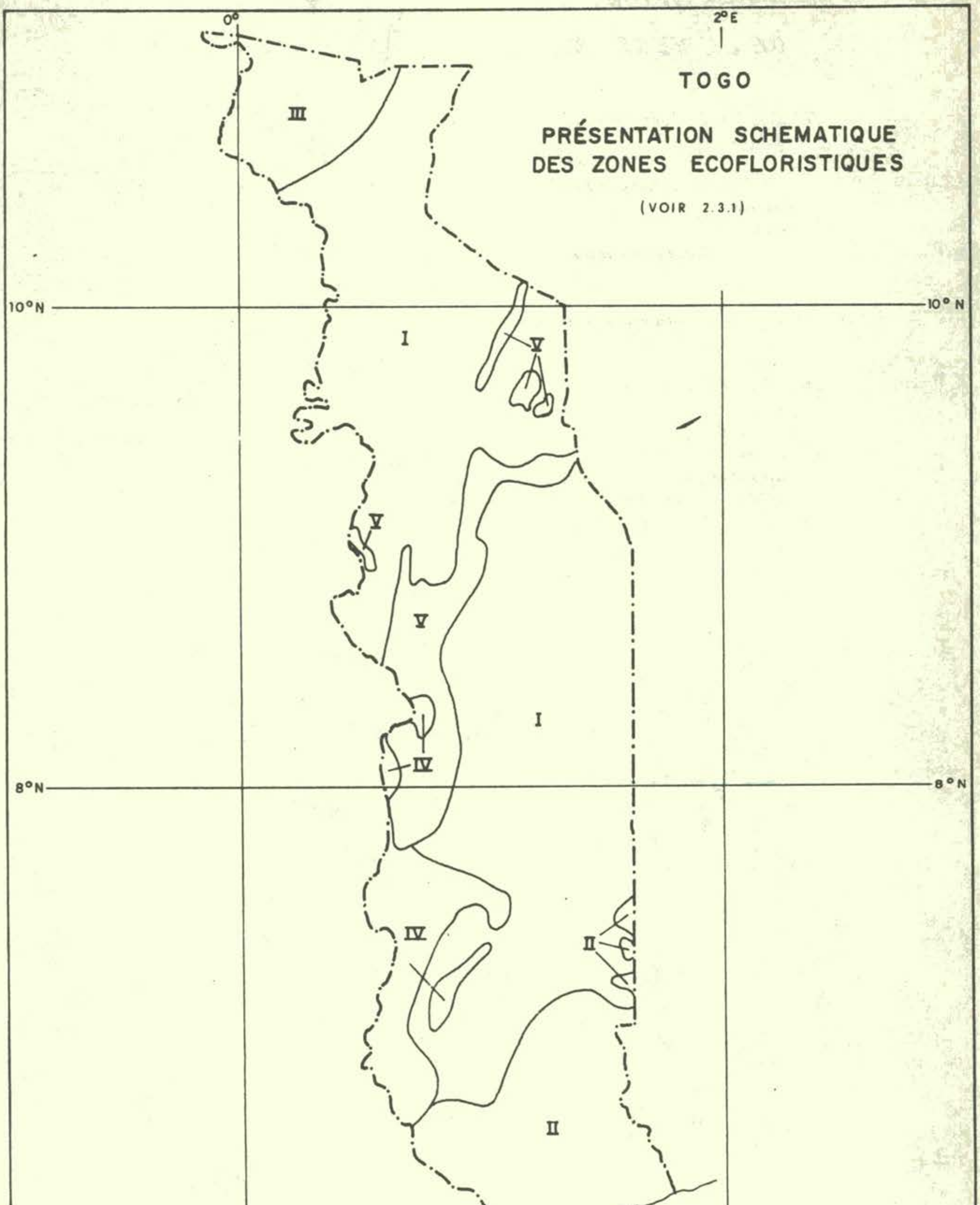
12°
10°
8°
6°
4°
2°
16°


TOGO
PRÉSENTATION SCHEMATIQUE
DES ZONES ECOFLORISTIQUES
(VOIR 2.3.1)
0°
2°E
10°N
8°N
I
II
III
IV
V

APPENDIX 5

TABLEAU 4.1

SUPERFICIE DES FORMATIONS VEGETALES ET TYPES D'OCCUPATION DU SOL CARTOGRAPHIES AU BENIN

Classe	Formation	km^2	%	Observations
1.5.8.14.23	Forêt semi-décidue et décidue y inclus galeries forestières importantes.	631,25	0,55	Forêt de la Lama 56,25 km^2 Galeries de la Pendjari 112,50 km^2
2.9.20	Forêt claire et savane boisée	12 743,75	11,13	
3.10.21	Savane arborée et arbustive	60 956,25	53,26	
6.24	Savane arborée et arbustive saxicole	2 350,00	2,05	
7.15.16.25	Savane boisée, arborée et arbustive, périodiquement inondée. Formations riveraines et marécageuses	1 625,00	1,43	
4.12.13.22	Savane cultivée	28 706,25		
11.18	Culture sous palmiers et palmeraies	6 475,00	30,84	
17	Teckeraies	68,75		
19	Plantations de cocotier	118,75		
	Sol nu (sans végétation)	456,25	0,40	
	Eaux	325,00	0,28	La Nokoué 187,5 km^2; Lac Ahemé 75 km^2
	Agglomérations importantes	68,75	0,06	Cotonou, Porto Novo, Parakou, Ouidah.
	Total	114 456,25	100,00	

Seules les galeries forestières importantes ont été estimées et incorporées à la formation "Forêt". La superficie totale (114 456,25 km^2) correspond à la somme des surfaces estimées sur la carte.

TABLEAU 4.1

SUPERFICIE DES FORMATIONS VEGETALES ET TYPES D'OCCUPATION
DU SOL DU CAMEROUN MERIDIONAL
(au sud du parallèle 6°30')

Estimation de la superficie des formations végétales et de l'occupation du sol pour la partie méridionale du Cameroun cartographiée. L'évaluation a été réalisée à l'aide d'une grille de points alignés à maille carrée de 5 mm de côté superposée à la carte à l'échelle 1:1 million établie par interprétation des images Landsat.

Classe	Formation	Superficie		Groupements	
		km²	%	km²	%
	Forêt dense humide sempervirente			54 075	16,88
11.	de basse altitude (< 800 m)	49 550	15,46		
11.	de moyenne altitude (800-1800 m)	3 800	1,19		
61.	montagnarde (> 1800 m)	725	0,23		
	Forêt dense humide sempervirente et semi-décidue. Forêt dense humide semi-décidue			120 325	37,55
21.31.	de basse altitude	117 775	36,76		
21.31.51.	de moyenne altitude	2 550	0,79		
	Formations forestières édaphiques			8 600	2,68
33.52	Galerie forestière (largeur > 1 km)	1 450	0,45		
12,22	Forêt dense périodiquement inondée	1 350	0,42		
41.	Forêt dense littorale périodiquement inondée	225	0,07		
23.32	Forêt dense marécageuse	1 350	0,42		
13.24	Raphiale	1 500	0,47		
42.	Mangrove	2 725	0,85		
14.25.34.53	Forêt dégradée	45 350	14,15	45 350	14,15
	Formations mixtes			68 550	21,40
311.	Complexe forêt semi-décidue-prairies	375	0,12		
35.54.	Savane boisée	7 200	2,25		
15.26.36.55.	Savane arborée et arbustive	60 850	18,99		
	Savane arborée saxicole	125	0,04		
	Formations herbeuses			3 425	1,07
37.	Savane herbeuse	2 450	0,76		
311.56.62.	Prairie	725	0,23		
27.	Prairie marécageuse	250	0,08		
38.39	Mosaïque cultures-savane	2 425	0,76		
	Culture	16 600	5,18	19 025	5,94
	Eaux (lacs, fleuves)	950	0,30		
	Agglomérations (Douala, Yaoundé)	100	0,03	1 050	0,33
	TOTAL	320 400	100,00	320 400	100,00

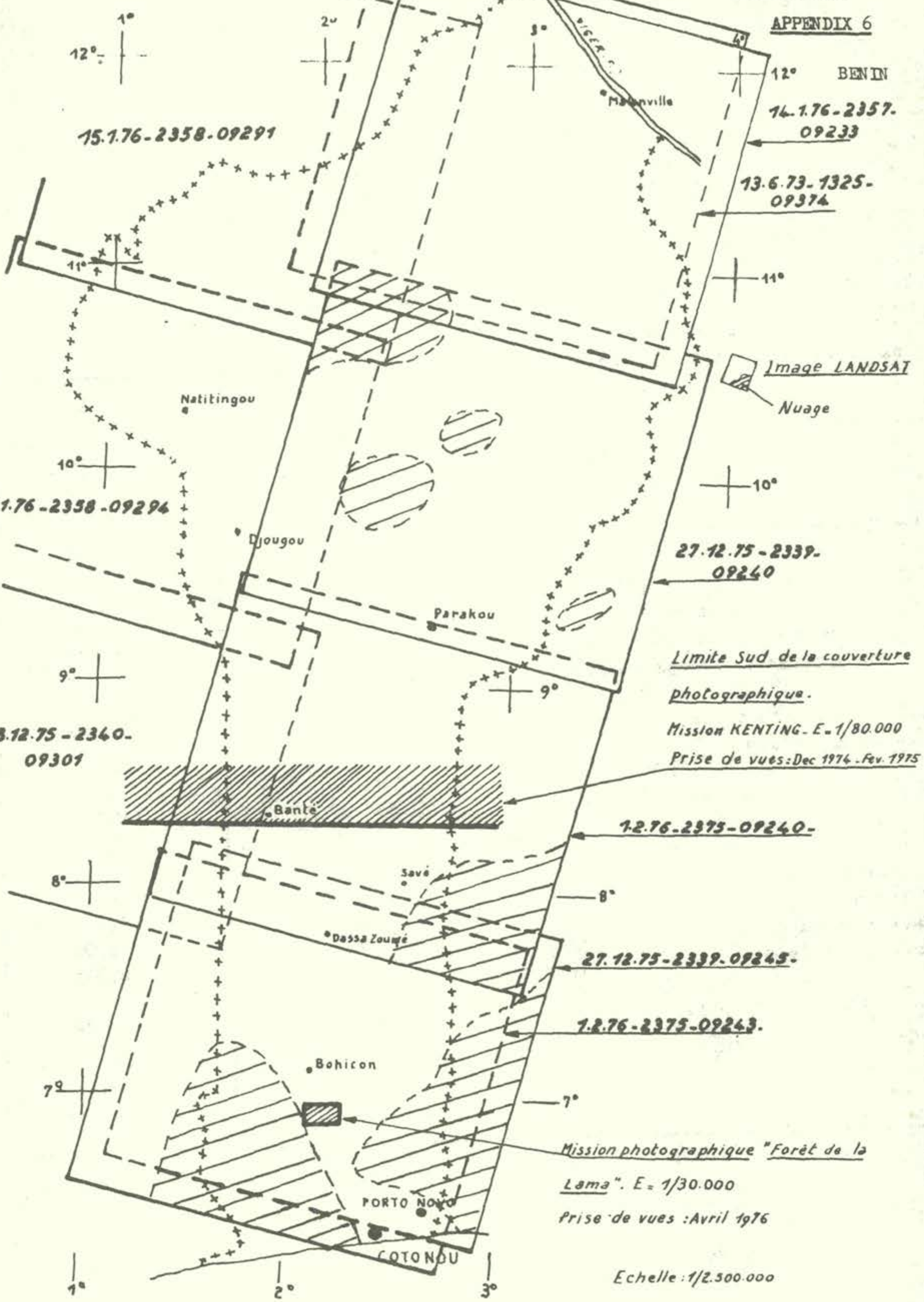
SUPERFICIES DES FORMATIONS VEGETALES DU TOGO

Formations végétales (voir légende de la carte, Annexe 2)	Superficie	
	km^2	%
1 Forêt semi-décidue et décidue	243,75	0,428
12 Forêt semi-décidue et décidue	2 631,25	4,627
5 Forêt dégradée	2 450,00	4,308
11 Forêt claire	12,50	0,022
14 Forêt claire et savanes	4 418,75	7,768
2 Savane arborée (principalement)	15 287,50	26,877
6 Savane arborée (principalement)	2 887,50	5,076
9 Formations arbustives	231,25	0,406
13 Savane arbustive	1 268,75	2,230
4 Formations riveraines	550,00	0,967
8 Formations riveraines	500,00	0,879
3 Savane cultivée	19 643,75	34,535
7 Cultures et jachères	2 993,75	5,263
10 Savane cultivée	3 356,25	5,900
15 Savane cultivée	350,00	0,615
Lac Togo	56,25	0,099
	56 881,25	100

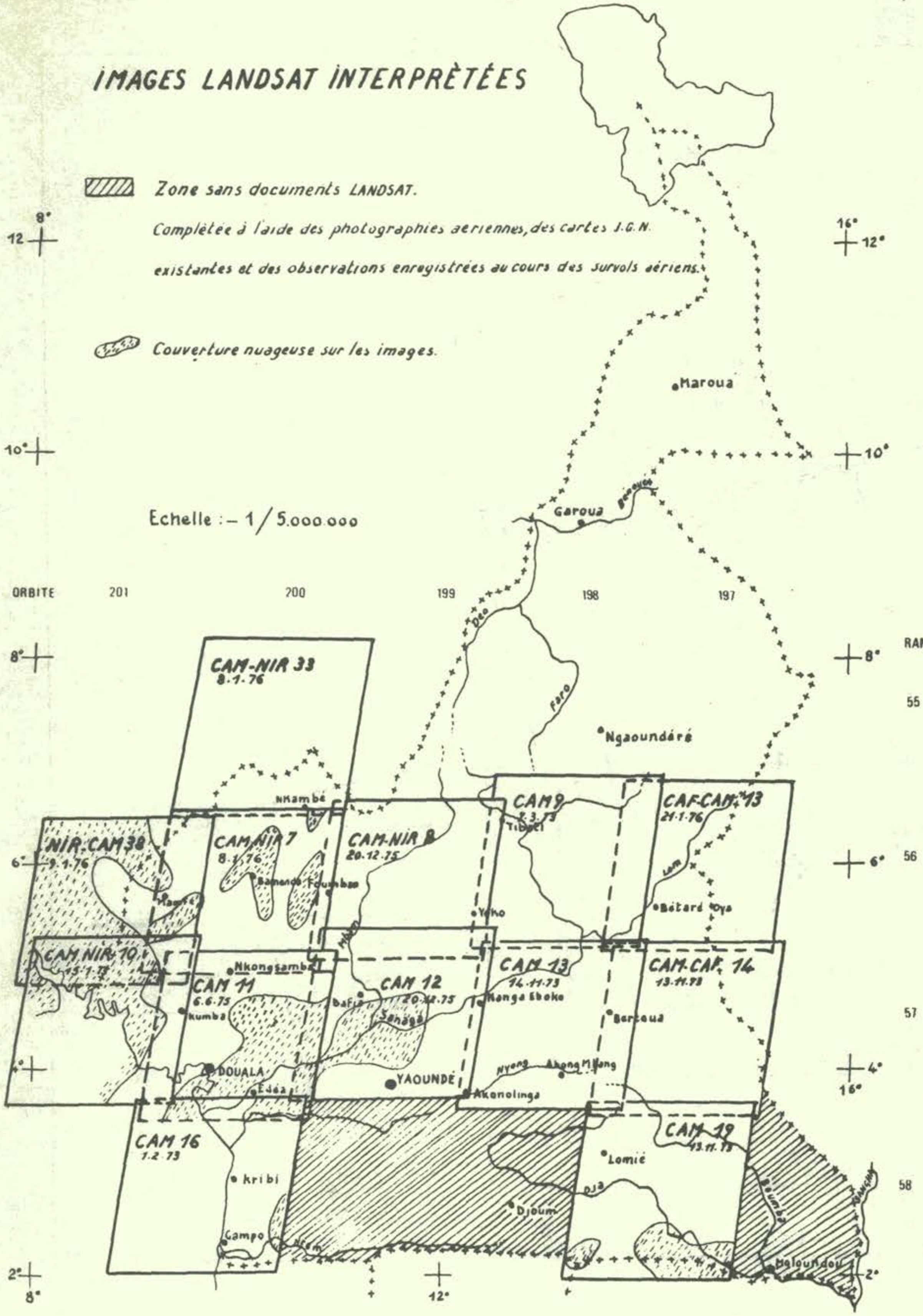
DOCUMENTS DE TÉLÉDETECTION UTILISÉS

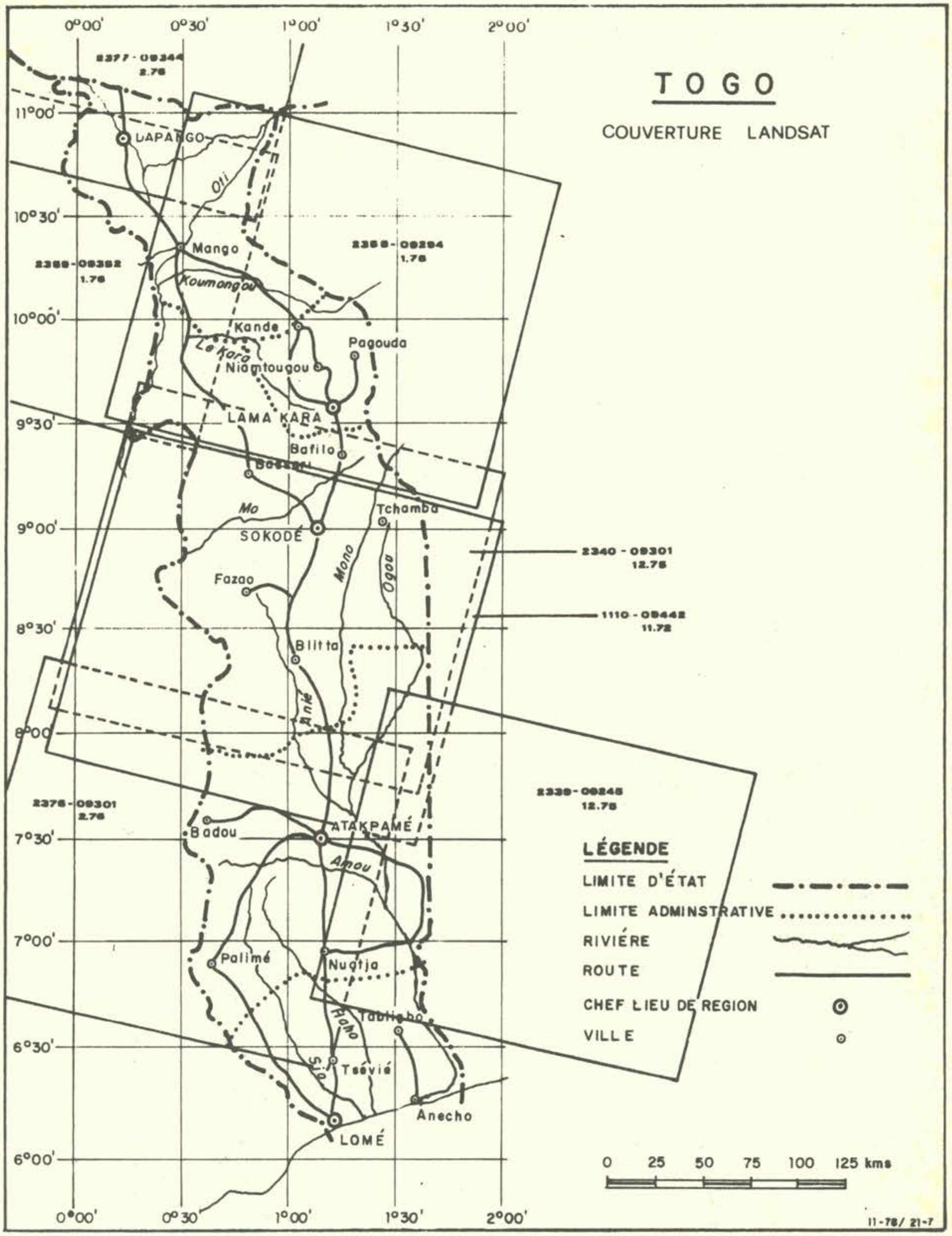
APPENDIX 6

BENIN



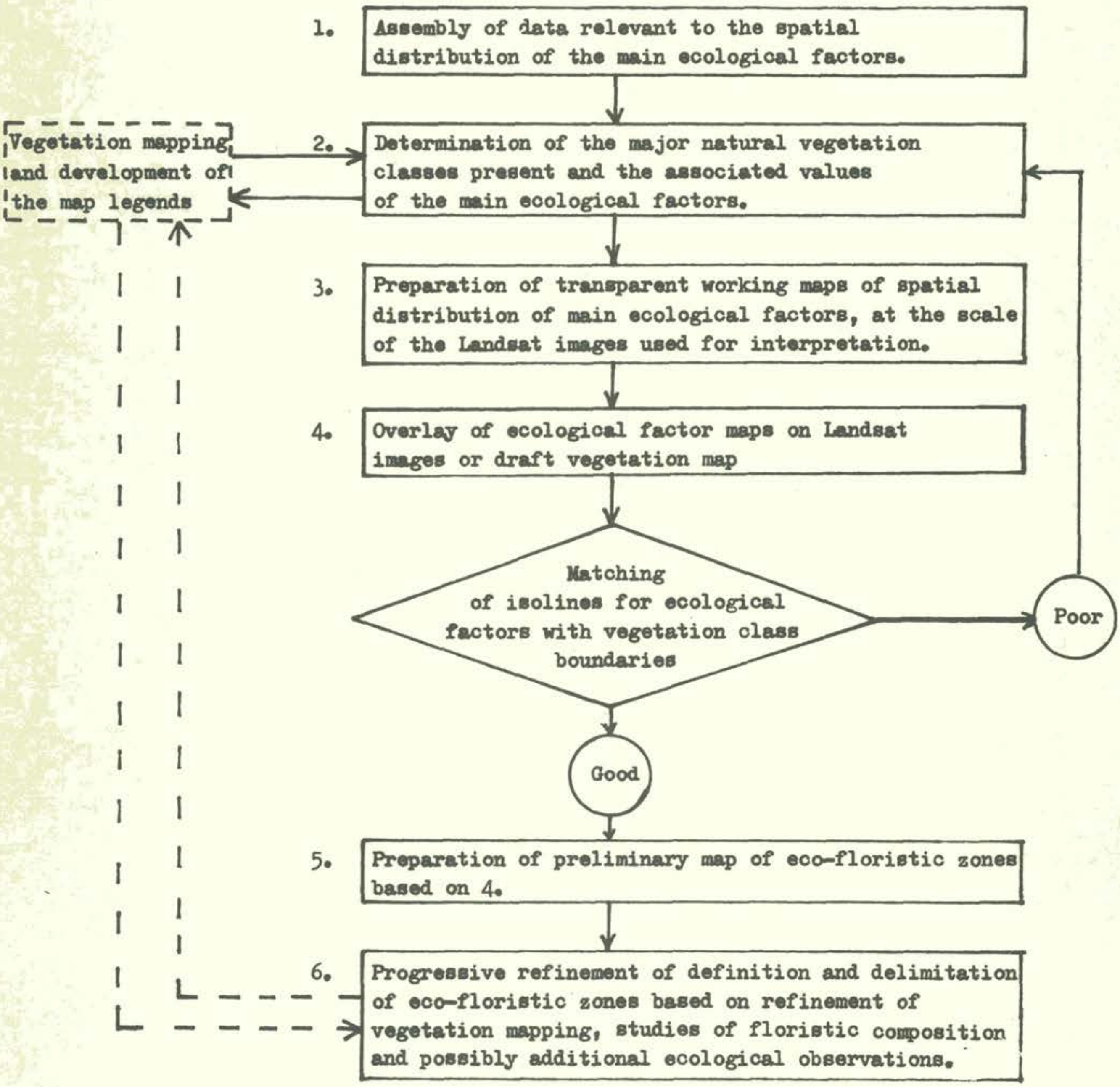
IMAGES LANDSAT INTERPRÈTÉES




TOGO
COUVERTURE LANDSAT
0°00'
0°30'
1°00'
1°30'
2°00'
11°00'
10°30'
10°00'
9°30'
9°00'
8°30'
8°00'
7°30'
7°00'
6°30'
6°00'
DAPANGO
Oti
Mango
Koumongou
Kande
Pagouda
Le Kara
Niamtougou
LAMA KARA
Bafilo
Mo
Tchamba
SOKODE
Mono
Ogou
Fazao
Blitta
Anié
ATAKPAMÉ
Badou
Amou
Palimé
Nuatja
Haho
Tabligbo
Sio
Tsévié
Anecho
LOMÉ
2340 - 09301
12.75
1110 - 09442
11.72
2339 - 09245
12.75
LÉGENDE
LIMITE D'ÉTAT
LIMITE ADMINSTRATIVE
RIVIÉRE
ROUTE
CHEF LIEU DE REGION
VILLE
0 25 50 75 100 125 kms
11-78/ 21-7

Appendix 7

DIAGRAMMATIC REPRESENTATION OF METHOD FOR DEFINITION OF ECO-FLORISTIC ZONES



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