Instituto Forestal
Chile

ELABORATION OF FOREST MAPS BASED ON SATELLITE IMAGERY

SWEDISH SPACE CORPORATION
Satellitbild

Kiruna, Sweden
Subsidary of Swedish Space Corporation

in co-operation with

INSTITUTO FORESTAL
Santiago de Chile

July 1994

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SUMMARY

Introduction

Chile has about 9.1 million ha of forest land, among which 7.6 ha are native forest and 1.5 million ha are plantations of exotic species. The number of plantations is constantly growing due to the important role these areas are playing in the national economy. Pino Radiata (*Pinus radiata*) is found in most of the plantations while the remaining parts are dominated by Eucaliptus (*Eucalyptus spp.*). Instituto Forestal (INFOR) is monitoring the rapid changes in these areas by frequent inventories. An inventory of this type takes about six years to complete in all areas - one region per year. From this point of view, it is of great interest to be able to cover these areas more quickly.

The native forest has in recent years been the subject of debate, not only for economic reasons, but also for ecological pressures on conservation. Where to conserve, where to put restrictions and where to allow forestry are the big issues. Against this background it is necessary to evaluate different data sources that can give relevant information about the present forest situation and provide the ability to monitor the changes. Therefore, an agreement has been made between Instituto Forestal, Santiago de Chile and SSC Satellitbild, Kiruna Sweden to elaborate the use of satellite imagery for forestry purposes in a ten-week project. The project had financial support from the Swedish Board for Investment and Technical Support (BITS).

The aim of the project is to evaluate whether satellite imagery can fulfil INFOR´s demand for forestry information, and to investigate the kind of data source and methodology to apply when using satellite data.

Current methods

Plantation maps are made in the regions V through X. The basic information sources are maps from Corporación Nacional Forestal (CONAF) showing the landowners intentions, and black and white aerial photos preferably on a scale of 1:20,000. Every stand greater than five ha will be interpreted in the photos and then transferred to the corresponding topographic map on a scale of 1:50,000. A later digitalisation into a Geographical Information System (GIS) will complete the map.

Monitoring of the native forest is not carried out as frequently as in the areas of plantation. However, an ongoing project, started in 1991, is now mapping the native resources on a scale of 1:250,000 in the regions of VIII through X. In that project the same methods are being used as for the plantations. Stands greater than 25 ha are classified into forest types using black and white aerial photos on a scale of 1:60,000. The borders are later transferred to the topographic map and finally digitised into a GIS.

Project areas

INFOR selected three areas for the project, each one containing four map sheets on a scale of 1:50,000 and one on a scale of 1:25,000. Generally, plantations dominate the Curanilahue area, a mix of plantations and native forest in the Malleco area and a mix of primary and secondary forest in the Neltume area. The topography is mountainous in all three areas with steep slopes along the creeks and flatter land along the main streams.

Forest description

The native forest types are approximately twelve, among which only a few are present in the project areas. The following native forest types can be found in the study areas:

1. Roble-Raulí-Coigüe (*Nothofagus obliqua, Nothofagus alpina, Nothofagus dombeyi*) is the principal and most common forest type. Heavily cut, it is now forming an important secondary growth forest.
2. Coigüe-Raulí-Tepa (*Nothofagus dombeyi, Nothofagus alpina, Laurelia philippiana*) is the forest type where Coigüe or Raulí accounts for less than 50% of the total number of trees.
3. Lenga (*Nothofagus pumilio*) is found at high altitudes, above 1000 metres, where it forms the arboreal limit.
4. Araucaria (*Araucaria araucana*). This forest type needs only one specimen of Araucaria per ha for a correct classification. Lenga and Coigüe are often found in mixed stands with Araucaria.
5. Ñirre (*Nothofagus antarctica*) is found in the highest, coldest and flattest places.
6. Evergreen forest, is a forest type containing a mix of a lot of species such as Coigüe, Ulmo (*Eucryphia cordifolia*), Tineo (*Weinmannia trichosperma*), Olivillo (*Aextoxicom punctatum*), Canelo (*Drimys winteri*), etc.
7. Ñadis. This forest type is found in flat and wet areas with shallow soils (hard pan). The predominant species belongs to the Mirtaceae family

The exotic species found in the stand defines the plantation class. The following classes can be recognised in the plantations:

1. Pino Radiata (*Pinus radiata*)
2. Eucaliptus (*Eucalyptus spp.*)
3. Pino Oregon (*Pseudotsuga menziesii*)
4. Alamos (*Populus spp.*)
5. Other species

Satellite data

Twelve different Satellite Orthophoto Maps (SOMs) on a scale of 1:50,000 and three on the scale of 1:25,000 were produced. All 1:50,000 scale maps were delivered as digital copy on CD-ROM media, as one analogous copy on photographic paper and as one copy on transparent film. The 1:25,000 scale maps were delivered in the same way except for the transparent film - which was not included. A total of one Landsat TM and eleven SPOT P and XS scenes were utilised, all precision-corrected to fit the corresponding topographic maps. A

Digital Elevation Model (DEM) was incorporated in the geometric correction to obtain orthophoto quality of the products produced.

The Landsat TM data, from January 1990, was used in the area of Curanilahue together with SPOT Panchromatic (P) data from November 1989. Band combination for Landsat was 4,5 and 3 with red, green and blue assignments respectively. The SPOT XS+P data, from December 1993 and January 1994, were used in the areas of Malleco and Neltume where the P data was merged with the XS (Multispectral) data to obtain better texture information. The band combination was in this case 3, 2 and 1 with red, green and blue assignments respectively.

Training

The project included three training sessions, all including introductions to the satellite data technique and the use of such data for forestry purposes. The first part was held in Kiruna, Sweden where the head of the forest inventory division at INFOR, Mr Rolando Bennewitz B. was introduced to the satellite data technique over a period of two days. The second part was held at the beginning of the project at INFOR, Santiago de Chile. Finally, the third part was held, for one week, at the start of the computer aided part of the project. The course was also attended by people from CONAF and Centro de Información de Recursos Naturales (CIREN).

Methodology

To provide a better and quicker way of learning how to interpret the satellite imagery, reference materials were used during both the hard-copy interpretation and the digital interpretation as well as during the field visit. The materials consisted of black and white aerial photos on various scales, some previously made maps and pictures taken during the field trip.

A total of five map-sheet areas were visited during the second week of the project. Photos were taken for later reference during the interpretations. Various stands of the forest types and plantations were visited in order to gain some idea of the area and the vegetation occupying them.

Three weeks were spent on the hard-copy interpretation. During that time the team was located at the office of INFOR, Santiago de Chile where three light tables were prepared for the task at hand. On top of the transparent film an overlay was attached on which the interpretation was drawn. Prior to the interpretation a legend was defined with a description of each class and class code. That legend was constantly evaluated and changed during the interpretation in order to find the optimum criteria and the limitations of the satellite imagery. Included in Appendix 5 is the final legend.

Following completion of the hard-copy interpretation, the light tables were exchanged for computers with the 4sys software installed. Productive work started after a week's training in using the 4sys software. The digital data delivered on the CD-ROM media was also prepared and downloaded in each of the PC's.

Results and discussion

The first conclusion is that the use of satellite imagery can partly fulfil the demand for forest information source for INFOR in both plantations and native forest. This is under the assumption that the data is used together with auxiliary data sources such as aerial photos. Alone, satellite data will only fulfil part of the requirements, but together with additional data the entire task can be completed.

The second conclusion is that further investigations must be made in order to find out which satellite data source should be utilised.

The third, and final, conclusion is that the hard copy method proved to be an efficient methodology for the first time interpretation. However, when thinking in terms of updating the digital method must be used.

INTRODUCTION

Chile's forest area comprises about 7.6 million ha of native forest and 1.5 million ha of plantations (or manmade forest). The country's forestation rate is constantly growing due to the increasing number of plantations. During 1993, a total of 135,000 ha were planted, among which approximately 90,000 ha were forestation areas. Since only a lesser part is cut each year, Chile has an increasing forest stock of approximately 70,000 ha per year. Forestry will therefore be an important contributor to the development of the national economy - both now and in the future. In 1993, the total value of the exported forest products reached a value of US$ 1.250 million that is an increase of 42% on the 1990 value of US$ 855 million[1] . The figures are expected to rise even more during 1994.

The plantations are defined as areas planted with exotic tree species, the majority of which, approximately 90 %, are planted with Pino Radiata (*Pinus radiata*) and the remaining part with mainly Eucaliptus (*Eucalyptus spp.*). The rapid increment of these tree species creates a forest with a high rate of change that quickly outdates even recently made inventories. Today, the time to complete an inventory of this kind in all plantation regions would take about six years. From this point of view it is of great interest to be able to cover the areas more quickly.

Even though the forest economy to a major extent is depending on the plantations, debate has in recent years been focused on the native forest. The reasons for this are several: increased interest in short fibre, greater demands on timber quality, ecological pressures on conservation and discussions concerning new forest legislation. Trying to conserve some parts while putting restrictions on others, as well as allowing commercial interest to utilise the remaining areas, is a major challenge to the decision makers. Thus, it is essential to have recent information on which to base the decisions. With a US$ 5 million World Bank credit, the country is now in the process of starting a complete mapping of the vegetation covering the whole country. This is expected to be completed in three years. A monitor concept then has to be applied in order to keep the database up-to-date.

Against this background it is necessary to find not only a data source that can give relevant information on the present forest situation but also provide the ability to monitor the changes. An agreement has therefore been made between Instituto Forestal (INFOR), Santiago de Chile and SSC Satellitbild, Kiruna, Sweden within the framework of the basic Treaty on Cooperation and Friendship between the Kingdom of Sweden and the Government of Chile. The agreement includes elaboration of the use of satellite imagery for forestry purposes in a ten-week project starting in March 1994, with financial support from the Swedish Board for Investment and Technical Support (BITS).

The aim of this project is firstly to evaluate whether the use of satellite imagery can fulfil, completely or partly, INFOR's demand for up-to-date forest information on both plantations and native forests, secondly to evaluate which data source that should be used, Landsat or SPOT data, and thirdly to evaluate which technique should be utilised when using satellite imagery, i.e. digital or analogue.

This report is the conclusion of the project mentioned containing a description of data and methodology used. Also included are advice and suggestions to be taken into account when establishing new or further developed inventory methods for the forest resources of Chile.

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[1] Chile Forestal nº 213 January-February 1994, Gestión 1990-1993 de CONAF.

For ease of use, this report consequently uses the Chilean names for tree species while the scientific names are written in italics in brackets the first times the name is mentioned. A complete list of the species and their scientific names can be found in Appendix 6.

INVENTORY METHODS USED AT INSTITUTO FORESTAL

Plantations

The most intensive inventories are made in the plantations. Here, Instituto Forestal (INFOR) is collecting cartographic information on the plantations from the controlling organisation of Chilean forestry - Corporación Nacional Forestal (CONAF) which is handling both the areas of plantations and the native forest. Forestry management plans made by the landowners must always be approved by CONAF, and in order to receive benefits for plantations (afforestations), thinnings and prunings the forest owner must present maps of the intended work to CONAF. These intentional maps, collected by INFOR prior to the inventories, are in various scales ranging from 1:5,000 down to 1:30,000.

Since the maps from CONAF only present the intentions of the landowners - not the present situation - INFOR has to check all stand borders as well as the species that is growing there. This task is fulfilled using the most recent aerial photos from the regular acquisitions made by Servicio Aerofotogramétrico (SAF) - preferably on a scale of 1:30,000. If acceptable photos are not available special flights can be ordered from SAF. To keep the cost of these flights as low as possible the photos are on a scale of 1:100,000.

Using stereo pairs, the stand boundaries are interpreted in the centre of each photo for stands greater than five ha. Along with the interpretation of the stand boundaries a form is filled in for each photo in which the stand number, species, age, special notes, etc. are noted. Some of this information is obtained from the CONAF maps, e.g. the age of the stand. Generally, all area information is available in the maps but sometimes additional areas of plantations have to be incorporated. The total area in the photo is therefore interpreted - not only the areas presented by the maps from CONAF. There is no verification made in the field.

Using a sketchmaster, the interpreted areas are transferred from the photos to the corresponding topographic map of Instituto Geográfico Militar (IGM) on a scale of 1:50,000. From there the areas are digitised into a Geographical Information System (GIS) for further database administration. Plantation maps are also plotted from the GIS.

Plantation maps are made by INFOR in the regions V through X and normally require six years to be completed - one region per year. In the intermediate years, when no objective figures are available from INFOR, the forestry figures of the region have to be based upon the information given by CONAF.

Native forest

Apart from the intensive inventories of the plantations the native forest has not been monitored in the same way and therefore lacks overall up-to-date information. In 1964, INFOR made a major inventory on a scale of 1:250,000 (presented in 1:500,000) , with support from FAO, but until 1991, when a new program was applied, it has only been actualised in areas of certain interest.

Regions VIII to X are included in the new programme where currently region IX has been completed on a scale of 1:250,000.

The current inventory in native forest uses aerial photos on various scales, 1:20,000 - 1:100,000, with some verifications made in the field. Using stereo pairs the central part of each photo is interpreted and classified into the different forest types of Chile. The minimum size of each stand is 25 ha. The interpretation is then transferred in the same way as for the plantations from the aerial photos to the topographic maps using the sketchmaster and digitised into a Geographical Information System (GIS).

PROJECT AREAS

Three areas were selected by INFOR for the project - each one containing four different map-sheets on a scale of 1:50,000 and one on a scale of 1:25,000. All map-sheets corresponded to the same sub-sectioning system as the topographic maps of IGM.

Curanilahue area

Compared to the other two areas the Curanilahue area, located in the coastal range (Cordillera de la Costa) between latitudes S 37°15' and S 37°45', and longitudes W 72°45' and W 73°30', has a topography that is less mountainous. The slopes are still often very steep although there are no very high peaks. Areas along the main streams are mainly gentle slopes and flat land. The annual rainfall fluctuates between 1200 and 1700 mm.

This area is to a major extent covered by plantations where Pino Radiata is the predominat specie. Relicts of old Roble (*Nothofagus obliqua*) can be found but now the secondary growth of that species is dominates the native forest in this area.

Malleco area

The Malleco area located along the outlying Andes Mountains, between latitudes S 37°45' and S 38°15', and longitudes W 71°30' and W 72°00', is characterised by mountainous topography with many slopes. Along the creeks steep slopes are very noticeable while flat areas and more gentle slopes are found along the main streams. High peaks are also present in the areas but are usually not covered with snow in the summer time. The annual rainfall fluctuates between 3000 and 4000 mm.

The principal type is Roble-Raulí-Coigüe (*Nothofagus obliqua, Nothofagus alpina and Nothofagus dombeyi*). The majority of the forest has been destroyed by earlier cuttings or fires, thus leaving an important secondary growth of Roble-Raulí-Coigüe. Additionally some other species are found in the secondary growth forest, Lingue (*Persea lingue*) and Avellano (*Gevuina avellana*) under the predominant species. In local areas, as a relict mostly along creeks, evergreen species are found that in addition to Coigüe contain Tepa (*Laurelia philippiana*), Ulmo (*Eucryphia cordifolia*) and Olivillo (*Aextoxicum punctatum*). The second type of importance is Araucaria (*Araucaria araucana*) which grows in pure or mixed stands of Coigüe and Lenga (*Nothofagus pumilio*) between Roble-Raulí-Coigüe or Coigüe-Raulí-Tepa. Lenga is also found but is here on its marginal and is therefore usually rotten at the centre of its stem.

Neltume area

The Neltume area, located further south along the outlying Andes Mountains between latitudes S 39°30' and S 40°00', and longitudes W 72°15' and W 71°45', is characterised by mountainous topography with many slopes. As in the Malleco area, steep slopes are found along the creeks while flat areas and more gentle slopes are found along the main stream. High peaks are also present in the areas but can, unlike the Malleco area, be covered with snow even in the summer time. The presence of volcanoes (Choshuenco, Villarrica and Quetropillán) inside or just next to the area is also notable. The annual rainfall is around 5000 mm.

The predominant species are Coigüe, Roble and Raulí both as original forest and secondary growth. They form the most common forest types in the area, Coigüe-Raulí-Tepa and Roble-Raulí-Coigüe. Araucaria, though, is very rare since it has its limits approximately at S 39° 30'. Evergreen species may also be found in small areas along the creeks with Coigüe, Tineo (*Weinmannia trichosperma*) and Ulmo sharing the top layer and with Tepa and Olivillo in the understorey. The area has a mix of both primary and secondary growth. The secondary growth is, in general, Raulí in pure stands but also Roble, Coigüe and Tepa. The Lenga type of this area contains stands of pure Lenga or a mix of Lenga and Coigüe. Finally, Ñirre (*Nothofagus antarctica*) is found in the high areas or in areas with frosty conditions, sometimes in the form of pure stands or mixed with Lenga achaparrado or Coigüe achaparrado.

FOREST DESCRIPTION

Native forest types

The native forest of Chile is divided into approximately twelve different types, among which only a few are present in the study areas. The forest types are more of a technical classification than a biological description intended to determine the method of felling or exploitation of the native forest. The three study areas are more or less similar to each other but show some variations. From north to south an environmental gradient can be found where the numbers of species increase towards the South. This gradient can be found in a change from deciduous to evergreen forest when moving towards the South of Chile.

The following types can be found in the study areas:

1. Roble-Raulí-Coigüe (*Nothofagus obliqua*, *Nothofagus alpina*, *Nothofagus dombeyi*) is the principal and most important forest type containing pure or mixed forests of the species mentioned. In this forest type either Roble, Raulí or Coigüe, or a mixture of these, must account for 50 % or more of the stand area. These trees are usually very big trees, with a good timber quality, and have therefore been heavily exploited for a long time. The Roble-Raulí-Coigüe type is generally found in the area between latitudes S 36°30' and S 40°30', between an altitude of 100 and 1,000 metres. These species are distributed in both ranges (coastal and the Andes mountains) especially on the interior slopes and in the range valleys occupying different altitudes. Roble occupies low lands, Raulí middle areas and Coigüe the upper part. However, in most areas mixed forests are to be found and no absolute border can be distinguished. Included in the type is secondary growth forest of Roble-Raulí-Coigüe, and the original forest containing Roble, Laurel (*Laurelia sempervirens*), Lingue (*Persea lingue*), Ulmo (*Eucryphia cordifolia*), Olivillo (*Aextoxicom punctatum*), Tepa (*Laurelia philippiana)* and Avellano (*Gevuina avellana*).
2. Coigüe-Raulí-Tepa (*Nothofagus dombeyi, Nothofagus alpina, Laurelia philippiana*) is found in the Andes mountains from latitudes S 37°00' to S 40°30' and in the coastal range from S 38°00' to S 40°30' where it grows between 600 and 1000 metres above sea level. In this forest type, Coigüe or Raulí accounts for less than 50% of the total number of trees. Other species found in the same type are Tepa, Trevo (*Dasyphyllum diacanthoides*), and more to the south Tineo (*Weinmannia trichosperma*) and Mañio (*Saxegothaea conspicua*). The usual understorey contains Avellano.
3. Lenga (*Nothofagus pumilio*) is found in the coastal range between latitudes S 36°50' and S 56°00' and in the Andes Mountains between S 36°50' and S 45°00'. The species forms the arboreal limit above an altitude of 1000 metres. Species associated with the type are Coigüe and Ñirre.
4. Araucaria (*Araucaria araucana*) is found in a small area in the coastal mountains, between latitudes S 37°40' and S 37°50', at altitudes of 1000 - 1400 metres. It forms an upper storey of some 30 metres high trees, often mixed with Lenga or Coigüe. Generally it is found in the Andes Mountains, between latitudes S 37°27' and 40°48', at altitudes ranging from 900 to 1700 metres.
5. Ñirre (*Nothofagus antarctica*) is not actually a forest type since it is of no commercial interest. It is found in both the highest and coldestparts and in flat valleys in the mountain ranges from S 37°00' and all the way down to the most southern part of Chile, mostly in the

Andes Mountains. Some examples large enough for commercial interest can be found, but very rarely.

6. Evergreen forest is a forest type containing a lot of species. It is found in both mountain ranges from latitude S 38°00' to S 47°00' below an altitude of 1000 metres. Associated with the type are Coigüe, Ulmo, Tineo, Tepa, Olivillo, Canelo (*Drymis winteri*), Mañio (*Podocarpus salignus, Podocarpus nubigenus*), Luma (*Amomyrtus luma*), Meli (*Amomyrtus meli*), and Pitra (*Myrceugenia exsucca*). In the study areas this type is not very common although some species may be found along the creeks.
7. Ñadis is found in flat and wet areas with shallow soils often with a so called hard pan. It is found in low lands from latitude S 39°00' to S 43°00' with dense vegetation where the predominant species belongs to the *Mirtaceae* family (Arrayán (*Mirceugenella apiculata*), Luma, Canelo and Coigüe).

Plantation classes

The plantations are by definition areas of manmade forest planted with exotic tree species. The plantations are dominate the study area of Curanilahue but decrease when moving to the south and represent only a minor part of the area of Neltume. Depending on the species found in the stand the following classes can be recognised in the plantations.

1. Pino Radiata or Pino Insigne (*Pinus radiata*)
2. Eucaliptos (*Eucalyptus spp.*)
3. Pino oregon (*Pseudotsuga menziesii*)
4. Alamos (*Populus spp.*)
5. Other species

SATELLITE DATA

A total of twelve different Satellite Orthophoto Maps (SOMs) were produced on a scale of 1:50,000. All maps correspond to the same scale and the same geographic coverage as the topographic maps of Instituto Geográfico Militar (IGM). Each map was delivered as one digital copy, one copy on photographic paper and one copy on transparent film.
Additionally, three Satellite Orthophoto Maps on a scale of 1:25,000 were produced. The areas covered by these maps were selected within the area of the twelve maps described above. The delivery format for these three maps was one digital copy and one copy on photographic paper each. The location of the maps is shown in Appendix 8.

The satellite data used, both Landsat and SPOT, were precisioncorrected using the reference spheroid International 1924 and the projection Universal Transverse Mercator (UTM). The same parameters that are used for the 1:50,000 scale topographic maps of IGM in Chile. Prior to the precision correction, contour lines were digitised from the IGM maps in order to be able to produce Digital Elevation Models (DEM) over the project areas. During the geometric correction process the DEM was used to remove the image displacement due to terrain and to obtain orthophoto quality of the products produced.

The digital processing performed during the production of the SOMs can be described simply as follows:

1. Radiometric normalisation of raw scenes using standard calibration coefficients. The correction compromises a gain or bias replacement and, optionally, convolution filtering. The filtering removes coherent noise, thereby taking advantage of the regularity of the noise in the geometrically raw data.
2. Geometric correction. A true precision correction of the scenes is done using an orbital model and direct resampling from the geometrically raw data. The DEM is applied to this process in order to remove image displacement due to terrain.
3. If applicable, different data sources are merged to obtain better geometric resolution - e.g. SPOT XS merged with SPOT P.
4. Sectioning of the scenes into SOMs. Mosaickning of adjacent scenes can thus be required if one scene is not enough to fill the area with image data. A sinusoidal blending in narrow overlap zones, preceded by a radiometric matching of the different scenes, is thus necessary.
5. Colour enhancement. A contrast stretch is applied to each map-sheet to optimise the interpretability before the analogue products are produced. The digital products are not colour enhanced, making it possible for the user of the digital data to have full control of the process in question.

The CD-ROM media was chosen for delivery of the digital data in order to ensure maximum compatibility and ease of use. File format was the SSC Satellitbild's GISimage rev 1.0 format.

Landsat TM satellite scene

A total of one Thematic Mapper (TM) scene was used where all the seven bands were precisioncorrected. The Thematic Mapper bands 4, 5 and 3, with red, green and blue assignments, were utilised for the analogue products while all seven bands where written to the CD-ROM and delivered with the digital product. The original pixel size of 30 metres for Landsat was resampled during the geometric correction process to 10 metres for the 1:50,000 scale maps and to 5 metres for the 1:25,000 map.

The following Landsat scene was used:

WGS	Date	Mission	Sensor	Map-sheets
001/086	1990-01-22	Landsat 4	TM	Curanilahue (G-13), Curanilahue (G-13 SE) Carampangue (G-14), Cordillera de Nahuelbuta (G-25) and Maitenrehue (G-26).

Due to technical problems with the Landsat TM data, no merge was made, as intended, between Landsat TM and SPOT P. Instead separate products of each data source were produced - both analogue and digital.

SPOT XS and SPOT P satellite scenes

A total of eleven SPOT scenes were used, four multispectrals (XS) and seven panchromatic (P). All three XS-bands were precision corrected. The SPOT XS bands 3, 2 and 1, with red, green and blue assignments, were utilised for the analogue products. The bands were also written in ascending order to the digital products on the CD-ROM media. In the areas of Malleco and Neltume, where only data from the SPOT satellite were used, the P data was merged with the XS bands 1 and 2. Thus, the final geometric resolution was 10 metres.

The following SPOT scenes were used:

K/J	Date	Mission	Sensor	Map-sheets
669/425	1989-11-09	SPOT1	P	Curanilahue (G-13), Curanilahue (G-13 SE) Carampangue (G-14)
670/425	1989-11-09	SPOT1	P	Carampangue (G-14), Cordillera de Nahuelbuta (G-25), Maitenrehue (G-26)
670/426	1989-11-09	SPOT1	P	Cordillera de Nahuelbuta (G-25), Maitenrehue (G-26)
673/426	1993-12-22	SPOT3	P	Loncopangue (G-41), Bío Bío (G-42), Laguna Malleco (G-51), Laguna Malleco (G-51 NE), Cordillera de Pemehue (G-52)

673/426	1993-12-22	SPOT3	XS	Loncopangue (G-41), Bío Bío (G-42), Laguna Malleco (G-51), Laguna Malleco (G-51 NE), Cordillera de Pemehue (G-52)
673/427	1993-12-22	SPOT3	P	Laguna Malleco (G-51), Laguna Malleco (G-51 NE), Cordillera de Pemehue (G-52)
673/427	1993-12-22	SPOT3	XS	Laguna Malleco (G-51), Laguna Malleco (G-51 NE), Cordillera de Pemehue (G-52)
674/429	1994-01-02	SPOT3	P	Pullingue (G-112), Liquiñe (G-113)
674/429	1994-01-02	SPOT3	XS	Pullingue (G-112), Liquiñe (G-113)
674/430	1994-01-02	SPOT3	P	Pullingue (G-112), Liquiñe (G-113), Choshuenco (G-122), Neltume (G-123), Neltume (G-123 NE)
674/430	1994-01-02	SPOT3	XS	Pullingue (G-112), Liquiñe (G-113), Choshuenco (G-122), Neltume (G-123), Neltume (G-123 NE)

Cost of satellite data

The costs of the satellite data are valid as of 15 February 1993. Prices are in SEK (Swedish kronor ≈ 7.70 / US$, May 1994) excluding taxes, ex works, subject to 1990 incoterms and including standard packaging.

The price per map sheet is related to the number of sheets ordered at the same time. Please note that the sheets must fit along one of the sides or in one of the corners.

SPOT XS or SPOT P Satellite Image Maps on a scale of 1:50,000. The price includes 1-3 bands on digital medium or positive colour film (from 3 bands).

	1	2	3-5	6-9	10-19	20-49	50-
SEK	44,600	32,300	25,000	21,100	18,600	16,400	14,800

Landsat TM Satellite Image Maps on the scale of 1:50,000. The price includes 1-7 bands on digital medium or positive colour film (from 3 bands).

	1	2	3-5	6-9	10-19	20-49	50-
SEK	43,400	25,700	21,800	17,400	15,300	13,400	10,900

SPOT P + XS or SPOT P + Landsat TM Satellite Image Maps on the scale of 1:50,000. The price includes 1-3 bands on digital medium or positive colour film (from 3 bands).

	1	2	3-5	6-9	10-19	20-49	50-
SEK	88,800	58,800	49,200	41,300	38,100	33,700	30,400

All prices includes:

- Precision corrected satellite data using map or ground control points.
- Map projection and ellipsoid at choice.
- Standard legend.

Options:

- If the satellite data are terrain displacement corrected using existing contoured maps, the price is increased by 50%.
- If the satellite data are terrain displacement corrected using an existing digital elevation model, the price is increased by 30%.

For further information and current price, please refer to the latest price list available from SSC Satellitbild, Kiruna Sweden.

TRAINING

The project included three training sessions, all including introductions to the satellite data technique and the use of such data for forestry applications.

The first session was held in February 1994 at SSC Satellitbild head office in Kiruna, Sweden and was attended by the head of the Forest Inventory Division at INFOR, Mr Rolando Bennewitz B. Over a period of two days he was introduced to the complete chain of satellite data processing, from data reception to final products. Included in the training was a visit to the satellite data reception facilities at ESRANGE, archiving of satellite data, radiometric and geometric corrections, visual interpretation and digital classification. Along with the presentation of the final products, the forest applications were emphasised. The remaining three days were spent on planning the pilot project. A complete programme for the visit to SSC Satellitbild can be found in Appendix 7.

The second training session was held in March 1994 at the office of INFOR, Santiago, Chile, where lectures were held in conjunction with the hard-copy interpretation. The lectures emphasised the knowledge of different satellite systems, various instruments and sensors, radiometric and geometric corrections. Furthermore, discussions were held on the properties of different wavelength bands and their suitability for forest interpretation. Finally the RGB (Red, Green and Blue) colour model was discussed, which is essential for understanding the colour variations in the imagery.

The third training session in April 1994, which also was held at INFOR in Santiago, included not only the same lecture as in the second training but also a five day course in 4sys software. Apart from various exercises and practical training in using the software, the course included the following:

- Introduction to satellite imagery interpretation for forestry applications.
- Presentation and documentation of the 4sys software.
- Updating of existing forest maps.
- Revision of forest maps.
- Introduction to image processing.

The third training session included six people from INFOR, as well as four specially invited participants: two from CIREN (Centro de Información de Recursos Naturales) and two from CONAF (Corporación Nacional Forestal).

METHODOLOGY

Reference materials

Reference material was used throughout the entire interpretation work and during the field visit. The material consisted of IGM maps on a scale of 1:50,000; black and white aerial photos on various scales; maps of management plans from CONAF; a number of maps of the plantation, made previously (on a scale of 1:50,000) areas and photos taken during the field trip. Information was not copied from the reference material. Instead the material served as a very valuable tool in the process of learning how to interpret the satellite data. The information also made it possible to see the advantages and disadvantages of the different data sources.

Field work

A field trip to the project areas was made during the second week of the project when a total of five map-sheets were visited. Approximately 70 photos were taken at strategic points for later reference during the interpretation work. The satellite data used during the trip were the copies produced on photographic paper on which a plastic overlay was attached. Notes were written on the overlay with waterproof pens marking the position of the photos taken, together with some information about the forest types identified.

The first two days of fieldwork were spent in the in the area covered by the Laguna Malleco map-sheet (G-51). Here, the most common forest type in the area, Roble-Raulí-Coigüe, was studied closely. Various stands of the secondary growth, some stands of primary forest, a frosty area typically covered by Ñirre and a managed stand of Roble were included in the round trip. A guided walk through parts of the Reserva Forestal Malleco gave a good view of various stands and areas of Pino Oregon, a managed stand of Raulí and open areas classified as extensive pastures (classified as Ganadero). Plantations of Pino Radiata were visited under the supervision of the Forestal Mininco company. Some young stands of Eucaliptus could also be identified.

The third and fourth days were spent covering the map-sheet areas of Liquiñe (G-113) and Neltume (G-123). These areas are dominated by the forest type Coigüe-Raulí-Tepa, and therefore various combinations of this type were visited. Two areas that had been heavily cut and were clearly visible in the satellite imagery were also visited and checked.

The last day of the field trip was spent in Curanilahue where the map-sheet areas of Maitenrehue (G-26) and Cordillera de Nahuelbuta (G-25) were visited. The areas are dominated by plantations of Pinus radiata of various ages and size that give different colours and patterns in the satellite imagery. Secondary growth of Roble and a managed stand of old Raulí were also checked. A small area classified as noneforestry (NF) was also visited.

Hard-copy interpretation

Hard-copy interpretation was carried out at the office of INFOR in Santiago where three light-tables were installed for the purpose. Since the project consisted of three different project areas, the team was divided into three groups dedicated to one area respectively. Two areas were covered by the merged products of SPOT XS and SPOT P, and one with Landsat TM and SPOT P on separate products. The same group concentrated on the same area all the time in order to optimise the interpretation and to decrease the time it took to obtain a good knowledge of the satellite data used. During this interpretation, the satellite data on the transparent film was used together with a plastic overlay attached on top on the film. Using a needle, four well-defined coordinates were transferred from the transparent film to the overlay by making holes in the plastic overlay. By doing this, the well-defined coordinates could be maintained and used later when the overlays were digitised into a GIS. Permanent marker pens in black with a pen size of 0.4 mm were used to draw the interpretation.

Prior to the interpretation a preliminary legend was defined. A legend defines the classes that are going to be interpreted and also explains the differences between the different classes. The complete legend and codes used can be found in Appendix 5. The iterative process of interpreting, defining the legend, interpreting, defining, etc. was clearly recognised by all the team members during the first week of interpretation. Discussions were made on how to interpret the satellite data and how to define the classes in a proper way. References were made to the knowledge of the INFOR team members and the reference materials. During the second week one full day was spent on redefining the legend and summing up the interpretation work done so far. I the third, and also the last week of the hard-copy interpretation, additional discussions were held on the interpretability of the satellite data, the differences between Landsat and SPOT and the overall impression of the data and the technique used.

Digital interpretation

Following the completion of the hard-copy interpretation, the light tables were exchanged for computers with the 4sys software installed. The computers were equipped with Intel 486 processors running at a clock speed of 66Mhz, with a RAM size of 16 Mb and a 345 Mb internal hard-disk. The operative system supplied with the PC's was IBM-DOS 6.1. As regards the hard-copy interpretation, the work was carried out in three different areas, one area on each PC. The personnel worked on the same test areas as the one they worked on for the hard-copy interpretation.

The work started with preparation of the backdrop images to be used during the interpretation and preparation of the multiband images for the segmentation. The next step was to use the segmentation technique to create a predelineation of the maps. The work consisted of test segmentations in small areas and adjusting the parameters and the filters that controll the segmentation process. All this was carried out by the personnel from INFOR. When a satisfactory segmentation was achieved the whole image was processed and a predelineation created. This predelineation was used as a basis for the interactive delineation.

The following parameters were used for the segmentation

Map	e-value	t-value	minstart	minend	lowpass filter
Curanilahue	5	50	20	300	3x3
Laguna Malleco	7	50	30	350	3x3
Neltume	10	60	30	350	3x3

where:

e-value = presegmentation threshold.
t-value = the T-ratio which controll the variance in the final segments.
minstart = minimum number of pixels allowed in segment after the presegmentation.
minend = minimum number of pixels allowed in a segment in the final segmentation.
lowpass = kernel size of the lowpass filter used prior to the presegmentation.

Assessment of interpretation accuracy

Ground truth data

It was decided, due to both time and cost limitations within the project, to use aerial photos to collect reference data instead of making a field survey. Aerial photos were available for the whole test area. Both the scale and year of acquisition varied for the aerial photos between the different areas (scale 1:20,000 - 1:100,000, year 1960 - 1993).

Area	Flight and Year Of Acquisition	Scale
Curanilahue	SAF/INFOR-1990	1:100,000
Malleco	JICA[2]-1991	1:20,000
	SAF-1983	1:60,000
	SAF/INFOR-1990	1:100,000
Neltume	SAF/CIREN-1991	1:60,000

Allocation of sample plots

Different methods of allocating the sample points were used for the different interpretations made, i.e. hard-copy and digital. For the hard-copy interpretation a systematic sample was used and for the digital an optimised allocation of sample points.

<u>Hard-copy</u>

Sample plots were allocated systematically over each satellite map. A grid was created on a transparent film on which each intersection marked the location of the sample point. The tick-marks, marking the UTM coordinate system, were used to position the grid on the satellite orthophoto map. The distance between sample points was eight cm in a northely direction and four cm in a easterly direction corresponding to four and two km on the ground respectively. The number of sample points ranged from 60 up to 70 for different satellite orthophoto maps.

[2] Japanese International Cooperation Agency

Digital

In the three areas where digital interpretation was carried out, another method was used to allocate the sample points - optimum allocation. By defining the minimum number of sample points in one stratum this method will guarantee that each stratum contains at least one sample point. Information about stratum size, variance within strata and the cost of taking a sample point in the strata is required to make the optimum allocation. In this case there was no information about the variance within the strata, and the cost of taking a sample in the aerial photo was assumed to be equal for all strata. For these reasons the allocation can be based on the relation between stratum area and the total area of all strata. The extra information given by an additional point in common classes decreases with a rising number of points in that class. To optimise value of the information given by a sample point, the probability of obtaining a sample point within a stratum should decrease with increasing stratum size. To achieve this, the following formula was used for the allocation:

$$n_i = n \frac{\sqrt{N_i}}{\sum_{i=1}^{m} \sqrt{N_i}}$$

n = total number of sample points taken
n_i = number of samples to be taken in strata i
N_i = area of strata i.
m = total number of strata

Interpretation evaluation

Hard-copy

For each sample point the class code from the previous delineation was registered on a form. The exact locations of the sample points were transferred to the aerial photos. A manual method was used, visually comparing the position of the point in the satellite image and finding the same point in the aerial photo. For the surroundings of that point a new interpretation was made in the aerial photo to determine the class. The results were registered on the form. When using a systematic sample borderline problems may occur; for example a point can be located exactly on a border between different interpretation classes. In these cases a simple rule was used to "move" the point into a class. If the point number was even, the class registered for that point was the lower and left polygon class and for odd numbered points the upper and right polygon class. When the interpretability was poor - as if the point was located on a cloud or in heavy shadows where the vegetation class could not be determined objectively either in the satellite image or in the aerial photo - the point was rejected.

Digital

The database created during the interpretation was updated with numeric-class codes and checked for variable errors with a FoxBASE+ application. An extract of the attribute database, polygon-id and numeric class code, was written to a file, (*reccode.txt*). The file was used as a lookup table when the polygon-id file, (*id.lan*) was copied and re-coded into a thematic file, (*theme.lan*), where the digital level for each polygon represents the numeric-class code. With the 4sys program ***farea.exe*** the area for each class code was calculated using *theme.lan* as input file and the result , class code and area, was written to a text file, *area.txt*. Calculation of number of sample points within each stratum was performed with an application in Microsoft

EXCEL. The *area.txt* file was imported to a EXCEL -sheet. Here the total number of sample points and minimum points within each stratum was specified. According to these specifications the number of points was calculated with the formula described above. The results, stratum and sample size, were saved in a text file, (*numofpnt.txt*). This file was then used as input to ***farea.exe*** for the allocation of sample points. The program ***farea.exe*** can be executed in two modes: area calculation or sample point allocation mode. A generate file was created containing class-code, point number in stratum and X and Y coordinates. The generate file was then modified in EXCEL to a file with only point-id and coordinates, *spoint.gen.*, to be displayed on the satellite map during registration of sample point data. Each number indicates the sample point location.

To access the data entered during interpretation of the satellite images the attribute panel was displayed showing the desired information. The cursor was placed in the same polygon as the sample point and the data displayed in the panel was registered on a form. The same method as for the material interpreted from the hard-copies was used to transfer and interpret the sample points in the aerial photos. Due to the nature of the method for sample point allocation, points were placed within its strata, so no borderline problem occurred.

To be able to compile the results from the accuracy interpretation, a program was written in FoxBASE+ database language to enter the information from the forms into a database. From this data base the information was extracted to be used in EXCEL to create confusion matrices for the interpretation evaluation. These matrices were studied to understand the kinds of misclassification errors which occured, for example to which classes Renoval de Coigüe-Raulí-Tepa was wrongly classified and vice versa.

To put the interpretation accuracy into figures, the proportion correct, the omission error, the comission error, and the user accuracy where computed and displayed in a table.

Proportion correct was defined as the proportion of the accuracy assessment samples units which were a given class according to the reference (aerial photography) data and were correctly classified to that class from the satellite data. That is:

$$\text{Proportion correct} = \frac{\sum_k C_{i\,sat,k}}{\sum_k C_{i\,phot,k}}$$

where $C_{i\,sat,k}$ is the samplingpoints of class i using satellite imagery and correctly classified according to photos.
$C_{i\,phot,k}$ is the sampling points of class i using aerial photography

Omission error is simply the complement of this , that is :

omission error = (1 - proportion correct for C_i).

Commission error represents the proportion of sample units classified to a given class using the satellite data that did in fact not belong to that class according to the reference photo data. This can be written as:

$$\text{Commission error} = \frac{\sum\limits_{\substack{k \\ k \notin C_{i\,phot}}} C_{i\,sat,\,k}}{\sum\limits_{k} C_{i\,sat,\,k}}$$

where $C_{i\,sat,\,k}$ is the samplingpoints of class i using satellite imagery

$C_{i\,phot,\,k}$ is the sampling points of class i using aerial photography

or if put in words:

$$\text{Commission error} = \frac{\text{Number of sampling points classified as } i \text{ in satellite that did not belong to that class according to aerial photos}}{\text{Total number of samplingpoints classified as } i \text{ in satellite}}$$

User accuracy is simply the complement of the commission error. It represents the reliability of the classification label for any segment of a map produced by the delineation method.

Area estimates

Hard-copy
After the delineation of the hard-copies the results of three map-sheets were digitised into a GIS. (The remaining map-sheets are going to be digitised later but not within the framework of this project.) INFOR is currently using a Canadian software PAMAP ver. 2.2 (1990). The codes registered for each area can be divided into three levels:

1. Class, Forest-type
2. Composition code
3. Sub code.

The area for each stratum in class level was calculated and written to a file.

Digital
Areas can be accessed directly with the area calculation module in 4sys. Areas were calculated for the same levels as in the case of the hard-copies.

These area estimates have errors coming from misclassifications and delineation errors made during the satellite image interpretation. 4sys has the facility to correct or straighten up the estimates by using the information from a control taxation. The program is designed to work with single point or cluster samples. In this case single point samples were used. The steps to create corrected area estimates are described in the following section.

In the satellite scene n points are inspected by the use of aerial photos and matched with the data retrieved from the satellite image. As stated previously, the aerial photos are in this case considered as true data. For a sample plot #k, a matrix P_k is obtained:

$$\begin{array}{cccc} & & \text{Photo} & \\ & C1 & C2 & C3 \end{array}$$

$$P_k = \begin{bmatrix} p_{k11} & p_{k12} & p_{k13} \\ p_{k21} & p_{k22} & p_{k23} \\ p_{k31} & p_{k32} & p_{k33} \end{bmatrix} \begin{array}{l} C_1 \\ C_2 \ \text{Satellite} \\ C_3 \end{array}$$

Here p_{kij} , (i, stands for satellite data and j stands for photo data) is the proportion of land classified as class C_i by the satellite and as class C_j by the photo, as we only have one registration in each matrix $\sum\sum p_{kij} = 1$. By averaging over k a new matrix is obtained:

$$P = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix} \qquad p_{ij} = \frac{1}{n}\sum_{k=1}^{n} p_{kij}$$

In this matrix p_{ij} represents the proportion of all the land classified as C_i in the satellite image and as class C_j in the photo. Each element in the matrix is then divided by the corresponding row sum:

$$\Pi = \begin{bmatrix} \pi_{11} & \pi_{12} & \pi_{13} \\ \pi_{21} & \pi_{22} & \pi_{23} \\ \pi_{31} & \pi_{32} & \pi_{33} \end{bmatrix} \qquad = p_{ij} / \sum_j p_{ij}$$

Here π_{ij} is an estimate of the proportion of land belonging to class C_j out of all land classified as class C_i in the satellite data.

If we now look at all of the land classified as C_i based on the satellite interpretation and let a_i denote the true area, the corresponding true area A_j in class C_j in is then estimated by:

$$\hat{A}_j = \sum_i a_i \cdot \pi_{ij} \qquad j = 1, 2, 3$$

or if it is put in matrix language:

$$\begin{bmatrix} \hat{A}_1 & \hat{A}_2 & \hat{A}_3 \end{bmatrix} = \begin{bmatrix} a_1 & a_2 & a_3 \end{bmatrix} \cdot \Pi$$

The true area is now estimated for the strata, or in other words to some extent corrected for the errors made during interpretation. To be able to see how well these estimates correspond to the true area we have to calculate the standard error for the area estimates. As already stated, the sample points are randomly located in the satellite image and we can calculate the standard error under that assumption. We will use Efron's general bootstrap method to make the calculation of the standard error. By considering all sample points P_k $k = 1, 2, ..., n$ and making a large number of copies of them we obtain sample point data that can be considered to be an estimate of data for the whole scene. We can now sample many times from this population exactly n matrices and each time form the estimates for A_j , $j = 1, 2, 3$ according to the above procedure. If this is done M times, M new estimates $\hat{A}_j^{(m)}, j=1, 2, ..., M$, of A_j are obtained. The standard error of $\hat{A}_j$ according to the bootstrap method is then calculated by:

$$(\text{Stand. error of } \hat{A}_j)^2 = \frac{1}{M-1} \sum (\hat{A}_j^{(m)} - \bar{\hat{A}}_j)^2, \text{where } \bar{\hat{A}}_j = \frac{1}{M} \sum \hat{A}_j^{(m)}$$

In principle, M should be very large. A recommendable value is M=10,000. In practice the n new sample points are each time sampled according to simple random sampling with replacements from the original owes.

RESULTS

Hard-copy interpretation

Interpretation Accuracy

Note, that the accuracy figures presented below must be put in relation with the actual number of observations in that class. If there are few observations in a class the reliability of the figures produced will be low.

Curanilahue

Proportion correct by class , expressed as "accuracy in percent" averaged 72 percent across the observations for the Type classes in the Curanilahue area (se Table 9.1). Average commission error (the proportion of all satellite assignments to a given class which were actually missclassified to that class) was 31 percent. Average omission error (the proportion of accuracy assessments units belonging to a given class not classified to that class) was 28 percent . Proportion correct for the class Renoval de Roble is 81 percent and for the plantation class 93 percent. If we look at the classes Ganadero and Matoral, commission error for Ganadero class was 87 percent . 85 percent of this commission error was due to misclassification of Matoral class into Ganadero.

AERIAL PHOTO

SATELLITE IMAGE

Class	R	RvR	Cg	RvCg	Ar	Le	Ñl	Ña	PL	Ex	Dr	Mt	G	O	W	NF	Sum
R																	
RvR		21							1			7					29
Cg																	
RvCg																	
Ar																	
Le																	
Ñl																	
Ña																	
PL		2							109	2		3					116
Ex									4	2						1	7
Dr																	
Mt		2							2			14					18
G		1							1	1		33	6			3	45
O																	
W															1		1
NF																7	7
Sum		26							117	5		57	6		1	11	223

Class	Omission	Comission	Prop. corr	Users Acur
R				
RvR	19	28	81	72
Cg				
RvCg				
Ar				
Le				
Ñl				
Ña				
PL	7	6	93	94
Ex	60	71	40	29
Dr				
Mt	75	22	25	78
G		87	100	13
O				
W			100	100
NF	36		64	100
ALL	28	31	72	69

Table 9.1 Confusion matrix and result from hardcopy interpretation for Curanilahue area.

Malleco

Both Proportion correct (79 percent) and Users Accuracy (79 percent) across the classes was higher in Malleco area than in Curanillahue area. In the class Renoval de Roble (RvR) proportion correct was 71 percent. Half of the Omission error and three fourth of the Commission error is related to misclassification of/into Renoval de Couigue class (RvCg). The highest individual accuracy both in Proportion Correct (100 percent) and Users Accuracy (100 percent) was in Lenga class (Le), but in this case there was to few observations to produce a reliable figure.

AERIAL PHOTO

SATELLITE IMAGE

Class	R	RvR	Cg	RvCg	Ar	Le	Ñl	Ña	PL	Ex	Dr	Mt	G	O	W	NF	Sum
R		3															3
RvR		39	1	3													43
Cg			5	1													6
RvCg		5	1	10			1										17
Ar		1		2	4												7
Le						2											2
Ñl							1										1
Ña																	
PL									22	1			1				24
Ex										2			1				3
Dr																	
Mt		1										8					9
G												1	12			1	14
Q												1		2			3
W																	
NF										1			4			7	12
Sum		49	7	16	4	2	2		22	4		10	18	2		8	144

Class	Omission	Comission	Prop. corr	Users Acur.
R		100		
RvR	20	9	80	91
Cg	29	17	71	83
RvCg	38	41	63	59
Ar		43	100	57
Le			100	100
Ñl	50		50	100
Ña				
PL		8	100	92
Ex	50	33	50	67
Dr				
Mt	20	11	80	89
G	33	14	67	86
Q		33	100	67
W				
NF	13	42	88	58
ALL	21	21	79	79

Table 9.2 Confusion matrix and result from hardcopy interpretation for Malleco area.

Neltume

Proportion correct (78 percent) was one unit lower than in the Malleco area but the Users Accuracy (81 percent) increased two units. The omission error for RvR is 69 percent, this result appears to be due to misclassification of RvR points into Cg class, two third of the cases, and one third into RvCg. For the Coigüe class (Cg) the Commission error was in half of the cases related to points wrongly classified into Renoval de Coigüe due to and in one fourth of the cases into Lenga respective Renoval de Roble. All of the Matoral class and Water class points was correctly classified.

AERIAL PHOTO

SATELLITE IMAGE

Class	R	RvR	Cg	RvCg	Ar	Le	Ñl	Ña	PL	Ex	Dr	Mt	G	O	W	NF	Sum
R	1																1
RvR		4	1	2													7
Cg		6	91	13	1	6										1	118
RvCg		2	3	15													20
Ar																	
Le			1			15	2										18
Ñl						1	5										6
Ña		1															1
PL									1								1
Ex																	
Dr				1							1					1	3
Mt												11					11
G													4				4
Q																1	1
W															10		10
NF						1	1				1		4			15	22
Sum	1	13	96	31	1	23	8		1		2	11	8		10	18	223

Class	Omission	Comission	Prop. corr	Users Acur.
R			100	100
RvR	69	43	31	57
Cg	5	23	95	77
RvCg	52	25	48	75
Ar	100			
Le	35	17	65	83
Ñl	38	17	63	83
Ña		100		
PL			100	100
Ex				
Dr	50	67	50	33
Mt			100	100
G	50		50	100
Q		100		
W			100	100
NF	17	32	83	68
ALL	22	19	78	81

Table 9.3 Confusion matrix and result from hardcopy interpretation for Neltume area.

Digital interpretation

Accuracy

Curanilahue

Proportion correct by class averaged 73 percent across the observations for the Type classes in the Curanilahue area (se Table 9.4). Average commission error was 30 percent and for the omission error the result was 28 percent . Proportion correct for the class Renoval de Roble (RvR) is 80 percent and for the Plantation class (PL) 82 percent.

AERIAL PHOTO

Class	R	RvR	Cg	RvCg	Ar	Le	Ñl	Ña	PL	Ex	Dr	Mt	G	O	W	NF	Sum
R																	
RvR		12										3					15
Cg																	
RvCg																	
Ar																	
Le																	
Ñl																	
Ña																	
PL		1							18			3					22
Ex									4	1		2				1	8
Dr																	
Mt		1							2			15					18
G												1	2				3
O																	
W															1		1
SATE NF									1							2	3
Sum		14							25	1		24	2		1	3	70

Class				

Table 9.4 Confusion matrix and result from digital interpretation for Curanilahue area.

Malleco/Neltume

Averaging over all classes Proportion Correct and Users Accuracy was respectively 60 percent. All points classified as R in the aerial photos was also classed as R in the satellite that gives the high value on proportion correct but some point classed as Cg in the aerial photo where also classed as R in the satellite image witch result in the low Users Accuracy. The classes RvR, Cg and RvCg where oftly missclassified among them selves.

Table 9.5 Confusion matrix and result from digital interpretation for Malleco/Neltume area.

AERIAL PHOTO

Class																	
R	4		3														7
RvR		14		3													17
Cg		2	9	1	1												13
RvCg		3	4	7										1			15
Ar			1	1	2	1	1										6
Le		1	4	3		5											13
Ñl				2		3	1					3					9
Ña																	
PL		1							1							1	3
Ex		1								2			1				4
Dr											3						3
Mt		2	1	1								5	1			1	11
G													6				6
Q			2				1					1		6			10
W															7		7
NF													1	2		12	15
Sum	4	24	24	18	3	9	3		1	2	3	9	9	9	7	14	139

Class				
	40	40	60	60

Area Estimations

Hard-copy interpretation:

No area figures could be calculated due to classes from the digitised hard-copy interpretation did not correspond to the legend defined.

Digital interpretation:

Area cover of Cordillera de Nahuelbuta

Only half of the map was interpreted. Area figures are calculated on the part of the map that was ready.

Corrected Area in Cordillera de Nahuelbuta (G25)			
Class	*Measured Area (%)*	*Corrected Area (%) Direct matrix*	*StdErr (+/- %):*
R			
RvR	21,71	19,12	2,86
Cg			
RvCg			
Ar			
Le			
Ñi			
Ña			
PL	38,25	38,67	4,25
Ex	6,72	0,84	0,84
Dr			
Mt	31,65	39,47	4,56
G	0,64	0,41	0,21
O			
W	0,19	0,12	0,09
NF	0,83	1,38	0,88
Tot	100,00	100,0	

Table 9.6 Area in percent of total area interpreted for Cordillera de Nahuelbuta. Both measured area and area corrected with direct matrix method are presented.

Area cover of Bio Bio

Whole map was interpreted. Area figures represents class area in percent of total area.

Corrected Area in BioBio (G42)			
Class	Measured Area (%)	Corrected Area (%) Direct matrix	StdErr (+/- %):
R	0,82	0,36	0,32
RvR	27,41	25,67	4,73
Cg	0,79	7,13	2,90
RvCg	14,32	24,76	5,73
Ar	7,36	2,78	1,58
Le	12,98	4,03	2,42
Ñi	6,84	4,10	2,46
Ña			
PL	2,15	0,69	0,66
Ex	0,97	Not Corrected 0,97	
Dr	0,03	0,02	0,02
Mt	1,96	6,06	2,40
G	1,39	3,05	1,39
Q	15,13	15,97	3,57
W	1,31	1,14	0,44
NF	6,53	3,28	1,73
Tot	100,00	100,0	

Table 9.7 Area in percent of total area for BioBio. Both measured area and area corrected with direct matrix method are presented.

Area cover of Pullingue

Whole map was interpreted. Area figures represents class area in percent of total area.

Corrected Area in Pullingue (G112)			
Class			
R	2,86	1,69	0,70
RvR	5,13	12,16	3,50
Cg	27,01	27,91	3,61
RvCg	4,89	2,26	1,25
Ar			
Le	4,02	3,27	0,88
Ñi	0,72	Not Corrected 0,72	
Ña			
PL			
Ex	0,55	0,47	0,18
Dr	0,32	0,27	0,10
Mt	7,06	2,63	1,28
G	1,08	1,90	0,90
Q	0,68	Not Corrected 0,68	
W	24,21	23,88	1,69
NF	21,49	22,17	0,87
Tot	100,00	100,0	

Table 9.7 Area in percent of total area for Pullingue. Both measured area and area corrected with direct matrix method are presented.

DISCUSSION

Instituto Forestal has long experience of forestry inventories, from the start of the FAO-project in 1962 until the recurrent plantation inventories of today. Data source has for more than 30 years been black and white aerial photos. One could therefore anticipate there being a bank of sound knowledge about the aerial photos themselves but also about remote sensing. During the project, this knowledge proved to be very valuable for the task at hand. Moving from black and white aerial photo to satellite imagery interpretation did not therefore involve any major difficulties. The methodology is the same and moving from one data source to another is normally just a matter of changing the key of interpretation used. Satellite data therefore requires no extra skills or special experience other than the normal application knowledge. Regardless of its advanced background, being a data source using the latest and most advanced technology, the methodology used is still the same as for any other data source and must not be considered as more difficult. Instead, the possibilities are merely increasing and offer the users a greater choice of possibilities.

The project concentrated on two of these possibilities: hard-copy and computer aided interpretation, both using visual decision rules for the delineation. Evaluating the possibilities mentioned, as well as the data source itself, is not an easy task in a period of only 10 weeks. Comparison are naturally made between the current methods and its data source. These are made even though satellite imagery and aerial photos should be regarded as supplementing, rather than conflicting with each other.

Even though the results of the accuracy test are both promising and discouraging results, it must be strongly emphasized that aerial photos were used for verifications rather than field visits. Real ground truth data should not be confused with the interpretations made in the aerial photos. The accuracy test will therefore produce an answer that shows how well the interpretations correspond to each other rather than to the ground truth. The one and only way of finding out what the truth is, is to make field visits.

Comments on the hard-copy interpretation

There is not much different in the methodology used between the satellite imagery and aerial photos. The material used (transparent film) is considered to be better than the photos on the 1:100,000 scale. Reasons for this are the map sheet format of the satellite imagery, the geometrically corrected data, the infrared information, homogeneous radiometry all over the image and the general overview. The overall impression is that the data is a good and useful tool, but there is still an unexplored potential. More experience is therefore needed to find out more about that potential. Together with other data sources it can probably be a very good tool for updating already existing maps.

It is a good idea to adopt the same format as the IGM-maps. It gives a better impression from the start of the final product, which is difficult to obtain in the aerial photos. Having a complete overview of the map is also of great importance when comparing different classes in the map.

The lack of stereoscopic vision is a major limitation which is not easily compensated by the colour information. The height of the trees is in many cases the crucial factor when distinguishing between different forest types. Some stand boundaries like the one between the forest types Ñirre and Lenga can easily be detected by the height information in aerial photos while the same colour is found in the imagery. In respect to the shadow problem, stereoscopic vision can also remove some of the negative effects associated with them.

The SPOT Panchromatic imagery is found to be sufficient in the plantations despite the fact that it was impossible to distinguish between Pino Radiata and Eucaliptus. Grown up stands of these species are very dark. The data is similar to the photos on the 1:100,000 scale but provides no information about the young plantations where the age is less than approximately 6 - 8 years. In these areas the plantations could be confused with Nonforestry (NF) or Exploited areas (Ex) and sometimes with Ganadero (G) or Matorral (Mt). However, plantations that have reached the middle age are normally easy to distinguish and separate into different age classes.

Despite these limitations, the data is of sufficient quality for inventory purposes. The geometric properties are in this context a factor that makes it possibly to speed up the general inventory work by avoiding transfer of data through the Sketchmaster. Therefore the conclusion is, provided the cost is comparable to the cost of aerial photos, that SPOT P imagery is preferable and will provide the information required for making the plantation maps.

The interpretation of native forest is to some extent similar to that made in the plantations. However, there is a larger number of species an they show a more irregular distribution which affects the way the interpretation is made. Therefore the use of auxiliary information such as aerial photos and topographic maps is necessary to complete the interpretation task. The photos do not necessarily have to be of a recent date as long as they provide relevant information on the forest types.

Auxiliary data should always be considered in every type of interpretation since it increases the chances of making better interpretations. In some areas it creates synergistic interpretation effects which are of great advantage to the work. and must be considered as being very useful in all projects. In this case, having the same map sheet format and scale of the satellite imagery as that of the ordinary topographic maps makes it very easy to make references from one source to an another. Contour lines can, for instance, be interpreted simultaneously.

Compared to the photos, the images are very rich in colour with clearer variations in the types or subtypes. They also extract the subtypes better, although it may, be somewhat more difficult to decide exactly what type it is. More experience of the data and the interpreted area itself will therefore increase the chances of making a correct classification.

Some limitations are found, especially when the resources are very young such as recently planted areas or areas of very young plantations. This is also the case when trying to distinguish between the young plantation of Pino Radiata and the young secondary forest in SPOT images. This difference can usually be distinguished from Landsat data by the colour of the area, its shape and its texture.

Stands of Pino Oregon show in most of the cases an intensive red colour (SPOT data) with a smooth texture making them comparatively easy to define. Some caution must to be taken though not to mix these stands with the secondary growth of Raulí.

Shadows caused by the topography are one of the major difficulties. They not only reduce the possibilities of making a proper interpretation; they also incorrectly produce an impression of a change in the vegetation. Sometimes this change is correct, but in many cases it is only a shadow. Thus, a close look at the height information in the corresponding topographic map is necessary.

Comments on the digital interpretation

It should be noted that digital interpretation in this report equals visual interpretation on a computer screen where the interpreted borders and appurtenant data are maintained digitally. This is completely different to a digital classification where a single pixel, depending upon its digital grey-level in each spectral band, is assigned a previously defined class. The digital classification is for some applications a useful tool, but in general visual interpretation is superior in many respects when incorporating landcover mapping of large areas for the first time. It is a simple method from the practical point of view, including training, and requires no sophisticated equipment for the crucial element of overlay preparation. It is also much more *intelligent* and gives more diversity and better results than digital classification, which cannot compete with the human brain during first time interpretation. Furthermore, to create a good digital classification a very good knowledge of visual interpretation is required.

The advantages and disadvantages of digital imagery are very similar to those of satellite hardcopies. It is worth mentioning that the shadows caused by topography were considered to be darker in the SPOT imageries, and some problems were experienced in distinguishing between Renoval de Roble and plantations in Landsat data.

The overall impression of the digital interpretation method was in general positive but it was noted that the digital interpretation was significantly slower than the hard-copy interpretation. It must be remembered that working with a new type of methodology, digital data and computer aided interpretation complicates the learning process. There is not only the data itself to be learned. The pen used in the hard copy interpretation has been exchanged for a computer and a mouse. Thus, when working with digital methods for the first time, a lot of effort has to be put into the educational process to be able to handle the software since sound knowledge of the software is essential in order to concentrate on the task at hand - the interpretation.

One advantage of the digital method is thatit is possible for the operator to enlarge the area of interest (zoom-in). This will increase the precision of the delineation but it may also create a risk of spending time on irrelevant details. In this way, it is possible to lose the general view or the ability to generalise. On the other hand - correctly used - the ability to zoom-in makes it far easier to place the border more exactly. If the interpreter is unfamiliar with digital imageries the feeling for how small an area can be delineated in a certain enlargement step/factor has not yet been developed.

The possibility of creating an automatic predelineation (segmentation) based on the digital imagery was a good help during the delineation. The segments are used as a suggestion of how the delineation could be made, and then it is up to the operator to decide whether the border should be kept or removed. If the predelineation is too fine, this process will be very time consuming.

The major gain to be gained from this method cannot be achieved the first time an area is mapped; the most important savings will occur when the area is to be updated. The old delineation is displayed on the monitor with a new image backdrop; only the areas that has changed since the last interpretation will be updated. Using this method, the time needed for revisions will be cut drastically. Even though the digital interpretation was more time consuming, it must be remembered that the result of the work is not only an interpreted map. It is a digital map, ready to be incorporated into a GIS. No extra work more than the digital conversion from one system to another should be needed.

Using the hard-copy method it is very simple to quickly compare the interpretations from one corner of the map to another. This is not easily done using the digital method and in this way the interpretation may change from one corner to another simply because of the inability to compare different areas.

Compared with hard copy interpretation it was monotonous and exhausting to work at the monitor the whole day. If it is decided to go on working with computeraided interpretation on a full scale, it will be very important to look over the ergonomic work environment to be able to create good work conditions. In practical work, the interpretation should be interspersed with other duties. Alternatively, the tasks could be shared by two people during the day.

As an experience from this pilot study it was noted that productive work using the virtual memory option in 4sys is to time consuming and shold be copnsidered as a safety net if the limits of the RAM memory is exceeded. There also has to be a connection between the scale in witch the final result will be presented in and the selection of pixelsize for the digital interpretation. In this case the results are to be presented in 1:50 000 scale and the pixelsize could be set to 20 m even as high as 30 m without loosing any accuracy in the final result. By doing this the each map will fit into the RAM memory installed on the PC's used for this study (16 Mb) and the time for processing data, unpacking and saving maps will drastically decrease. Another problem might also be avoided with this approach - the delineation of to small areas.

The limiting factor for size of the maps (the number of rows and columns) that can be edited with 4sys is the RAM memory can be dealed with in at least two different ways:

I. By more RAM memory. Most of today's PC's can be upgraded with additional memory up to between 32 -128 Mb.

II. Increase the pixel size. Regarding the scale the maps are going to be presented in and the accuracy in the delineation, the pixelsize can be adjusted so the map fits within the RAM memory.

Below is two formulas that can be used as a rule of thumb:

Where:

Mb	Mb in RAM memory.
y	Map size northing in meter.
x	Map size easting in meter.
pix	Pixel size in meter.

To calculate RAM memory needed for a map:

$$Mb = \frac{x \cdot y}{pix^2 \cdot 10^6} \cdot 4$$

Calculate the pixelsize for a certain map so it will fit in to RAM memory:

$$pix = \sqrt{\frac{4 \cdot x \cdot y}{Mb \cdot 10^6}}$$

The time devoted to working on the digital method was not enough to give a concise answer to the question of the usability of the method within INFOR´s work. The general feeling is to go on with the work and decide what steps to take after additional testing.

The goal for the productive work within the project has been an extra burden to carry. As this was a pilot study, the working methods were gradually were refined during the project. However, there was no time to implement the refinements into the interpretation method and restart the interpretation from scratch. On the other hand, the pressure has forced the project along in a high pace.

For the future work there is also an additional way to use the digital method. Instead of buying already made Satellite Orthophoto Maps it is possible to bye low cost precisioncorrected satellite scenes. Use the facilities of 4sys for geometric correction and remove the image displacement due to terrain. By using the facilities in 4sys for image prepossessing the cost for satellite material can decrease. Select the pixelsize according to the accuracy needed in the final result. For this type of interpretation performed at INFOR it should be sufficient with 20 m or 30 m pixels, or in other words use only SPOT XS or Landsat TM data.

Comments on the results of the accuracy test

The evaluation of the accuracy test does not permit the use of percentages of proportional correct as an valid value of correctly classified classes. In many cases, the observations are too few. The confusion matrix can then instead serve as an important source of information for evaluation of the variance in each class. As mentioned, the verifications were made on aerial photos of various scales in which the interpretability or grade of reliability changed. The results can therefore only be regarded, with some probability of course, as indications of the correct classes. The most important questions are therefore; which class are confused with each other, and why.

Looking at the following forest types (classes) some comments can be made:

Roble
This class had only one observation and it was correctly classified.

Renoval de Roble
The class was in most cases correctly classified, but was also confused with Coigüe, Renoval de Coigüe. This is not considered as a major misclassification since the classes by definition are very similar and the border between them is considered as more or less floating. The misclassification into the Plantation class is in this case notable even though the number is very

low. The confusions with Matorral is more easy to understand since the Matorral class has the type of definition that means it is usually confused.

Coigüe
Overall, an easy class that to a large extent is correctly classified. The same confusions are made as in the Renoval de Roble class for the same reason. Confusion with the Araucaria type was found to be insensitive to the characteristic of the Araucaria pattern. Confusion with Lenga may occur when Coigüe is developing in to the Achaparrado subtype.

Renoval de Coigüe
Like Renoval de Roble, Renoval de Coigüe is a class in which the misclassifications into RvR and Coigüe should not be considered as a major misclassification. They are very mixed and do not have a certain border between them.

Araucaria
During the project this class was considered to be a type with certain characteristics and should therefore be comparatively easy to classify. The misclassification into Renoval de Roble was a result of too much generalisation where the Renoval de Roble type was included in a larger area of Araucaria. The small areas of Renoval de Roble were in this case large enough to form a separate stand and should therefore had been delineated. Confusions were also made in the Renoval de Coigüe class

Le
Can also be considered as a class that is easy to define. Confusions are made with Ñirre since they are very similar in composition to the type where the predominant species is hard to define. Coigüe is also found among the confusion classes but may in this case be Coigüe Achaparrado.

Ñirre
Usually easy to define but may, as mentioned, be confused with Lenga.

Ña
Only one observation point, since the class was not very common. This single point was misclassified with Renoval de Roble.

PL
Usually very easy to classify but problems may be faced with the definition of species, except for Pino Oregon which has a different colour in the SPOT data. The class can also be confused with Exploited areas in the case of an expected young plantation. Ganadero, Matorral and Renoval de Roble are also among those classes that may confuse the classification.

EX
This class is easy to see but may easily be confused with areas of young plantations. Areas of NonForestal and Ganadero may also be among the misclassified.

DR
Among three observations, only one was correctly classified. One was confused with Renoval de Coigüe, which is actually possible since several years had passed between the date of the photo and the acquisition of the satellite data. A land slide in that area could therefore quite easily have occured. The NonForestal confusion can be expected due to similarity in the definition of the classes.

Mt
Easily confused with many different classes like Renoval de Roble, Plantations, Exploited areas, Ganadero and NonForestal

G
Can be confused with the same classes as for Matorral, Renoval de Roble, Plantations, Exploited areas, and NonForestal

W
Very easy class as long as the waterbed is big enough. The very dark area may, however, sometimes be confused with shadows from clouds. For visual interpretation this is not really a problem since the corresponding cloud can be detected in almost all cases.

Q
Easily confused with NonForestal because of the definition problem. Both are in many cases large areas with exactly the same radiation, the only difference being the history and land-use.

NF
Can be confused with Ganadero, Landslides (DR) and Exploited areas where probably Ganadero is the main problem. This problem is caused by class definitions overlapping each other. One sample point was incorrectly classified as Lenga in the aerial photo while another point was covered by snow in the imagery and classified as Ñirre in the aerial photo.

When looking at the factors that caused the misclassifications it is obvious that land-use classification is very difficult to complete with a good result. Even though land-use is often of great interest, it is in many cases very difficult to interpret from both aerial photos and satellite imageries. There are many factors that can not be registered in either data source that affect the actual land-use. A land-cover classification should therefore be used instead. From this land-cover classification a later land-use classification can be calculated with some probability.

It should also be noted that after only ten weeks of intensive work with the satellite data it is still a very unknown data source. The comparison with a data source used for more than 30 years is therefore for natural reasons unfair. The full extent of satellite data is still unknown. It will only decrease by the time the data is used. One can therefore expect to find the maximum variance possible in the interpretations done during the project.

Another level of misclassification is the generalisation problem. The hard copy interpretation was generalised too much in some cases thereby making the accuracy worse than it probably would have been if the correct generalisation level had been applied from the beginning.

Comments on the sensor type

Landsat data was used in the Curanilahue area and SPOT data in the Neltume and Malleco area. As already mentioned, these areas are covered by different types of vegetation, where the vegetation in the Curanilahue area is considerably different from the other two areas. It is therefore more or less impossible to make a fair comparison, even though the same types or species may be found in all areas. The comparison is consequently more technical than one based on the interpretability in the different sensors.

With its seven bands, Landsat has a better spectral resolution than SPOT. This increases the possibility to find the optimum band combination. The band combination 4,5,3 makes no difference between Pino Radiata and Eucaliptus, while the secondary growth of Renoval de Roble could easily be delineated from plantations on the basis of the colour. In this band combination, the Landsat imagery is richer with regard to the number of colours. However, the texture information is not as good as for the SPOT imagery.

SPOT-data shows a higher degree of texture information but lacks the ability to change the band combinations. Concerning the vegetation, the SPOT colours are almost entirely shades of red, while the texture information is much greater. The question of which data source should be used might therefore in many cases only be a matter of the task at hand. In reality another parameter might instead be the one which in fact determines what data source should be used - availability!

Conclusions

The first conclusion is that satellite data can be considered as usable for INFOR in both plantations and native forest. This is based on an assumption that the data is used together with auxiliary data sources such as aerial photos. Alone, satellite data will only fulfil some of the requirements, but together with additional data the task may be completed.
The second conclusion is that further investigations must be made in order to find out which satellite data source should be utilised.
The third, and final, conclusion is that the hard copy method proved to be an efficient methodology for the first time interpretation. However, when thinking in terms of updating, the digital method must be used.

APPENDICES

APPENDIX 1

Detailed time schedule of activities

Date	Activity
Mon. March 14	Start of the project. A first meeting at which the project was presented. Aim and goal were discussed. Team members from Chile and Sweden were presented.
Tu. March 15	Planning. Information given on basic biological classification of native forest, tree species and climatic conditions focused on the three study areas.
Wed. March 16	Planning. Information was given on inventory methods used in native forest.
Th. March 17	Planning. Information was given on inventory methods used in plantation forest. Field trip to study areas planned. A table of first contents of the preliminary report was created.
Fri. March 18	Planning. Explanations were given on the types of native forest. Field visit planned.
Sat. March 19	Report writing.
Sun. March 20	Start of the journey to the study areas
Mon. March 21	Visit to the Malleco area. Map sheet Laguna Malleco (G-42).
Tu. March 22	Visit to the Malleco area. Map sheet Laguna Malleco (G-42).
Wed. March 23	Visit to the Neltume area. Map sheet Neltume (G-113).
Th. March 24	Visit to the Neltume area. Map sheet Liquiñe (G-123). Mr Lars Björk returns by bus to Santiago.
Fri. March 25	Visit to the Curanilahue area. Map sheets Maitenrehue (G-26) and Cordillera de Nahuelbuta (G-25). Return to Santiago in the late afternoon. At INFOR in Santiago, Mr Lars Björk prepares and gathers some information for database preparation and later use with the 4sys software.
Sat. March 26	Early arrival to Santiago after the field trip. Mr Lars Björk returns to Sweden
Sun. March 27	Arrival of Mrs Marianne Orrmalm in Santiago. Briefing on current project status. Planning of the visual interpretation part of the project. Report writing
Mon. March 28	Training. Introduction to satellite remote sensing. Satellite platforms, data reception, processing, properties of satellite data, the influence of different wavelength bands for interpretation, different of satellite data products, digital media, etc. Defining the legend.
Tu. March 29	Discussions about the definitions of the legend.
Wed. March 30	Interpretation, Laguna Malleco, Neltume and Maitenrehue

Th. March 31	Interpretation, Laguna Malleco, Neltume and Maitenrehue
Mon. April 4	Interpretation, Laguna Malleco, Neltume and Maitenrehue
Tu. April 5	Discussions about and defining the preliminary legend.
Wed. April 6	Interpretation, Laguna Malleco, Neltume, Maitenrehue and Curanilahue.
Th. April 7	Interpretation, Laguna Malleco, Neltume, Maitenrehue and Curanilahue.
Fri. April 8	Interpretation, Laguna Malleco, Neltume, Maitenrehue and Curanilahue.
Mon. April 11	Discussions about the results so far from the interpretation weeks. Emphasis placed on how to distinguish between different forest types and what the limits in using satellite data. Discussions were also held on interpretations from SPOT versus Landsat.
Tu. April 12	Interpretation of Loncopangue, Cordillera de Pemehue, Choshuenco, Liquiñe, Carampangue
Wed. April 13	Interpretation of Loncopangue, Cordillera de Pemehue, Choshuenco, Liquiñe, Carampangue
Th. April 14	Interpretation of Loncopangue, Cordillera de Pemehue, Choshuenco, Liquiñe, Carampangue
Fri. April 15	Interpretation of Loncopangue, Cordillera de Pemehue, Choshuenco, Liquiñe, Carampangue. Ending the interpretations made on the light tables. Discussions about the results so far. Preparing next week's course on the 4sys software.
Sat. April 16	Mrs Marianne Orrmalm returns to Sweden.
Sun. April 17	Mr Lars Björk arrives in Chile.
Mon. April 18	Preparations are made for the coming 4sys software course. The map-sheet Cordillera de Pemehue is finalised.
Tu. April 19	Start of the 4sys course with six people from INFOR, two from CONAF and two from CIREN. An introduction to 4sys and to the satellite systems was made. Different kinds of raster data were examined, from NOAA data to rasterised black and white aerial photos.
Wed. April 20	4sys course. Photos taken on the earlier field trip were used to give a first impression of how to interpret the satellite data. Lessons were also given on how to use the 4sys program when digitising on the screen.
Th. April 21	4sys course. Revision and updating of existing forest maps. The segmentation technique was presented and tested on the satellite data available.
Fri. April 22	4sys course. Introduction to image processing. Merging of SPOT XS and SPOT P data, filtering, geometric correction using a digital elevation model (DEM) and contrast stretching.
Mon. April 25	4sys course. Classification of segments. Database administration. This was the final day of the 4sys course.

Tu. April 26	Productive work on the 4sys software. Data preparation of the remaining map sheets, Cordillera de Nahuelbuta (G-25), Bío Bío (G-42) and Pullingue (G-112). Building map libraries, copying data from the CD-ROM and making 4sys data files. Information was also given on what kind of information could be found in the digital data files on the CD-ROM delivered by SSC Satellitbild.
Wed. April 27	Productive work on the 4sys software. Preparations and adjustments were made to optimise the performance of the segmentation. Segmentation was also made. Discussions about and planning of the coming accuracy test.
Th. April 28	Productive work with the 4sys software. Defining the optimum segmentation parameters for the different data sources and areas. The segmentation process was started at the end of the day and was completed during the night for the Cordillera de Nahuelbuta (G-25), Bío Bío (G-42) and Pullingue (G-112) map-sheets.
Fri. April 29	Productive work on the 4sys software. Interpretation and editing of the previously made segmentations.
Mon. May 2	Productive work on the 4sys software. Interpretation and editing of the previously made segmentations. Preparation for the classification and for the accuracy test.
Tu. May 3	Productive work on the 4sys software. Interpretation and editing of the previously made segmentations.
Wed. May 4	Productive work on the 4sys software. Interpretation and editing of the previously made segmentations.
Th. May 5	Productive work on the 4sys software. Defining the 4sys database. Labelling the previously interpreted areas.
Fri. May 6	Productive work on the 4sys software. Labelling the previously interpreted areas. Systematic sampling in the areas where the hard copy interpretation was performed.
Mon. May 9	Productive work on the 4sys software. Labelling the previously interpreted areas. Systematic sampling.
Tu. May 10	Productive work on the 4sys software. Labelling the previously interpreted areas. Systematic sampling. Preparations for the interpretability assessment.
Wed. May 11	Systematic sampling. Preparations for the interpretability assessment. Report writing.
Th. May 12	Productive work on the 4sys software. Labelling the previously interpreted areas. Systematic sampling. Preparations for the interpretability assessment. Report writing
Fri. May 13	Preparations for and processing of the data gathered via the systematic sample. Report writing.
Sat. May 14	Processing of the data gathered via the systematic sample. Report writing. Preparations for the stratified sample. Report writing.

Sun. May 15	Report writing. Preparations for the stratified sample
Mon. May 16	Stratified sampling in the areas interpreted in 4sys. Report writing
Tu. May 17	Stratified sampling in the areas interpreted in 4sys. Processing of the data gathered during the stratified sampling. Report writing
Wed. May 18	Evaluation of the project.
Th. May 19	Evaluation of the project.
Fri. May 20	Evaluation of the project. Final discussion.

APPENDIX 2

Team members

The INFOR team members consisted of the following persons:

Mr Patricio González Díaz
Mr Sergio Fuenzalida Avila
Mr Sergio Cortés Riquelme
Mr Marcos Cohen Iturra
Mr Carlos Bahamondez Villarroel
Mr Jaime Valenzuela Lambert
Mr Claudio Bermúdez Chandía

The team members from Sweden consisted of the following persons:

Mrs Marianne Orrmalm, SSC Satellitbild
Mr Lars Björk, ForeSys
Mr Anders Persson, project manager, SSC Satellitbild

APPENDIX 3

Application criteria for interpretation of Landsat TM imagery

(Spectral bands 4,5,3 in the order Red, Green and Blue; scale of interpretation 1:50,000)

Code	Int.	Notes
W - Water	1	As long as the area of water is large enough this class is easy to interpret. Black for deep water or lilac in areas with shallow water. Rivers with a lot of sediments in the moving water will show a colour that is almost light blue; could be mixed with cloud shadow.
NF - Other	2	A very complex class witch includes a lot of different landuse giving totally different signatures. It is important to interpret the location of the actual area, whether it is at high or low altitude, close to roads, in a flat or steep location, etc.
PL - young forest	3	Newly planted forest is very difficult to see. Young forest is difficult to differentiate from the young secondary growth.
PL - old forest	1	Usually easy to see because of the very dark colours.
Native Forest	1- 2	Old easy, young problems. .
Primary forest	1 - 2	
Secondary growth		Colour orange, clear brownish, irregular texture
Ex - Clear cuts	1 - 2	Could be mixed with and young plantations.
Dr - Land slides	1	Usually very easy, can be mixed with NF.
G - Pastures	1	Since this class is very mixed could be mixed with Mt and NF. Bluish, generally, yellow in small areas. The bluish areas do not have straight lines or borders. They are all in irregular forms that give them a higher possibility of being a pasture.
Q - Burnt areas	1 - 2	Light blue.
PO - Pino oregon	2 - 3	A clear, soft and intensive red colour is connected to this species. The areas are usually small. It may be very difficult to see the difference from RvRa.
PR	3	Very difficult to distinguish from EU
Ñi - Ñirre	1	Light orange colour, usually easy.
Le- Lenga	1	High altitude makes it easy. Red colour.
Cg - Coigüe type	1	Old Coigüe type is usually easy to see. Dark grey, almost black. Composed of a lot of tolerant species. A high amount of understorey gives these dark colours.
R - Roble type		Composed of a lot of intolerant species, giving a dark red to red colour in the images.

Rv Cg - Secondary growth of Coigüe.	3	
Rv Ro versus Rv Ra	2,3	Difficult to distinguish.
Age classes	1	I - red, II-brown, III - dark brown
Mt - Scrubs and Bushes	1	Easy to see when using the Panchromatic information together with the Landsat imagery. The colours are the same as fore the Rv.

The use of SPOT panchromatic data is essential to obtain a better interpretation of the Landsat data. The experience from the interpretation was also that it was much more easy to work with Panchromatic data than the false colour data in the areas of plantations.

APPENDIX 4

Application criteria for interpretation of SPOT XS + P imagery

(Spectral bands 3,2,1 in the order Red, Green and Blue; scale of interpretation 1:50,000)

Code	Int.	Notes
W - Water	1	As long as the area of water is large enough this class is easy to interpret. Black for deep water or lilac in areas with shallow water. Rivers with a lot of sediments in the moving water will show a colour which is almost light blue. Could be mixed with clouds shadow.
NF - Other	2	A very complex class witch includes a lot of different landuse giving totally different signatures. It is important to interpret the location of the actual area, whether it is at a high or a low altitude, close to roads, in a flat or steep location, etc.
PL - young forest	3	Newly planted forest is very difficult to see. Young forest is difficult to differentiate from the young secondary growth.
PL - old forest	1	Usually easy to see because of the very dark colours and very smooth texture and the regular borders.
Native Forest	1,2	Relatively easy to distinguish from plantations by irregular borders.
Primary forest	1,2	Relatively easy to see because of the thick texture and dark grey colour.
Secondary growth	1,2	Young Rv can be mixed with young plantations.
Ex - Clear cuts	1,2	Could be mixed with G and young plantations.
Dr - Land slides	1	Usually very easy, may be mixed with NF
G - Pastures	2	Since this class is very mixed, it could be mixed with Mt and NF.
Q - Burnt areas	1,2	Usually easy to see when the area has been burnt recently. Sometimes confused with NF.
PO - Pino Oregon	2,3	A clear, soft and intensive red colour is connected to this specie. The areas are usually small. It may be very difficult to see the difference from RvRa.
PR - Pino Radiata	3	Old Pino Radiata is dark, almost black while younger compartments shows a lighter red colour. The species can be mixed with EU.
Ñi - Ñirre	1	Soft pink colour, usually easy.
Ar - Araucaria	1	In high altitude areas with a typical colour, brownish, yellow
Le - Lenga	1	High altitude makes it easy. Red colour.

Cg - Coigüe type	1	Old Coigüe type is usually easy to see. Dark grey, almost black. Composed of a lot of tolerant species. A large amount of understorey gives these dark colours.
R - Roble type	1,2	Composed of a lot of intolerant species, giving a dark red to red colour in the images.
RvCg - Secondary growth of Coigüe.	3	In areas where Coigüe is the colonising species, e.g. land slides, volcanic ashes or lava, etc., this class is relatively easy to identify. Red colour but less intensive than Lenga
RvRo versus RvRa	1	In areas of more Roble the colour is more red - brownish which makes it possible to distinguish it from secondary growth of Raulí
Age classes	1	I - red, II-brown, III - dark brown
Mt- Scrubs and bushes	2,3	Easily confused with RvRo, young plantations, EX, G and NF

APPENDIX 5

Legend description

NON-FORESTRY

All areas covered with non-woody vegetation. Also includes all areas without any kind of vegetation on soils that are not suitable for forestry, such as urban, agriculture, rocky sandy, wetlands, water or snow, etc.

W **Water**
Includes large open natural water bodies, major lowland rivers and man-made reservoirs, controlled by dams.

NF **Other non-forestry areas**
Includes agricultural land, wetlands, urban areas and non-productive lands such as the tops of mountains and rocky areas.

FORESTRY

Includes all areas suitable for forestry covered with woody vegetation or areas lacking vegetation as a result of human activities or natural causes.

<u>Woody vegetation</u>
Forestry areas with woody vegetation

Native forest
Areas of woody vegetation naturally tree-covered with native trees forming forest types. The native forest types are forest formations developed or distributed in a specific way categorised by, in the upper level, the presence or predominance of a species or a typical composition of several species.

Primary forest
Native forest in which the majority of the trees are composed of old trees.

R **Roble-Raulí-Coigüe**
Primary forest composed of the forest type Roble-Raulí-Coigüe.

Cg **Coigüe-Raulí-Tepa**
Primary forest composed of the forest type Coigüe-Raulí-Tepa.

CgRa **Coigüe-Raulí**
Primary forest composed of the forest type Coigüe-Raulí-Tepa with a predominance of Coigüe over Raulí.

RaCg **Raulí-Coigüe**

Primary forest composed of the forest type Coigüe-Raulí-Tepa with a predominance of Raulí over Coigüe.

Ar **Araucaria**
Primary forest composed of the forest type Araucaria with purely Araucaria trees.

ArLe **Araucaria-Lenga**
Primary forest composed of the forest type Araucaria with Araucaria trees mixed with Lenga trees.

ArLeCg **Araucaria-Lenga-Coigüe**
Primary forest composed of the forest type Araucaria with a mixture of Araucaria trees together with Lenga and Coigüe trees.

ArÑi **Araucaria-Ñirre**
Primary forest composed of the forest type Araucaria with Araucaria trees mixed with Ñirre.

Le **Lenga**
Primary forest composed of the Lenga forest type with purely Lenga trees.

LeÑi **Lenga-Ñirre**
Primary forest composed of the Lenga forest type with a mixture of Lenga and Ñirre trees.

LeCg **Lenga-Coigüe**
Primary forest composed of the Lenga forest type with a mixture of Lenga and Coigüe trees.

Ñi **Ñirre**
Primary forest composed by the Ñirre forest type with purely Ñirre trees.

ÑiLe **Ñirre-Lenga**
Primary forest composed of the Ñirre forest type with a mixture of Ñirre and Lenga trees.

Ña **Ñadis**
Primary forest composed mainly of Coigüe, Canelo and Mirtáceas species.

Secondary forest
Native forest where previously cutting activities have resulted in a composition of young trees.

RvR **Renoval de Roble-Raulí-Coigüe**
Secondary forest of Roble-Raulí-Coigüe forest type.

RvRoRa **Renoval de Roble-Raulí**
Secondary forest of Roble-Raulí-Coigüe forest type where Roble predominates over Raulí.

RvRaRo **Renoval de Raulí-Roble**
Secondary forest of Roble-Raulí-Coigüe forest type where Raulí predominates over Roble.

RvRo **Renoval de Roble**

Secondary forest of Roble-Raulí-Coigüe forest type where Roble predominates.

RvRa **Renoval de Raulí**
Secondary forest of Roble-Raulí-Coigüe forest type where Raulí predominates.

RvCg **Renoval de Coigüe**
Secondary forest of Coigüe-Raulí-Tepa where Coigüe predominates (almost pure Coigüe).

RvCgRa **Renoval de Coigüe-Raulí**
Secondary forest of Coigüe-Raulí-Tepa where Coigüe predominates over Raulí.

RvRaCg **Renoval de Raulí-Coigüe**
Secondary forest of Coigüe-Raulí-Tepa where Raulí predominates over Coigüe.

Man made forest
Areas planted with Pino radiata, Eucaliptus, Pino oregon, Alamos or other exotic species.

PR **Pino radiata**
Man made forest of Pino radiata.

EU **Eucaliptus**
Man made forest of Eucaliptus.

PO **Pino oregon**
Man made forest of Pino oregon.

AL **Alamos**
Man made forest of Alamos.

OE **Otras especies**
Man made forest of other species.

MT **Matorrales**
Woody vegetation, dominated by species not forming trees. 50 - 100% coverage of bushes and trees.

Open areas
Forestry land, presently without a productive woody vegetation or with a woody vegetation covering less than 10%.

EX **Explotado**
Open areas where practically all woody vegetation has been extracted. Includes clear cuts and other exploited areas.

DR **Derrumbes**
Open areas caused by erosion.

G Ganadero

Usually open areas, but sometimes also an area covered by woody vegetation. Previously cut, now extensively used for cattle grazing. 0 - 50% coverage of bushes and trees.

Q Quemado

Areas destroyed by fire, now open areas which, however, could also be covered with destroyed vegetation.

APPENDIX 6

Scientific names of the tree species

Chilean name	Scientific name
Araucaria	Araucaria araucana
Arrayán	Mirceugenella apiculata
Avellano	Gevuina avellana
Canelo	Drimys winteri
Coigüe	Nothofagus dombeyi
Coligüe	Chusquea coleu
Laurel	Laurelia sempervirens
Lenga	Nothofagus pumilio
Lingue	Persea lingue
Luma	Amomyrtus luma
Mañio de hojas cortas	Saxegothaea conspicua
Meli	Amomyrtus meli
Ñirre	Nothofagus antarctica
Olivillo	Aextoxicon punctatum
Pitra	Myrceugenia exsucca
Quila	Chusquea quila
Raulí	Nothofagus alpina
Roble	Nothofagus obliqua
Tepa	Laurelia philippiana
Tineo	Weinmannia trichosperma
Trevo	Dasyphyllum diacanthoides
Ulmo	Eucryphia cordifolia

APPENDIX 7

Daily programme for the visit to SSC Satellitbild

Sunday, February 6

Time	Activity	Responsible
17.25	Pick up at Kiruna Airport. Dinner	APE
19.30	Arrival at Hotel Samegården	

Monday, February 7

Time	Activity	Responsible
8.15	Visit to Samegården Museum. A guide to the scandinavian lifestyle.	Bengt Unga
9.00	Introduction to SSC Satellitbild	APE
9.30	Presentation of SSC Satellitbild	ALF
10.00	Coffee	
10.15	Presentation of Instituto Forestal	Rolando Bennewitz
11.30	Lunch	
13.00	Visit to Esrange. Satellite TT&C and receiving station, rocket launching facilities and TELE-X control.	Esrange

Tuesday, February 8

Time	Activity	Responsible
8.30	Data search, Quick-looks, the CatEye system	JEK
9.00	Archiving and standard production	TLX
10.00	Coffee	
10.15	SSC Satellitbild's model for radiometric and geometric precision correction of satellite data.	TW
12.00	Lunch	
13.00	Image processing and satellite data correction in the production environment	LAR
14.00	Coffee	
14.15	DEM (Digital Elevation Model) generation from SPOT imagery	DKL
14.45	Change detection maps. A recently developed product from SSC Satellitbild.	PER
15.00	Digital classification. An example of a digital terrain type classification of Sweden	UMA/MOR
16.00	Satellite data for forest planning, visual interpretation, satellite data and GIS	APE

Wednesday, February 9

Time	Activity	Responsible
8.00	Satellite data for forest ... Continued	APE
10.00	Coffee	
10.15	Introduction to 4sys. Discussion about the INFOR implementation.	Lars Björk
12.00	Lunch	
13.00	4sys implementation. Continued	Lars Björk

14.00	Coffee	
14.15	4sys implementation. Continued	Lars Björk

Thursday, February 10

Time	Activity	Responsible
8.00	Project management and project planning. Continued.	APE
9.00	Photo laboratory. from digital product to high quality photographic media.	MEX
10.00	Coffee	
10.15	Project management and project planning. Continued.	APE
12.00	Lunch	
13.00	Project management and project planning. Continued.	APE
14.00	Coffee	
14.15	Project management and project planning. Continued.	APE

Friday, February 11

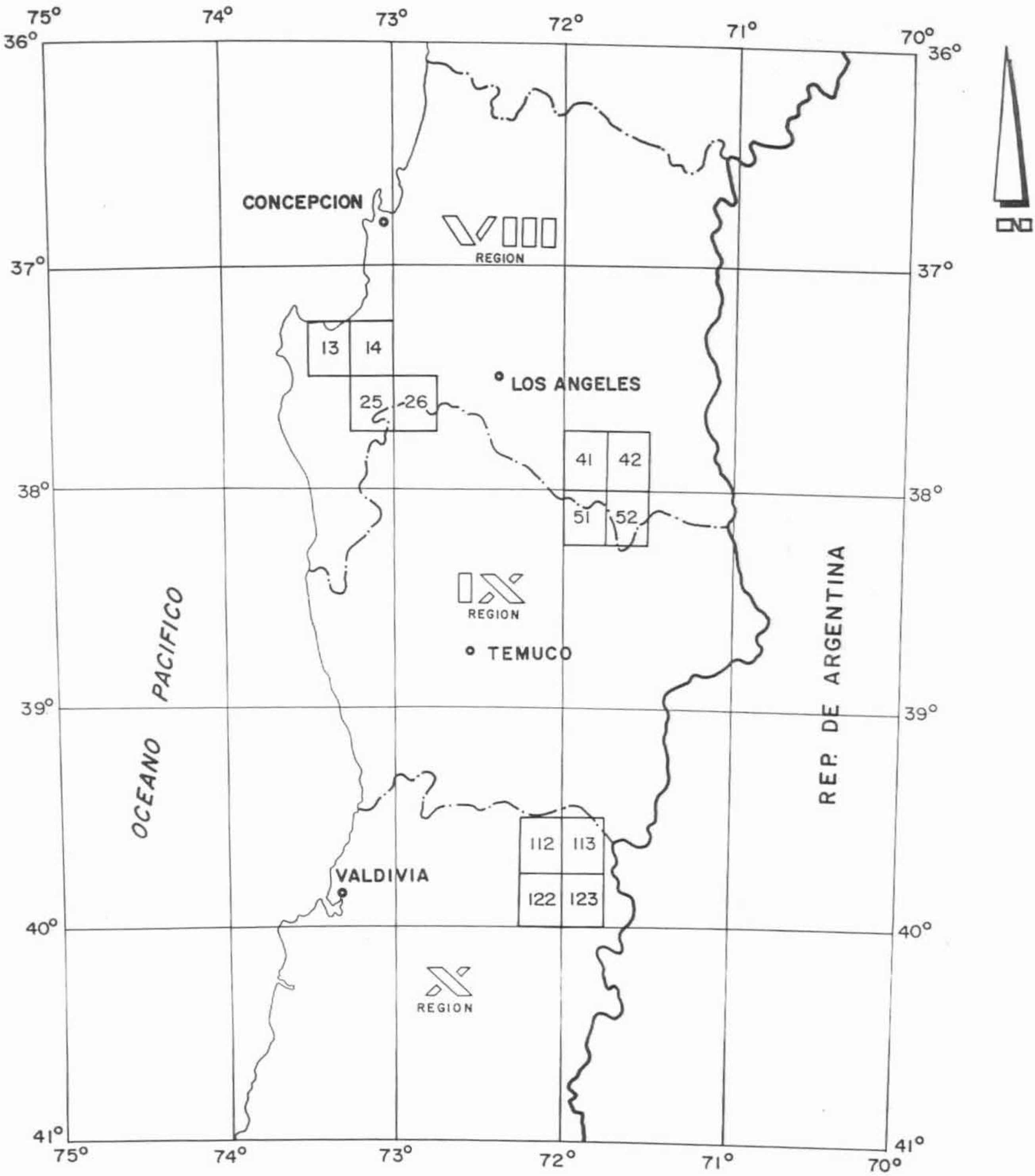
Time	Activity	Responsible
8.00	Project management and project planning. Continued.	APE
10.00	Coffee	
10.15	Project management and project planning. Continued.	APE
12.00	Lunch	
13.00	Project management and project planning. Continued.	APE
14.00	Coffee	
14.15	Project management and project planning. Continued.	APE

Saturday, February 12

Time	Activity	Responsible
12.00	Pick up at Hotel and transport to Kiruna Airport	JÖR
12.55	Departure from Kiruna to Stockholm	
14.30	Arrival at Arlanda Airport in Stockholm	

APPENDIX 8

Location of the project areas



APPENDIX 9

4sys plotted map (an example)

Laguna Malleco G-42