# AERIAL SKETCHMAPPING FOR MONITORING FOREST CONDITIONS IN SOUTHERN BRAZIL

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## ABSTRACT

Aerial sketchmapping is a simple, low cost remote sensing method used for detection and mapping of forest damage caused by biotic agents (insects, pathogens and other pests) and abiotic agents (wind, fire, storms, hurricane, ice storms) in North America. This method was introduced to Brazil in 2001/2002 via a USDA Forest Service/EMBRAPA technical exchange program, which included demonstration flights, a feasibility study, workshops, production of satellite maps, observer training and operational flights, primarily for assessment of damage caused by European wood wasp (*Sirex noctilio*), monkeys (*Cebus nigritus*), armillaria root disease (*Armillaria* spp.), and other damaging agents in pine plantations in Southern Brazil. New applications have been investigated in the most recent campaigns, carried out in 2003 and 2004. These include the use of this technique to monitor land use changes, evaluate the accuracy of classifications from satellite imagery, and to classify successional phases in remnants of *Araucaria angustifolia* forests in Southern Brazil. The operational flights have demonstrated that clearcuts, land use change detection and other anthropogenic activities may be suitably mapped and monitored from the air. Future activities are aimed at consolidation of this technique in Brazil, the identification of other damage signatures, such as those caused by the eucalyptus red gum lerp psyllid (*Glycaspis brimblecombei*), and the use of digital aerial sketchmapping methods.

**Key Words:** aerial sketchmapping, environmental monitoring, forest damage, remote sensing, Brazil, *Sirex noctilio*, *Cebus nigritus*, *Armillaria* spp, *Glycaspis brimblecombei*

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## THE AERIAL SKETCHMAP PROGRAM IN BRAZIL

Aerial sketchmapping is the oldest and most widely used remote sensing tool for forest health assessment in North America (CIESLA, 2000). This is a relatively simple and low cost method of monitoring forest condition. Trained observers, working in low-flying aircraft generally at a flying height between 300 and 800 meters above ground level, locate areas of tree mortality or foliar injury and "sketch" those locations onto maps as coded points or polygons according to predetermined classification schemes. Resultant data are used to monitor pest damage, initiate salvage harvesting, plan pest management operations and develop historic databases on the occurrence and severity of forest insect and disease outbreaks (CIESLA and others, 2002).

This approach to forest health assessment has potential value in southern Brazil, due to the existence of large areas of pine and eucalyptus plantations (about 2.7 million acres), where the presence of an insect or disease might cause widespread damage. These fast growing forests provide raw material for pulp, paper and wood products industry, supplying both domestic and export markets and thus play a key role in the regional economy.

The first infestations by the European wood wasp (*Sirex. noctilio*) were reported in 1988 (IEDE and others, 1988) in Rio Grande do Sul – the southernmost State – and presently the insect is known to have spread also to Santa Catarina and Paraná States (DISPERATI and others, 1998). In 1998 a technical exchange agreement was celebrated between USDA Forest Service and the Brazilian Agricultural Research Agency (EMBRAPA), thus providing the basis for the development of an aerial sketchmap program oriented primarily to assessment of damage caused by *S. noctilio*, but also for other forest pests in pine plantations in Brazil's three southernmost states: Paraná, Santa Catarina and Rio Grande do Sul. The following activities have been carried out:

- **Demonstration flights** – About 2,400 hectares of *Pinus taeda* plantations were flown over by an Aero Boero 115 aircraft, from which the mapping of various levels of tree mortality caused by *S. noctilio* was done (CIESLA et al, 1999)..

- **A feasibility study** – The study concluded that aerial sketchmapping was indeed feasible in southern Brazil due to: low costs (similar to those in North America); aerial visibility of damaging agents; availability of satellite maps for aerial sketchmap surveys; an interest on the part of EMBRAPA and representatives of forest industry to look into the implementation of this technology; and a potential capability to detect and map damage caused by forest pests other than the European wood wasp.

- **Production of aerial survey maps** – The traditional topographic maps used in North America were substituted by satellite maps in Brazil, produced from Landsat 7 ETM data with varying scales (1: 100,000; 1:50,000; 1:25,000), printed in a band 543 (RGB) configuration, which resembled a natural color image or in 453 (RGB) – false color. The maps were overlaid with a 4 km UTM grid, major roads, drainages and the polygons of pine plantations.

- **Training of aerial observers** – During the period 8-12 April 2002, in Brazil, twelve trainees, representing EMBRAPA (6 trainees), private industry (3), a non-government organization (NGO) (1), Universidade Federal do Paraná (1) and a pilot attended aerial sketchmap classes and took part on training flights, mapping damage caused by several damaging agents. On July of the same year a member of the EMBRAPA team was trained in USA, taking part ion a 2-week aerial survey to detect forest insect and disease damage in Colorado State.

- **Workshop** – A technical workshop held in Curitiba, Brazil, on November 22 – 23, 2003, brought together USDA Forest Service aerial sketchmappers, the EMBRAPA team and the Paraná State Government staff in order to discuss the potential use of aerial sketchmapping techniques and other remote sensing approaches in the so called "Paraná Biodiversity Project", which is related to the conservation of native forests in Paraná State.

- **Operational flights –** Operational flights were conducted immediately after the first training period and since then many flight campaigns have been carried out. The approaches, objectives and results of these surveys are described and discussed in this paper.

## OPERATIONAL FLIGHTS

Three operational flight campaigns were carried out by the USDA Forest Service/EMBRAPA team during the years 2002, 2003 and 2004 (**Table 1**). In 60.5 hours of flight, the surveys covered an area of more than one million hectares, which, in fact, corresponds to 5% of the area of Paraná State (**Figure 1**). The same Cessna 185 aircraft used for the observer training was also used for operational aerial sketchmap surveys (**Figure 2**). All surveys were flown using the grid method. Flight lines were established at 4 km intervals and observers mapped a 2 km wide swath. A Garmin GPSMAP 295 Global Positioning System (GPS) receiver (**Figure 3**) was used to help the pilot keep the survey aircraft on the flight lines and to facilitate location of beginning and ending points of flight lines.

Table 1 – Characterization of aerial sketchmapping flight campaigns in Southern Brazil

| Flight region | Area (ha) | Objectives | Flight duration (hours) | Date |
|---|---|---|---|---|
| Palmas/União da Vitória - PR | 379,200 | Forest damage assessment (wood wasp, monkey); accuracy assessment of satellite imagery visual interpretation | 32 | April, 2002 |
| Pitanga - PR | 35,200 | Forest damage assessment (wood wasp, *Armillaria* spp); accuracy assessment of satellite imagery visual interpretation | 3 | April, 2002 |
| Caçador - SC | 57,600 | Classification of *Araucaria angustifolia* (Parana-pine) cover classes in remnants of *Araucaria angustifolia* forests | 3 | April, 2002 |
| Abapã - PR | 108,800 | Forest damage assessment (wood wasp); accuracy assessment of satellite imagery visual interpretation | 5 | June, 2003 |
| Rio Branco do Ivaí - PR | 41,600 | Forest damage assessment (wood wasp); accuracy assessment of satellite imagery visual interpretation | 3.5 | June, 2003 |
| Rio dos Touros - PR | 48,000 | Discrimination of different successional phases in remnants of *Araucaria angustifolia* forests; accuracy assessment of satellite imagery classification | 3 | June, 2003 |
| Mangueirinha Indian Reserve - PR | 64,000 | Discrimination of different successional phases in remnants of *Araucaria angustifolia* forests; accuracy assessment of satellite imagery classification | 2 | June, 2003 |
| São Mateus do Sul - PR | 216,000 | Detection of afforestation in remnants of *Araucaria angustifolia* forests; forest damage assessment (wood wasp, monkey); accuracy assessment of satellite imagery visual interpretation | 4.5 | April, 2004 |
| Guarapuava - PR | 216,000 | Detection of afforestation in remnants of *Araucaria angustifolia* forests; forest damage assessment (wood wasp, monkey); accuracy assessment of satellite imagery visual interpretation | 4.5 | April, 2004 |
| TOTAL | 1,166,400 | | 60.5 | |

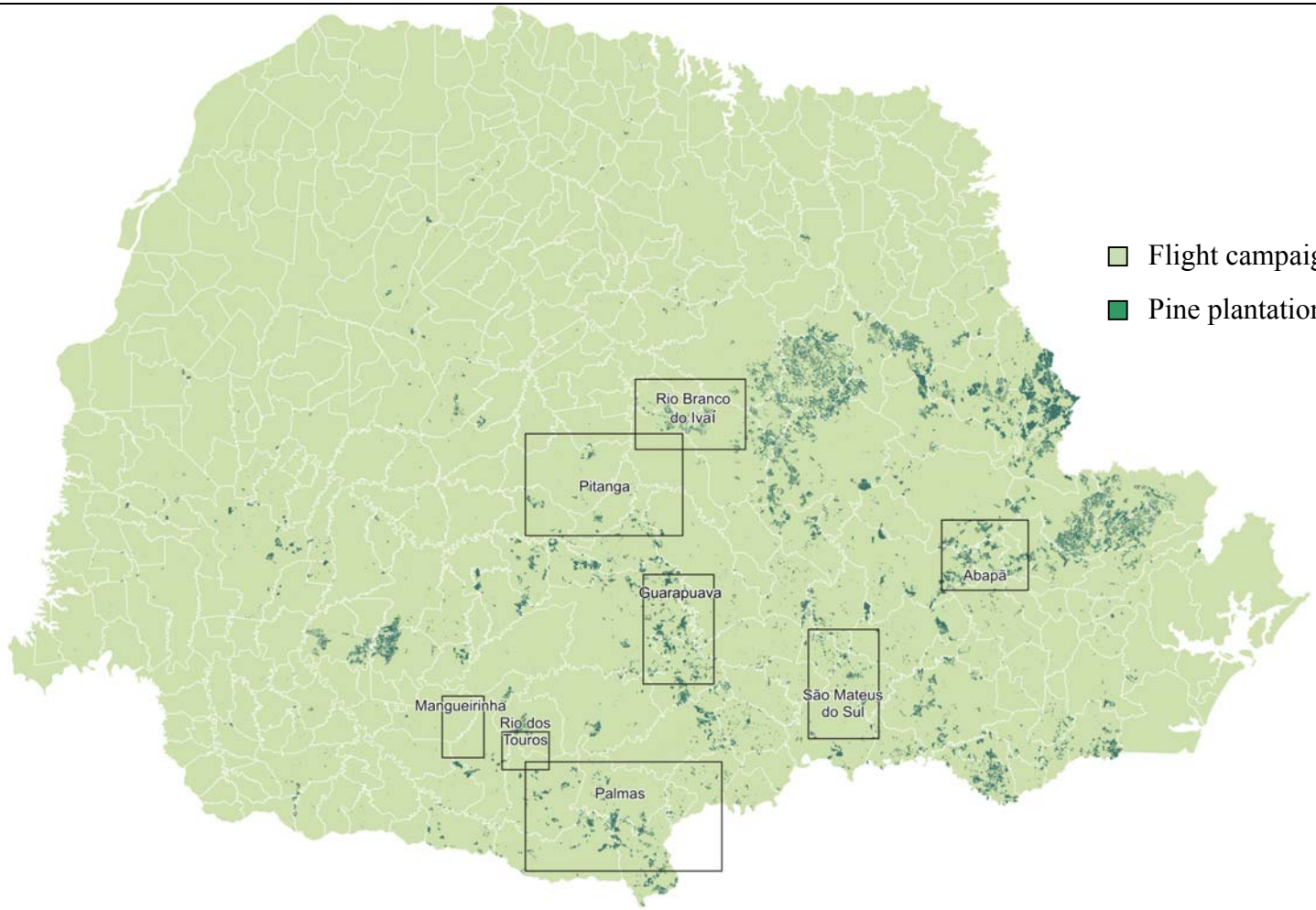


Figure 1 - Flight Campaign Areas in Parana State

Figure 2 – Cessna 185 Aircraft Used for Both Observer Training and Operational Aerial Sketchmap Surveys in Southern Brazil.

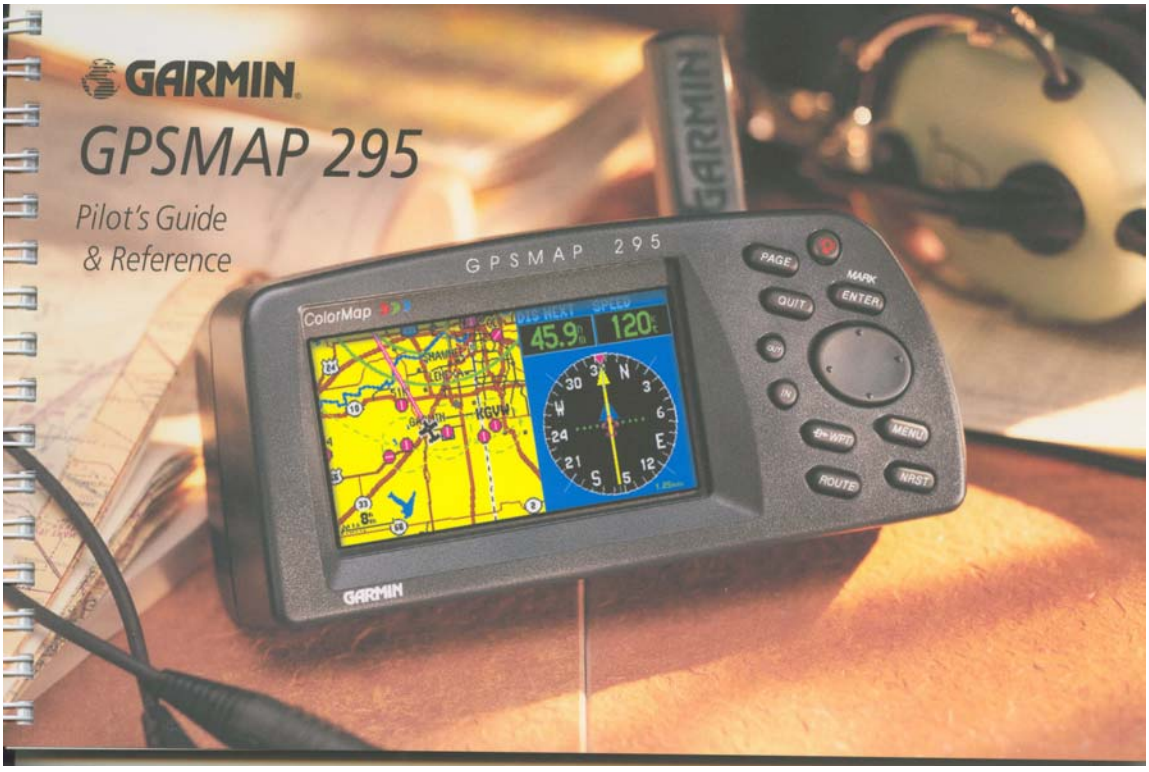


Figure 3 – The Garmin GPSMAP 295 Global Positioning System (GPS) Receiver Used in Aerial Sketchmap Surveys

**Surveys for Forest Damage Detection and Thematic Accuracy Assessment**

In surveys whose objectives were the assessment of forest damage in pine plantations and also the accuracy of satellite imagery visual interpretation, flight lines were established in such a manner as to include all areas classified as pine plantations and eliminate non-pine-forested areas (**Figure 4**). Universal Transverse Mercator (UTM) coordinates of each flight line beginning and end point were entered into the GPS.

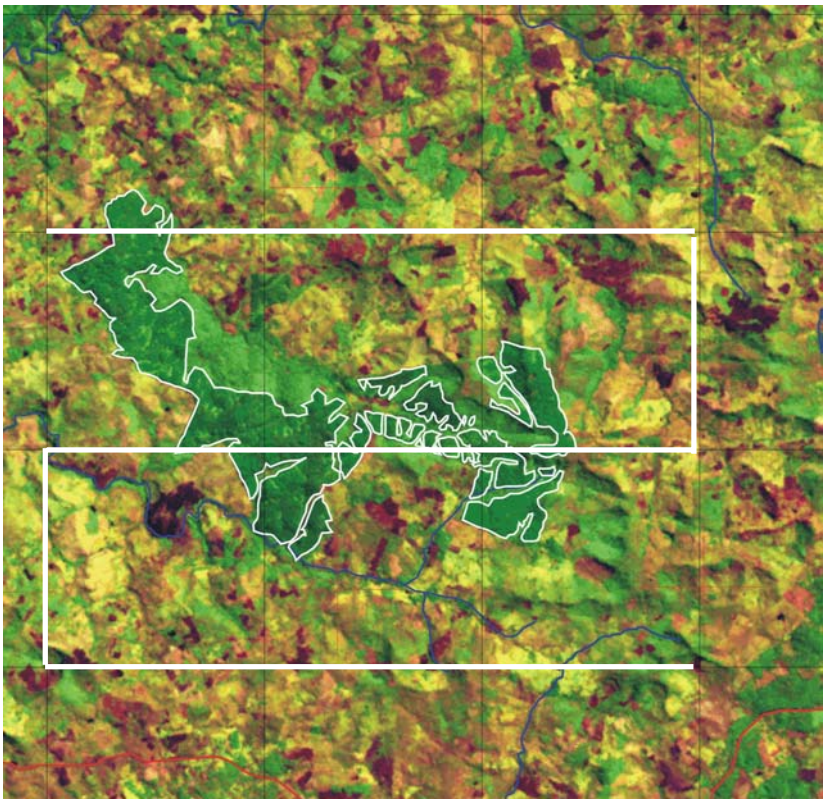

Figure 4 – Flight Lines Established on Satellite Map

CIESLA and others (2002) describe a number of damage signatures detected and mapped in the 2002 flight campaign:

1. Scattered tree mortality in pine plantations suggestive of infestations of *Sirex noctilio.*

2. Top kill in both pine and *Araucaria* plantations suggestive of damage caused by indigenous monkeys. This is a relatively new problem in southern Brazil.

3. Yellowing or chlorosis in pine plantations. This may be associated with either soil nutrient deficiencies and/or root disease caused by a species of *Armillaria.*.

4. Small group kills of 5-20 trees in pine plantations. These resemble the classic signature associated with bark beetle infestations in North America.

A provisional coding system was developed for the prevailing forest damage types in Brazil and included host, damage type and intensity of damage. This system was slightly modified during the 2003 surveys as Brazilian aerial sketchmappers gained more experience and became more familiar with conditions in their country (**Table 2**). Future modifications may include a new code for the eucalyptus red gum lerp psyllid.

Table 2 – Coding system for Aerially Visible Forest Damage Signatures in Southern Brazil

| **Host/code** | **Damage type/code** | **Damage intensity (% of trees affected in plantation or polygon)/code** |
|---|---|---|
| *Araucaria angustifolia*/**Au** | Monkey/2 | Light (<5%)/**L**<br>Heavy (≥ 5%)/**H** |
| *Pinus spp*/**Pi** | Wood wasp/1<br>Monkey/2<br>Armillaria/3<br>Cinara spp/4<br>Defoliation/5<br>Chlorosis or yellowing/6 | Same as above<br>Same as above<br>Same as above<br>Same as above<br>Same as above<br>Same as above |
| *Eucalyptus spp*/**Eu** | Chlorosis or yellowing/6 | Light (<5%)/**L**<br>Heavy (≥ 5%)/**H** |

Following the completion of the aerial surveys, damage polygons were transferred to mylar overlays, which were scanned, georeferenced and vectorized for entry into the EMBRAPA Geographic Information System (GIS), including the damage signature information as tabular data.

The results of the aerial surveys regarding forest damage were checked through ground surveys. **Table 3** shows omission and commission errors found for the flights over the region of União da Vitória and Pitanga, in Paraná State. The general accuracy for the survey achieved 91.43%. However, about 40% of the stands damaged by monkeys could not be detected by the aerial survey. The same happened to the stands injured simultaneously by monkey and wood-wasp, fifty percent of them being omitted. All the stands attacked by the wood-wasp have been discriminated, while 10.71 % of the stands annotated as damaged by wood-wasp belonged, actually, to other damage classes.

Table 3 – Omission and Commission Errors Related to the Causal Agent as Determined by Aerial Sketchmapping Surveys

| Causal agent | Omission error (%) | Commission error (%) |
|---|---|---|
| Wood wasp | 0 | 10.71 |
| Monkey | 40 | 0 |
| Wood wasp/monkey | 50 | 0 |
| Chlorosis | 0 | 0 |

A final forest damage map for the region of União da Vitória, Paraná State, is shown in **Figure 5**. The GIS environment allows the selective display of all information collected during the aerial survey. As new flights are performed, one can add new information to the database. Further spatial analyses may help develop a spatial distribution pattern for certain forest pests, as well as risk maps.

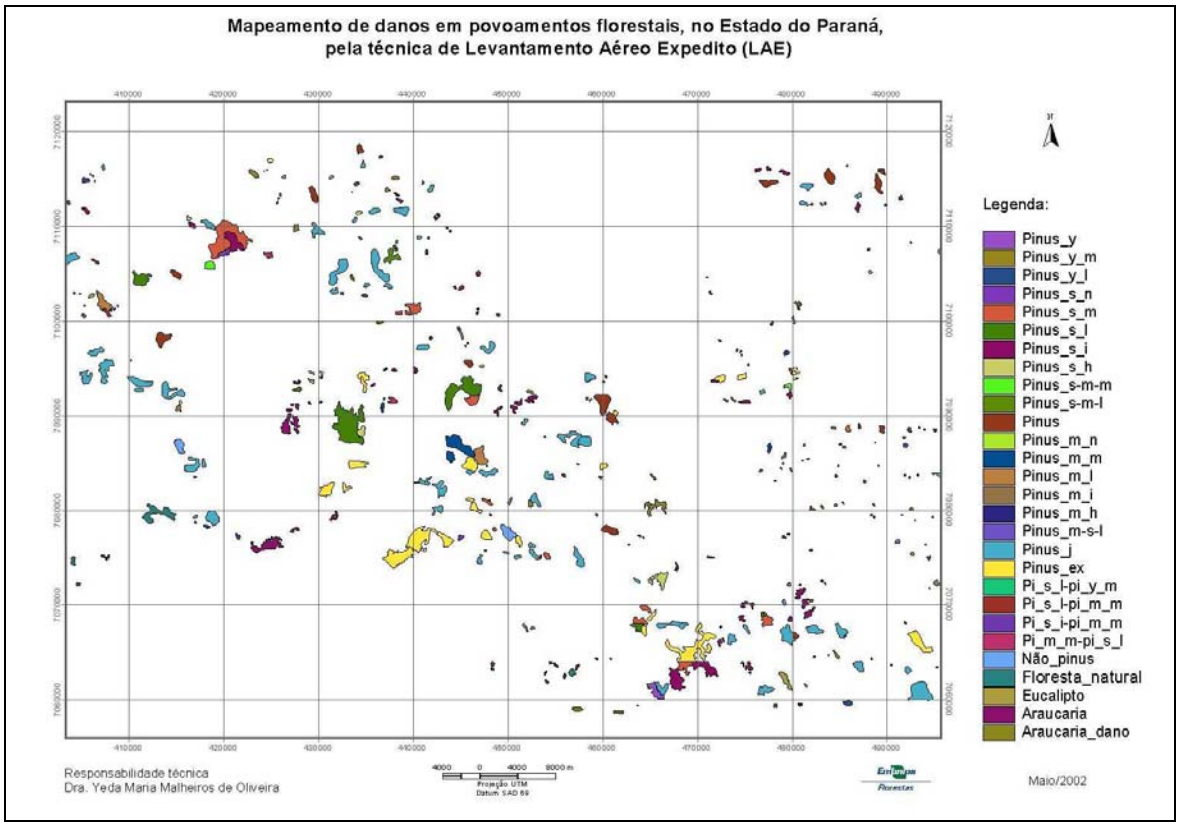


Figure 5 – Forest Damage Map Resulting from an Aerial Sketchmap Survey Over the Region of União da Vitória – Paraná State

Although the visual interpretation of satellite imagery has proved to be the most efficient method of mapping pine plantations in Southern Brazil (ROSOT and others, 2003), the assessment of thematic accuracy demanded heavy economic and personal resources due mainly to the need of several trips in order to get reliable ground data in forest plantations. As the EMBRAPA team decided to produce satellite maps for the training of aerial observers, they realized that the aerial sketchmap survey could be used as an opportunity to check the accuracy of the pine classification. The sketchmapper should, thus, be responsible for the observation of forest damage as well as for the checking of forest type, which was easily done. The most frequent classification errors included:

- omission errors: non-classified young plantations, less than 8 years old; non-classified small pine plantations (1-5 years old);
- commission errors: natural and planted Araucarian forests; eucalyptus plantations.

The accuracy assessment was performed in GIS environment on a polygon basis, i.e., the ground control points were represented by the centroids of “ground truth” polygons. For the region known as Abapã it was found that the visual interpretation of satellite imagery ommited 10.74% of the existing pine stands. On the other hand, 2.4% of the polygons assigned to the "pine class" belong actually to other vegetation classes on the ground. For this region the overall accuracy equaled 87.46%, which is rather good considering average accuracies around 80 % for automatic classification of Landsat imagery (COLEMAN and others, 1990; CAMPBELL, 1996).

**Surveys for the Discrimination of Different Successional Phases in Remnants of Araucarian Forests in Southern Brazil**

In the year 2000 the Paraná State Government has mapped all the remnants of Araucarian forests present in the State (PROBIO Project) using automatic digital classification of Landsat TM imagery. The classification results, which included five forest types, were refined by ground checks and ancillary data. In 2003, as a part of the aerial sketchmapping program, an aerial survey was conducted over a sample area in remnants of the Araucarian Forest with two main objectives:

1) To develop an aerial signature for the classes considered in the previous mapping;
2) To update the year 2000 classification.

For this type of survey the satellite maps were overlaid with a 4 km UTM grid, major roads, drainages and the polygons resulting from the final digital classification made by the Government staff. Before the operational flight actually took place, the USDA Forest Service/EMBRAPA team and the government staff have flown over a demonstration site so that the sketchmappers could be trained in recognizing the different forest types.

After the survey was done the first thing to be pointed out was the indubitable richness of details one can gain from a 300-meter-high flight perspective. Not only the forest remnants could be mapped, but also different land cover classes such as bare soil and row crops (**Figure 6**). Depending on the scale of the base map (in this case, 1:25.000) even the presence or absence of riparian forests could be annotated.

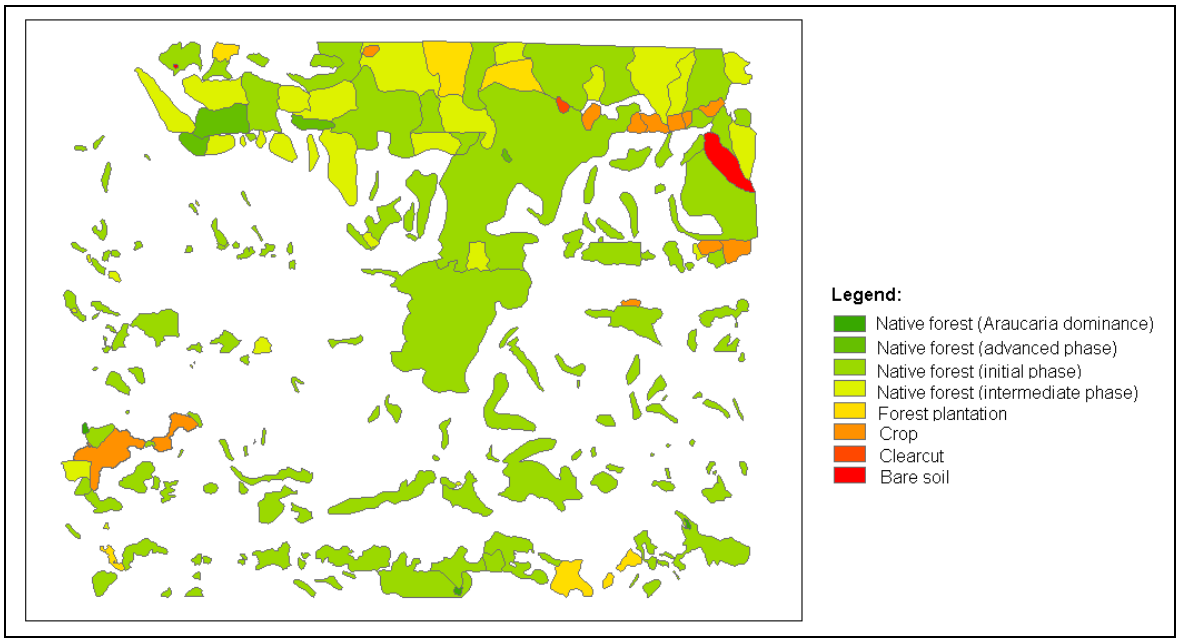


Figure 6 – Results of the Aerial Sketchmap for the Region of Rio dos Touros Showing Land Use and Native Forest Classes

The sketchmappers also discussed the benefits and trade-offs of superimposing the previous classification results on the satellite maps. Due to the dynamic changes of land cover classes and also to the subjectiveness in defining the forest types it would sometimes be recommended not to overlay any polygons on the base map. In fact, the classes considered for the digital classification represented 3 different successional phases of secondary native forest, a forest plantation class and a native forest class with 80% or more of Araucaria trees cover. Excepting the forest plantation class, the four other classes resemble so much each other that it is rather difficult to perform even a regular classification. Many differences concerning location and classification of forest types were found in the two survey approaches. When considering solely the "native forest" and "non-native forest" classes, the agreement between the two approaches could reach 49 % in terms of the total surveyed area.

The aerial sketchmapping of the Mangueirinha Indian Reserve (**Figure 7**) presented similar results to those obtained by the digital classification only for the polygons representing the "intermediate stage" and "araucaria dominance", whose calculated areas differ in about 30%. Major differences between the survey and the classification are related to the class "initial stage", which seems to be represented in a larger extent in the aerial survey than in the PROBIO classification results. Many areas recognized (from the air) as "initial stage" have been misclassified as "araucaria dominance". Confusion arose also in the class "advanced stage", with differences in measured areas around 90% between the PROBIO and the aerial survey results.

The aerial survey was also concerned with other land use classes, such as "bamboo", which occurs often in Araucarian Forests and has lately been considered as a threatening factor to the natural regeneration of the species *Araucaria angustifolia* (parana-pine).

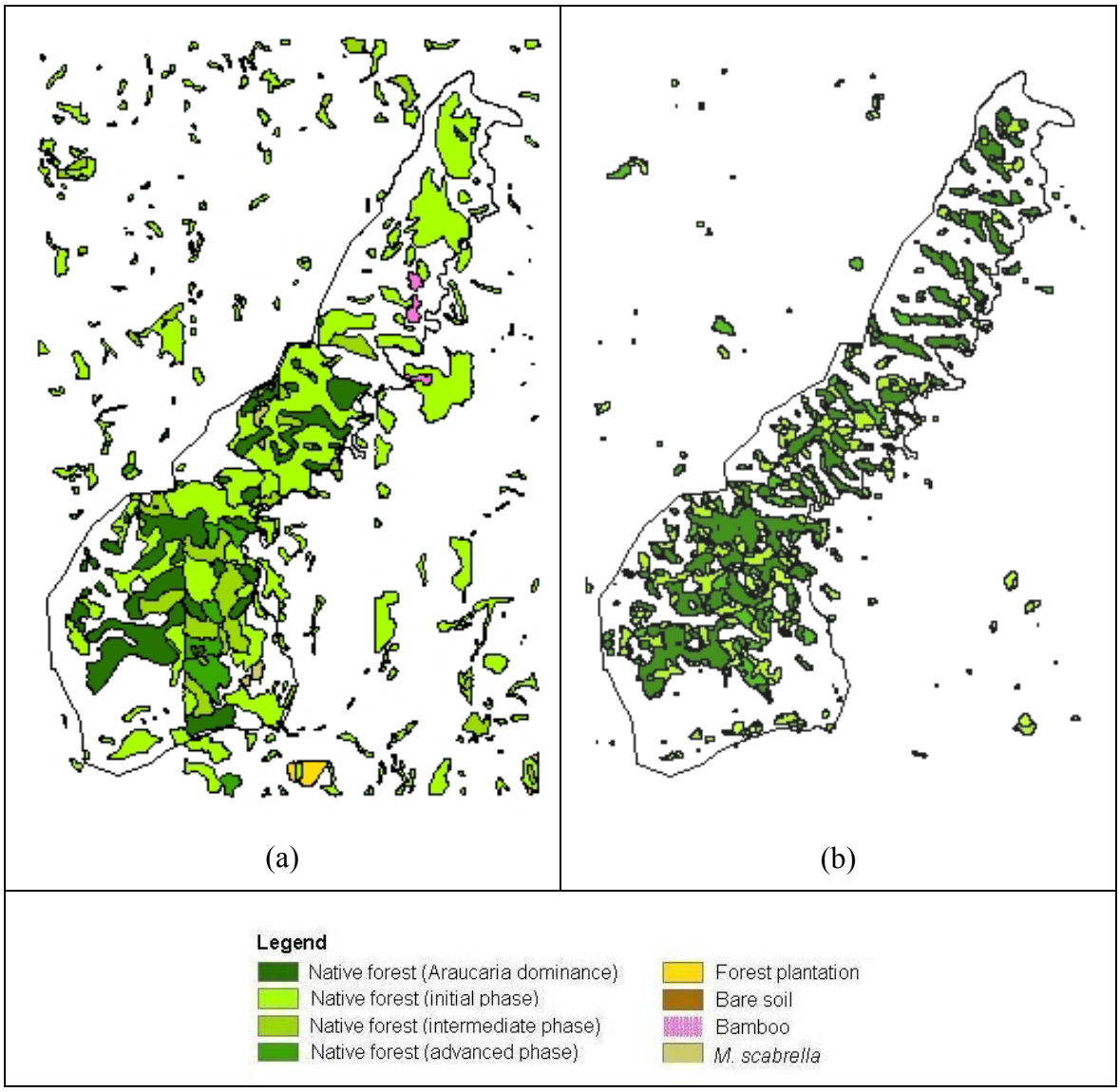


Figure 7 – Results of Aerial Sketchmap Survey (a) and Digital Classification (b) for the Mangueirinha Indian Reserve, Paraná State

The Forest Reserve of Caçador, in Santa Catarina State, was also flown during the 2002 campaign. The main objective was to classify the remnants of Araucarian Forest inside and outside the Reserve in three *Araucaria angustifolia* (parana-pine) cover classes, which can be seen on the resulting map, showed in **Figure 8**. "*Au1*" labels represent forest patches with more than 80% of araucaria cover, while "*Au2*" represent classes between 80% and 20% of araucaria cover, and "*Au3*", less than 20%. Pine (*Pi*)

and Eucalyptus (*Eu*) plantations, as well as exploited areas (*Ex*), were also mapped. These results provided the basis for further research involving landscape analysis approaches and the visual interpretation of high resolution satellite imagery.

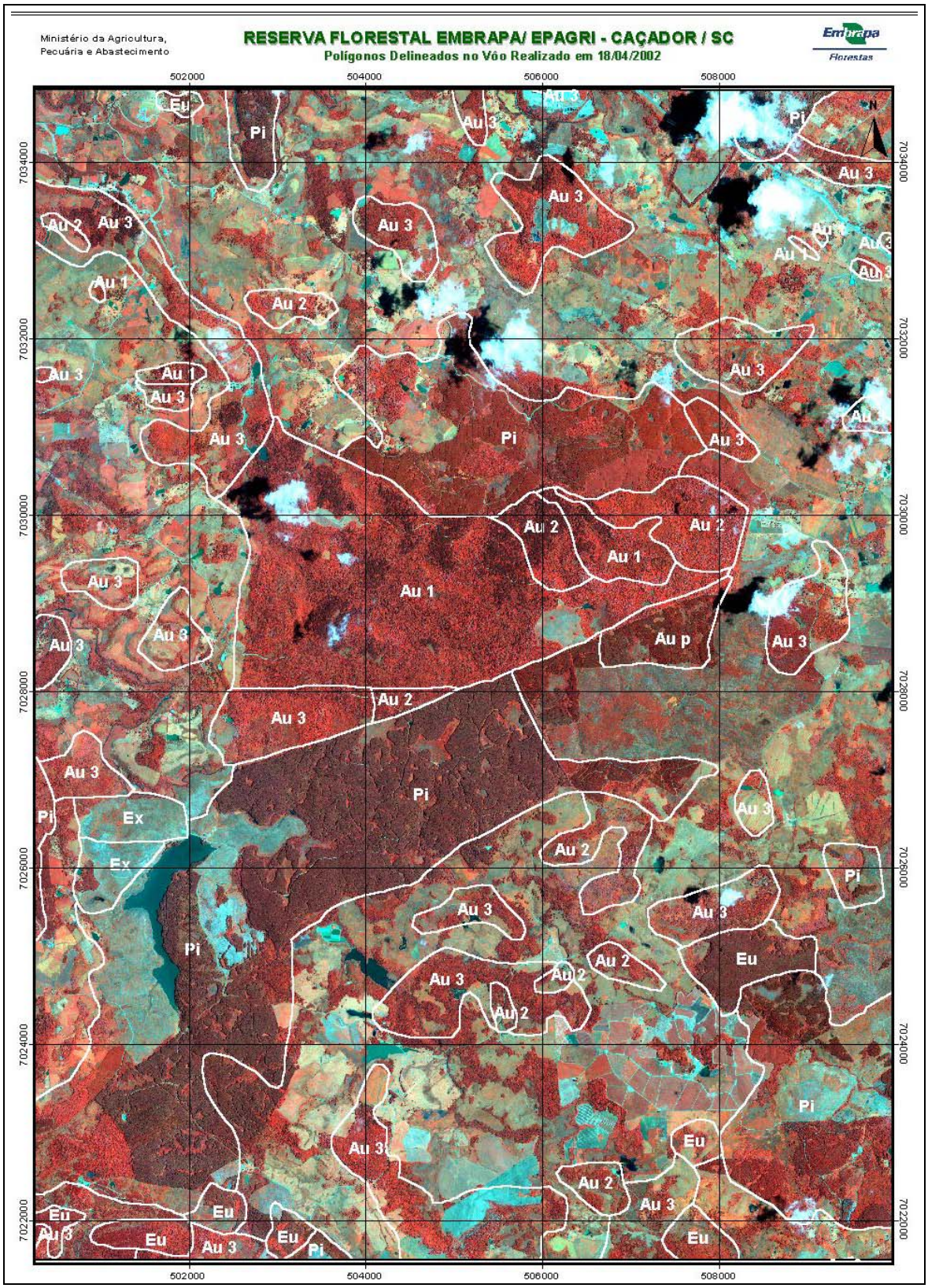


Figure 8 – Results of the Aerial Sketchmap Survey for the Forest Reserve in Caçador, Santa Catarina State, Overlaid on an IKONOS (NIR-G-B) Composition

**Surveys to monitor deforestation in remnants of Araucarian Forests**

The most recent campaign carried out by the EMBRAPA team was a survey requested by the Brazilian Environmental and Renewable Natural Resources Agency (IBAMA) to monitor anthropogenic deforestation in remnants of Araucarian Forests in two different areas in Paraná State. The low-altitude flight allowed the mapping of 48 points of varying intensities of deforestation, including areas where the process has just begun ("deforestation traces").

The observers used the same flight to check the forest plantations for accuracy assessment as well as for the detection of woodwasp infestations (**Figure 9**). The IBAMA staff is now engaged in ground checking operations using data (maps, reports and tables) generated by the EMBRAPA GIS.

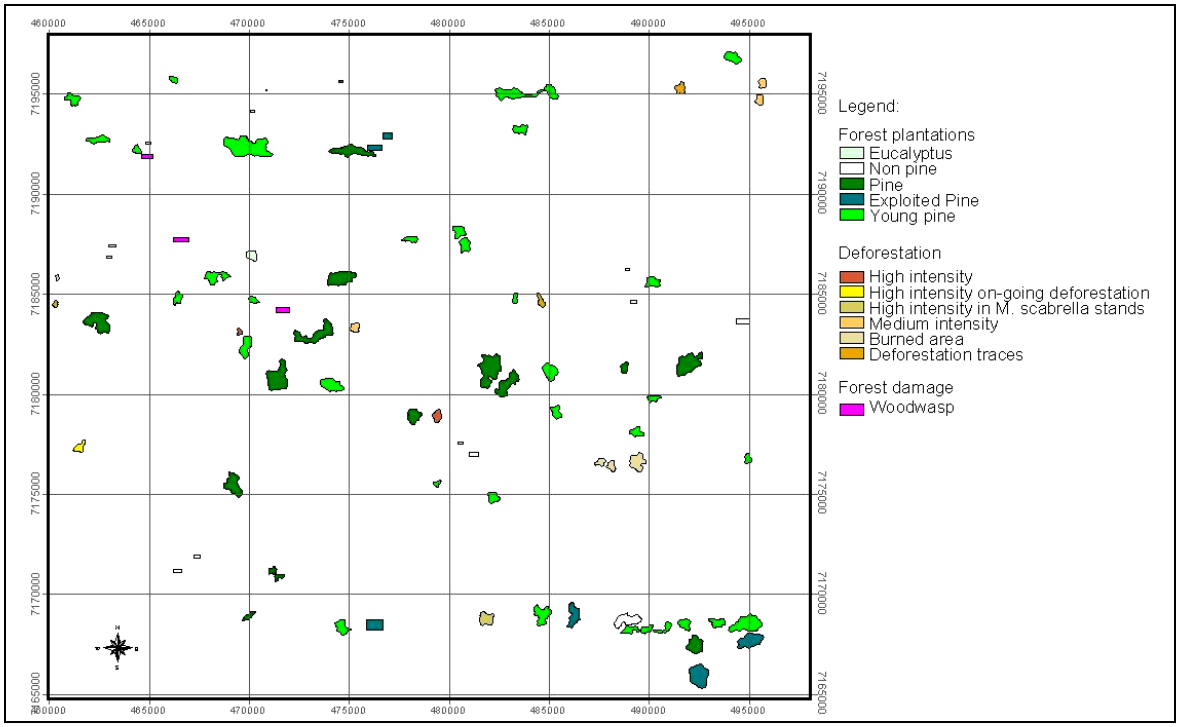


Figure 9. Partial Results of the Aerial Sketchmap Survey for the Monitoring of Deforestation in Remnants of Araucarian Forests (Region of Guarapuava – Parana State).

This last campaign (April, 2004) provided also the opportunity for two addtional EMBRAPA employees to be trained as aerial observers, thus contributing to the consolidation of the technique in Brazil.

## FUTURE STEPS

Until now four major approaches were identified for the use of aerial sketchmap surveys in Southern Brazil:

- the detection and mapping of forest damage, mainly in – but not limited to – forest plantations;
- the assessment of thematic accuracy of other remote sensing techniques, like, for instance, digital classification or visual interpretation of satellite imagery;
- the updating of existing forest maps;
- the mapping and classifying of forest remnants and other environmentally relevant features such as riparian forests, wetlands, etc.

As annual flight campaigns are being carried out, the EMBRAPA aerial observer team is becoming more proficient at identification of damage types typical of Southern Brazil and is now able to expand the provisional coding system developed during the first years of this project.

Forest health researchers are concerned with recent infestations of the eucalyptus red gum lerp psyllid in Eucalyptus stands located in Paraná and São Paulo States. The detection and mapping of forest damage caused by this insect seems to be a new challenge for the aerial sketchmap surveys in Southern Brazil.

Another important aspect of full-scale implementation is prompt ground checking of damaged areas detected from the air. In this regard EMBRAPA is expecting to develop partnership with forest plantation owners, who would be able to give field support for ground checking as well as to provide silvicultural and management information related to the forest stands for which damage has been reported.

An interesting issue has arisen after the 2003 flights over the Araucarian Forest regions and it is related to the need of recording some kind of imagery during the flight. When analyzing the survey results, the sketchmappers and the government staff pointed

out that it would be very useful to have some video imagery or aerial pictures to help them characterize and identify the aerial signature of the feature, vegetation class or phenomenon being studied. This topic was discussed during the workshop held in Curitiba, in November 2003 and the sketchmap team decided that it is worth testing different methods of image acquisition in future steps of the aerial sketchmap program.

Significant advances in computer technology, GPS, and GIS have led to the interest in the development of electronic enhancements, both in Canada and the U.S., to allow direct recording of forest damage on maps stored in a laptop computer during aerial sketchmap surveys (CIESLA, 2000). The USDA Forest Service/EMBRAPA team is now planning to introduce the digital aerial sketchmap system in Brazil. Previous feasibility studies concluded that the application of this new technique would pose no difficulties for the Brazilian conditions, since the base maps used in the surveys are already composed and stored in digital format and that the USDA Forest Service Forest Health Technology Enterprise team can provide some of the software and other equipment necessary for the system to operate. It should, thus, be tested and implemented in future flight campaigns.

## CONCLUSIONS

The aerial sketchmap program in Brazil is in full development and some facts that have contributed to its successful implementation are:

- the constant support of USDA Forest Service Forest Health Technology Enterprise Team, through its members, who introduced the aerial sketchmapping in Brazil and who were always eager to adapt the technology to Brazilian environmental and working conditions;
- the great extent of forest (natural or planted) present in Southern Brazil and the land use dynamics which demand new methods for forest monitoring;
- the interest of forest owners and public agencies in applying the new technology for various purposes;
- the interest of EMBRAPA – being a public research agency – in developing and adapting techniques that will contribute to the sustainable use of forest resources.

Flight campaigns in Brazil have demonstrated that clearcuts, land use change detection and other anthropogenic activities in Araucarian Forests may be suitably mapped and monitored from the air. The aerial sketchmapping technique represents, therefore, an inexpensive and effective alternative to the monitoring and conservation of this endangered biome in Southern Brazil.

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## List of Figures

Figure 1 – Flight Campaign Areas in Parana State

Figure 2 – Cessna 185 Aircraft Used for Both Observer Training and Operational Aerial Sketchmap Surveys in Southern Brazil.

Figure 3 – The Garmin GPSMAP 295 Global Positioning System (GPS) Receiver Used in Aerial Sketchmap Surveys

Figure 4 – Flight Lines Established on Satellite Map

Figure 5 – Forest Damage Map Resulting from an Aerial Sketchmap Survey Over the Region of União da Vitória – Paraná State

Figure 6 – Results of the Aerial Sketchmap for the Region of Rio dos Touros Showing Land Use and Native Forest Classes

Figure 7 – Results of Aerial Sketchmap Survey (a) and Digital Classification (b) for the Mangueirinha Indian Reserve, Paraná State

Figure 8 – Results of the Aerial Sketchmap Survey for the Forest Reserve in Caçador, Santa Catarina State, Overlaid on an IKONOS (NIR-G-B) Composition

Figure 9 – Partial Results of the Aerial Sketchmap Survey for the Monitoring of Deforestation in Remnants of Araucarian Forests (Region of Guarapuava – Parana State).