

AUTOMATIC INTERPRETATION OF VEGETATION AREAS IN BRAZIL

Kian Pakzad¹, Guilherme Lúcio Abelha Mota²,
Margareth Simões Meirelles^{3,4}, Heitor Luiz da Costa Coutinho⁴, Raul Queiroz Feitosa^{2,3}

¹Institute of Photogrammetry and GeoInformation
University of Hannover, Germany - pakzad@ipi.uni-hannover.de

²Departments of Electrical Engineering and Material Science,
Catholic University of Rio de Janeiro, Brazil - {guimota, raul}@ele.puc-rio.br

³Department of Computer Engineering
State University of Rio de Janeiro, Brazil - maggie@eng.uerj.br

⁴Brazilian Agricultural Research Corporation
EMBRAPA-Soils, Rio de Janeiro, Brazil - heitor@cnps.embrapa.br

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ABSTRACT:

This paper describes a procedure for a multitemporal interpretation of vegetation areas in Brazil using Landsat TM images. We started with a monotemporal interpretation of the first epoch of the scene by using both spectral and structural features. For interpretation of temporal changes we discretely described temporal conditions of regions, and transferred the most probable temporal changes of the given conditions as temporal knowledge into a state transition diagram, which was used for the multitemporal interpretation of the images. This diagram contains limitations of possible state transitions derived from biological reasons as well as limitations given by law. We included the interpretation strategy into the image analysis system eCognition. In this paper we describe how we created the state transition diagram for our test area and how we included it in eCognition. By using temporal knowledge it is possible to reduce the search space during the multitemporal interpretation and reduce therefore the classification errors. The results show that the presented procedure is suitable for multitemporal interpretation of that area, and leads to better results than the procedures used for those areas so far.

1. INTRODUCTION

The preservation of environmental resources has been pursued with growing determination worldwide, which increases the demand for methods to support the rational utilization of natural resources. In Brazil, there are a large number of natural areas, as well as countries' municipalities and rural states, where most of environmental changes are still taking place. It is important to monitor all those areas with the minimal periodicity required to effectively follow the environmental changes and subside natural resources management.

Motivated by this need the ECOWATCH cooperation involving two German and three Brazilian institutes was initiated. The cooperation is about investigating methodologies to increase the level of automation in the image interpretation processes. It endeavours to emulate inside a computer system the reasoning of a skilled image analyst during the process of image interpretation, so that many image analysis tasks can be performed automatically.

The extent of the areas in Brazil as well as economical restrictions imposes the use of low resolution low cost imagery. So the aim of the ECOWATCH research is to develop knowledge based methods for the interpretation of low resolution images allowing people with lower training to use the traditional remote sensing technology as well as improving the productivity of image analysts.

One area selected as test site for this research is part of the Taquari Watershed, located in the State of Mato Grosso do Sul, in southwest of Brazil. The economical activity in this area is strongly associated to extensive cattle-raising for the meat business. Unfortunately, improper managing of the pastures and low nutritional potential of the grass species used contribute to

a weak productivity. In addition, excessive cattle grazing pressure causes severe soil erosion and pasture degradation. These phenomena reduce the value of rural properties and augments regrettably the amount of sediments carried by the rain that get to the water-streams.

The need to monitor the evolution of this degradation process, and in parallel, to perform researches looking for viable technologies capable of detecting novel occurrences of such processes gave birth to the S.O.S. Taquari Project carried out by the Brazilian Agriculture Research Corporation and coordinated by its Soil National Research Centre (EMBRAPA-Soils). This project has been providing data and knowledge about the Taquari Watershed for the research within ECOWATCH cooperation.

In this paper we present a procedure for a multitemporal interpretation of these areas. We started with a monotemporal interpretation of the first epoch of the scene by using both spectral and structural features. For interpretation of temporal changes we discretely described temporal conditions of regions, and transferred the most probable temporal changes of the given conditions as temporal knowledge into a state transition diagram, which was used for the multitemporal interpretation of the images. This diagram contains limitations of possible state transitions derived from biological reasons as well as limitations given by law.

In section 2 we describe some prior knowledge about our test site, which was used for both mono- and multitemporal interpretation. Section 3 shows the interpretation procedure for such regions employed hitherto, section 4 describes the approach for monotemporal interpretation and, based on that, section 5 the strategy of multitemporal interpretation and the results. The paper ends with a conclusion in section 6.

2. PRIOR KNOWLEDGE ABOUT TARGET SITE

The Taquari Watershed, located in the Northeast of the State of Mato Grosso do Sul, in southwest of Brazil, is one of the main contributors to the Pantanal wetlands, with a total area of approx. 80.000 km², being approx. 50.000 km² in the Pantanal lowlands. The main factor that impacts the environment at the Taquari area is the land occupation without land use planning. Because of that, 100 million ha of Savannah vegetation were originally removed, aiming the development of agricultural / pasture areas. The result of this process was the reduction of a rich biodiversity, not to mention more than 8.000 species of plants (including ornamental and medical), removal of riparian vegetation, erosion, siltation and reduction of hydrological resources quality. All this, also affects other sectors of economy like tourism and fishing. The changes in land use (native vegetation converted mainly to cultivated pasture) observed during the last 30 years, particularly in the highlands of this watershed, has been associated with increased sedimentation of the Taquari river and smaller rivers and streams, as well as an increase in the occurrence of gullies in the highlands. This process is considered to be a major threat to the Pantanal hydrological dynamics equilibrium, with unknown consequences downstream along the Plata basin (Mendes et al., 2001). Rainfall in the test area is concentrated from October to April (1,500 – 2,000 mm), and heavy storms are common during the rainy season. The dry season (May to September) can be extremely intense and cause severe damage to pasture production. The topography is dominated by gentle slopes with the presence of reminiscent geological features that “survived” erosion (hills with small plateaus). The soils are mostly of sandy texture, with some podzolic formations too (a sandy top layer and a clayey sub-surface layer).

The areas studied are part of the Cerrado, a heterogeneous vegetation formation covering 23% of the Brazilian territory, between the Amazon and the Atlantic Coast Rainforests (Furley and Ratter, 1988). The Cerrado type that dominates the areas studied is the Dense Savannah Woodland (“Cerradão”), defined as a formation of low trees (8-12m) densely packed, but without significant contact between their crowns so that the shading effect is not complete, allowing development of an under story vegetation containing grasses, dwarf palm trees and ground woody plants (Veloso et al., 1991).

The low fertility and highly erosive sandy soils that dominate the landscape, and the pronounced dry season, that is characteristic of this region, turns it highly susceptible to land degradation processes (Oliveira et al., 2000). Human activities in the region concentrate on cattle ranching, whereby the native vegetation is replaced by pastures, constituted mainly by species of *Brachiaria*. Removal of the vegetation cover results in greater impoverishment of soil fertility on a medium term, due to loss of soil organic matter and nutrients. This situation is aggravated by the reduced application of soil conservation procedures and sound pasture management practices, which lead to soil erosion and placement of an excessive number of cattle on the pastures, respectively. These processes combined result in a progressive elimination of the original vegetation cover and increase of soil loss by erosion, and the appearance of large portions of land with exposed Bare Soil.

3. INTERPRETATION METHOD USED UNTIL NOW

This section describes the interpretation method used until now, which should be improved and automated by the methods of the ECOWATCH cooperation. It was employed by a group of

experts of the National Soil Research Center of EMBRAPA, the Department of Mineral Resources of State of Rio de Janeiro and the Geomatics Department of the University of the State of Rio de Janeiro (UERJ) to interpret manually Landsat TM images. In addition to the input images, the drainage network, the digital elevation model and a videography (images recorded by a video camera from plane) were used as supplementary sources of input data.

The following procedure describes the methodology employed in the visual interpretation.

1. Selection of training set

Manual selection of training samples to be delivered to the supervised pixel classifier.

2. Supervised pixel classification

In this step it is employed a maximum likelihood classifier trained with the previous selected samples.

3. Deleting small regions

A filter is applied to eliminate small regions.

4. Post editing

Since the classes which present similar spectral responses can not be properly discriminated, a human photo-interpreter based on his background and additional information (e.g. drainage map) solves the inconsistencies produced so far. The reasoning of the photo-interpreter can be expressed by a set of rules. Some examples of these rules are:

-Riparian forest [far away from river] → dense savannah

-Dense savannah [near to river] → riparian forest

-Wetland [on mountain] [far from river] → dense savannah

-Dry pasture [on slope] → dense savannah

-Dense savannah [inside a region of great density of rivers] and [wet land] → riparian forest

This process is time consuming, needs experienced photo-interpreters and contains many errors. The reason for the errors is that the basis of the interpretation is, as described above, a multispectral maximum likelihood classification. The results of this step contain many inconsistencies, which have to be corrected by the photo-interpreter. Because of the high value of regions the photo-interpreter is not able to do this for the whole segments, only for some of them. Otherwise the time exposure would be too high. Because of these reasons an automation of these procedures was preferable.

4. MONOTEMPORAL INTERPRETATION

The first task was to create a procedure for a classification of the Landsat TM image (ground pixel size 25m, band 3, 4, 5) using only monotemporal information, based on the manual approach, described in section 3. Among the available “Commercial Of The Shelf” Software-Packages, we decided to use the image analysis system eCognition, because it allows to represent a higher degree of prior knowledge and to explore both spectral and structural information. For this reason, eCognition was used to implement and refine the interpretation strategy. Later this strategy can be employed to create an autonomous and automatic interpretation system outside eCognition.

The first step was to define the land use classes. These classes should be identifiable in the Landsat TM images and fulfil the needs of the Brazilian institutions. Taking both aspects into account, the following land use classes were selected:

Class	Description
Dense Savannah	Dense Savannah Woodland (“Cerradão”)
Dense Savannah in Regeneration	A previous area used for pasture that was left aside by the farmer, and is under regeneration of its native vegetation.
Riparian Forest	Dense woodland situated alongside rivers and streams.
Green Pasture	A well managed pasture, eventually irrigated and fertilized, or a newly formed pasture.
Dry Pasture	The most common situation, whereby the pasture is not managed properly, with no irrigation, no use of fertilizers, and that suffered excessive cattle grazing pressure. It is aggravated by climatic stress (dry spells).
Bare Soil	A soil that has been degraded by erosion or that is being prepared for cultivation.
Other Classes	Water, Shadows, Swampland

According to the classification strategy in eCognition the image is first segmented and then the segments are classified. So we created in the first step the segmentation with a segment size, which was fine enough to separate all classes we needed (coarse segmentation level). Additionally we created a segmentation with segments with half the size of the first segmentation (fine segmentation level). Later we used this segmentation to separate particular classes (see below). For the segmentation we optimized the homogeneity criterion rather than the shape criterion, which means, that the created segments were rather homogeneous than compact.

After the segmentation we started with the classification. As a basis for the classification eCognition offers the possibility to start with a supervised multispectral classification. For this we had to define training regions for the classes.

Because of the difficult discrimination of some classes based on spectral signatures, we started the classification by grouping some classes. We used the following classes and groups of classes for the first multispectral classification:

- Pasture=Green Pasture + Dry Pasture
- Forest=Dense Savannah + Riparian Forest
- Bare Soil
- Dense Savannah in Regeneration
- Other Classes (Water, Shadows, Swampland, ...)

We defined training areas on the coarse segmentation level and performed a supervised multispectral classification. The selection of training areas in this step was easier than before in the manual steps described in section 3, because we grouped the classes which were difficult to separate.

Afterwards the classes within the grouped classes were separated by using additional features such as brightness and NDVI (Normalized Difference Vegetation Index). In the fine segmentation level we created the two classes bright areas and dark areas by using a threshold. This classification was used later e.g. for the discrimination between “Dry Pasture” and “Green Pasture”. Inside the coarse segmentation level a membership function was created with the feature, that if less than 50% of the segment is filled with high NDVI areas and

other conditions are also fulfilled the segment should be connected to the class “Dry Pasture”.

The grouped class forest was refined by using a map of all rivers inside the region. The refinement of the class forest was performed by assigning all segments in the vicinity of a river segment to the class Riparian Forest, otherwise the segment was connected to the class Dense Savannah. The same criterion was used for Dense Savannah in Regeneration: All segments in the coarse level in the vicinity of a river segment were connected to the class Riparian Forest.

Fig. 3 shows the result of the monotemporal interpretation. A visual validation by photo-interpreters showed that this result is better than the result of the former method described in section 3. The validation was done visually because no accurate reference data were available for that area.

5. MULTITEMPORAL INTERPRETATION

One goal of this project was also to perform a multitemporal interpretation by using temporal knowledge. For the monitoring procedure a repeating interpretation of the same area is necessary. Until now this is performed by new independent multispectral classifications of the same area. This means that the classification procedure generally applied in many operational systems until now does not take previous classification results into account, which could significantly improve the classification accuracy. If for example the classification of a particular area in the year 1999 led to the class “Bare Soil”, the classification procedure of the same area in 2000 does not need to search for the class “Dense Savannah”, since “Dense Savannah” can not grow in 1 year. Using temporal knowledge like this can improve the interpretation stability and enable the discrimination between additional land use classes.

Literature discusses different approaches for multitemporal interpretation of remote sensing data (Lunetta & Elvidge, 1999). The first group of approaches is known as pixel-wise comparison. These approaches compare pixels of different epochs (e.g. Peled et. al., 1998). One possible way is to subtract the grey values of the pixel, thus detecting changes. Also, different vectors can be subtracted, based on multispectral images. The disadvantage of these approaches is the necessity of precise spatial rectification.

The second group of approaches are known as postclassification approaches. These approaches start with a separate multispectral classification of the images of every epoch (e.g. Weismiller et. al., 1977). Then the classification results of the different epochs are compared to each other. Here it is of disadvantage that these approaches depend on the classification methods. It is difficult to decide whether the differences between the classifications of the various epochs result from inaccuracies of the classification method or from real changes in the scene. These approaches also need precise spatial rectification.

The third group of approaches compares the images of different epochs on the semantic level. Different conditions are formulated for the possible changes of different regions from one epoch to another. Therefore, the regions in the scene are interpreted by using the knowledge of possible temporal changes. The approach which was used in this project, is assigned to this group.

The approach discretely describes temporal conditions of regions, and it transfers the most probable temporal changes of the given conditions as temporal knowledge into a State Transition Diagram, which is used for multitemporal

interpretation. Further details of this approach can be found in (Pakzad, 2001) and (Grove, 2001). Hence we transferred for our test area the most probable temporal changes into a State Transition Diagram in order to be able to use such knowledge, as described in section 2, for an automatic multitemporal interpretation. The proposed State Transition Diagram was developed taking into account land use changes that can take place in the period of time of one year, using the dry season as the starting and end point, because this is the season of our images. Fig. 1 shows the developed State Transition Diagram for our test area.

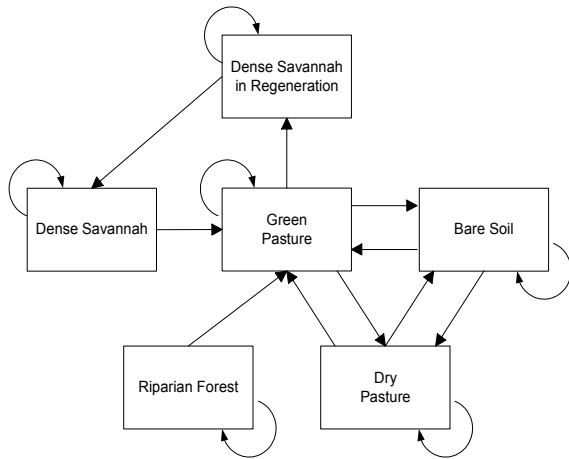


Figure 1: State Transition Diagram

The reason for the state transition from “Green Pasture” to “Dry Pasture” is pasture degradation as a result of excessive cattle grazing, associated with soil fertility impoverishment due to erosion, possible climate effects (dry spells) and bad pasture and soil management. The opposite state transition from “Dry Pasture” to “Green Pasture” can be found because of pasture recovery due to management practices such as fertilization and irrigation, or reduced cattle grazing pressure, or possible pasture renewal by cultivation. Environmental conditions (soil humidity, temperature, etc.) enabled greater vegetation growth and change of spectral response and is the reason for the state transition from “Dense Savannah in Regeneration” to “Dense Savannah”. Although deforestation of riparian forests is an illegal activity under current Brazilian legislation you can find this in some places. This is the reason, why we included also the state transition from “Riparian Forest” to “Green Pasture”. Deforestation and cultivation of new pasture is also the reason for the state transitions from “Dense Savannah” or “Dense Savannah in Regeneration” to “Green Pasture”. The reason for the state transitions from “Green Pasture” or “Dry Pasture” to “Bare Soil” is land preparation for cultivation of new pasture (pasture renewal). The transition from “Dry Pasture” to “Bare Soil” can be also caused by extensive land degradation due to soil erosion. The way back from “Bare Soil” to “Dry Pasture” is caused by slight recovery of pasture growth due to better environmental conditions (soil humidity and temperature). The state transition from “Bare Soil” to “Green Pasture” is caused by pasture cultivation or renewal.

As for the monotemporal approach (section 4) we wanted to implement the multitemporal approach in eCognition. We used Landsat TM Images (Bands 3, 4, 5) from 05.08.1999 and 07.08.2000. We started as described in section 4 with a segmentation. Instead of using the three bands of one epoch we had to use all epochs simultaneously. The reason is the goal to interpret the images for different epochs. As the segmentation is

created only one time at the beginning of the interpretation process, we had to use the same segmentation for the interpretation of all epochs. That means that we had to create segments, which are nearly homogenous not only for one epoch, they have to be homogeneous through all epochs. This means compared with the segmentation of one epoch the segments for all epochs are smaller. This avoids also the problem of comparing segments of the same area in different epochs with each other during multitemporal interpretation. For this reason we included all epochs with all bands in the segmentation procedure. As in the monotemporal interpretation we optimized the homogeneity criterion rather than the shape criterion.

The second step was the classification of the segments. Since eCognition does not provide the ability for a multitemporal interpretation by using State Transition Diagrams we had to use an indirect way to do this. In order to be able to interpret different epochs in the same project we created for every epoch a new segmentation with the same segment size. The reason is that eCognition enables the classification of images in different segmentation levels and uses at the same time relations between the segmentation levels. Because we wanted to do the same with different epochs, not with different segmentations, we used different segmentation levels with the same segments and declared them as different epochs.

Starting with the classification of the epoch 1999 we used the same strategy as described in section 4. The result of this classification was the basis of the classification of the next epoch. For the classification of the next epoch we used the State Transition Diagram in Fig. 1. The way we have done this was to use the classification of 1999 as an initial classification of 2000. Because changes of classes (we call them state transitions) are possible, we divided all segments of a class into those that changed to another class and those without a change according to the state transition diagram.

For example for the segments classified in 1999 as “Green Pasture”, in 2000 the following classifications are possible:

- “Green Pasture” in 1999
 - “Dense Savannah in Regeneration” in 2000
 - “Bare Soil” in 2000
 - “Dry Pasture” in 2000
 - “Green Pasture” in 2000

This means that we had to check all segments classified as “Green Pasture” in 1999 for the three state transitions, the last possibility is keeping the same state.

We can use as prior knowledge the fact, that the most probable state transition is that the state will not change. In this example the most probable class in 2000 is “Green Pasture”. For that reason we defined very restrictive criteria for the other state transitions. That means that we had to check every segment for the state transitions with very restrictive criteria in order to be sure that a state transition really occurred. If the checks fail the segment will keep its old state. We used as criteria for the state transitions changes in NDVI, in the brightness and in the values of the different greyscale channels.

Fig. 4 shows the results of the multitemporal classification procedure. Due to missing ground truth data for the whole area the verification was done visually by experts. The result was that for most areas the automatically created results were better than the manually created results (see section 3) because the manually created results were based on multispectral classifications with posteditation. The errors of the multispectral classification procedure were too much to be corrected in the posteditation procedure.

One advantage of this procedure is the reduction of the search space by exploring the multitemporal information. The number of possible classes for each object and consequently the possibility of classification errors are reduced. On the other hand this method requires an accurate classification of the first epoch since errors in the results of the first epoch may lead to false state transition predictions and consequently to false class assignments.

6. CONCLUSION

In this paper we described a strategy for a multitemporal interpretation of particular vegetation areas in Brazil. Starting with a monotemporal interpretation, which utilises both spectral and structural information we extended the method to a multitemporal interpretation by using temporal knowledge modelled in the form of a State Transition Diagram. We implemented this strategy into the image analysis system eCognition.

A visual validation of the results shows an improvement when compared with the results created by photo-interpreters using manual interpretation. An important advantage of the presented approach is the improvement of the classification accuracy because of the usage of temporal knowledge. Temporal knowledge reduces the search space of the interpretation and reduces in that way the possibility of errors. On the other hand it is also possible that wrong interpretations of the first epoch lead to wrong interpretations of the next epochs, because of wrong predictions. This shows the necessity of a correct interpretation for the first epoch. This can be done for example by a manual validation of the interpretation of the first epoch.

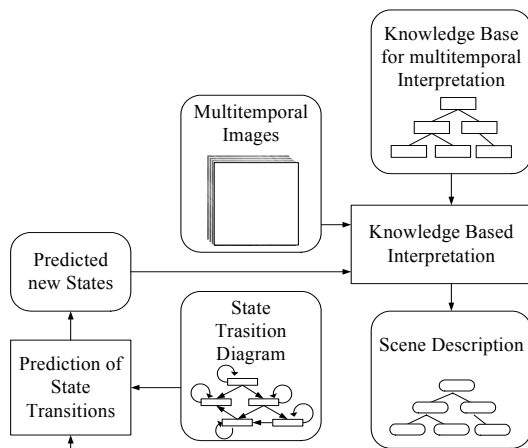


Figure 2: Possible System Architecture

Future work in this field has do be done in different areas: One is the implementation of the described strategies into an autonomous system. The possible architecture of the system is depicted in fig. 2. Another area is to improve and to refine the temporal knowledge, which is described in the State Transition Diagram. After the experiences with our test area we want to collect structural and temporal knowledge about areas with other vegetation characteristics and implement them into our system for an automated multitemporal interpretation. Another interesting area is the work with high resolution images. For some applications it is necessary to use images with higher resolution because the target objects are not or only very

bad visible in the low resolution images. This is for example the case for the observation of some degradation processes. A strategy, which we plan to use, is to work with both resolutions. The low resolution images can be used simply to define the area of interest where degradation is occurring or is more probable. Then, inside the area of interest, high resolution images can be used to look into such regions in more detail. This strategy can avoid the inconvenience of buying high resolution images for the entire region.

7. ACKNOWLEDGEMENTS

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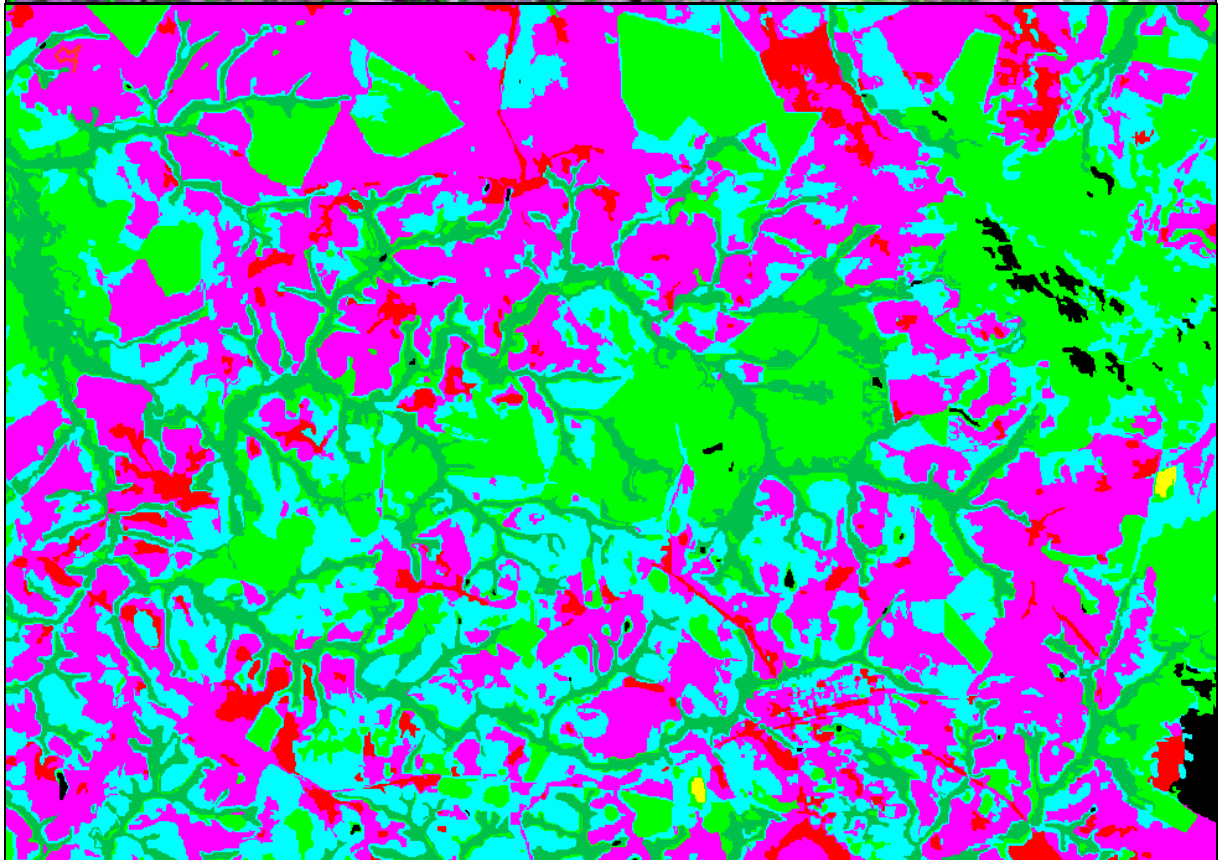
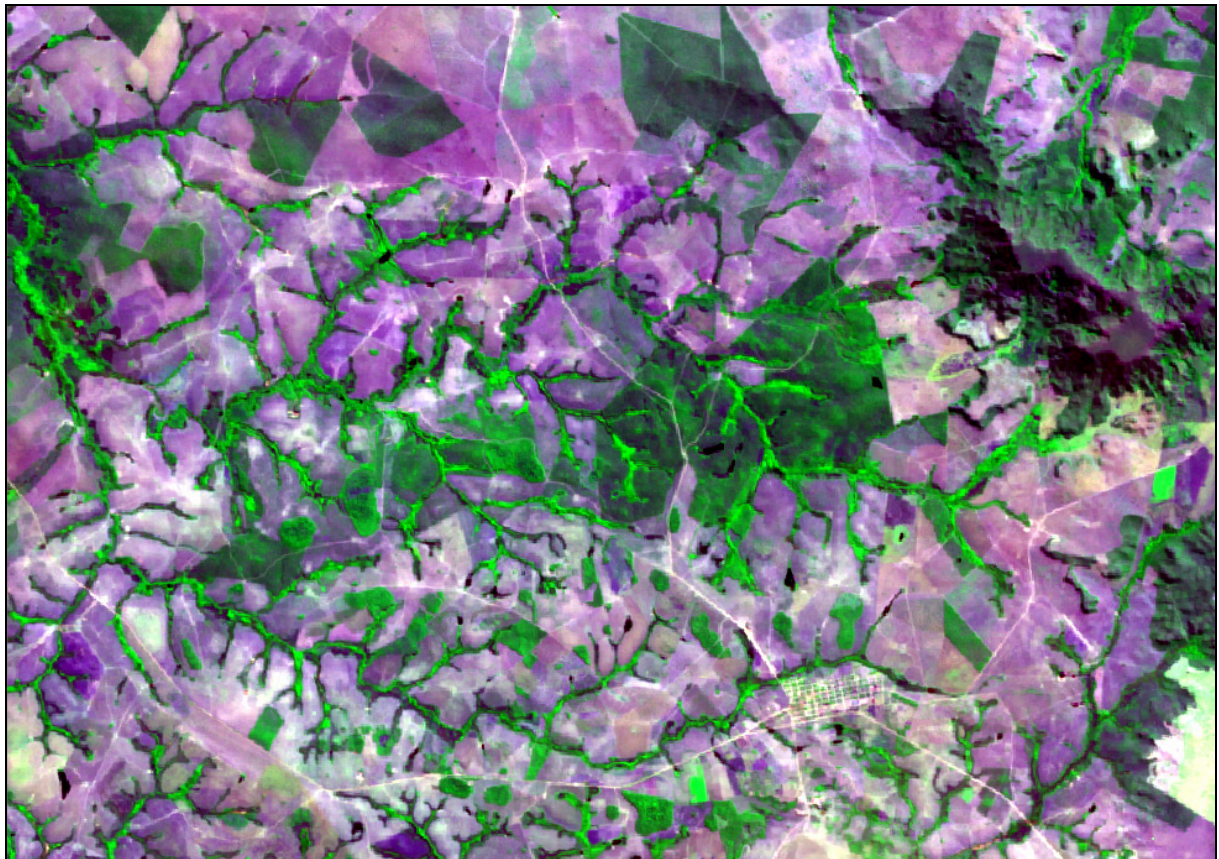


Figure 3: Interpretation Result of 1999

- dense savannah
- dense savannah in regeneration
- riparian forest
- green pasture
- dry pasture
- bare soil
- other

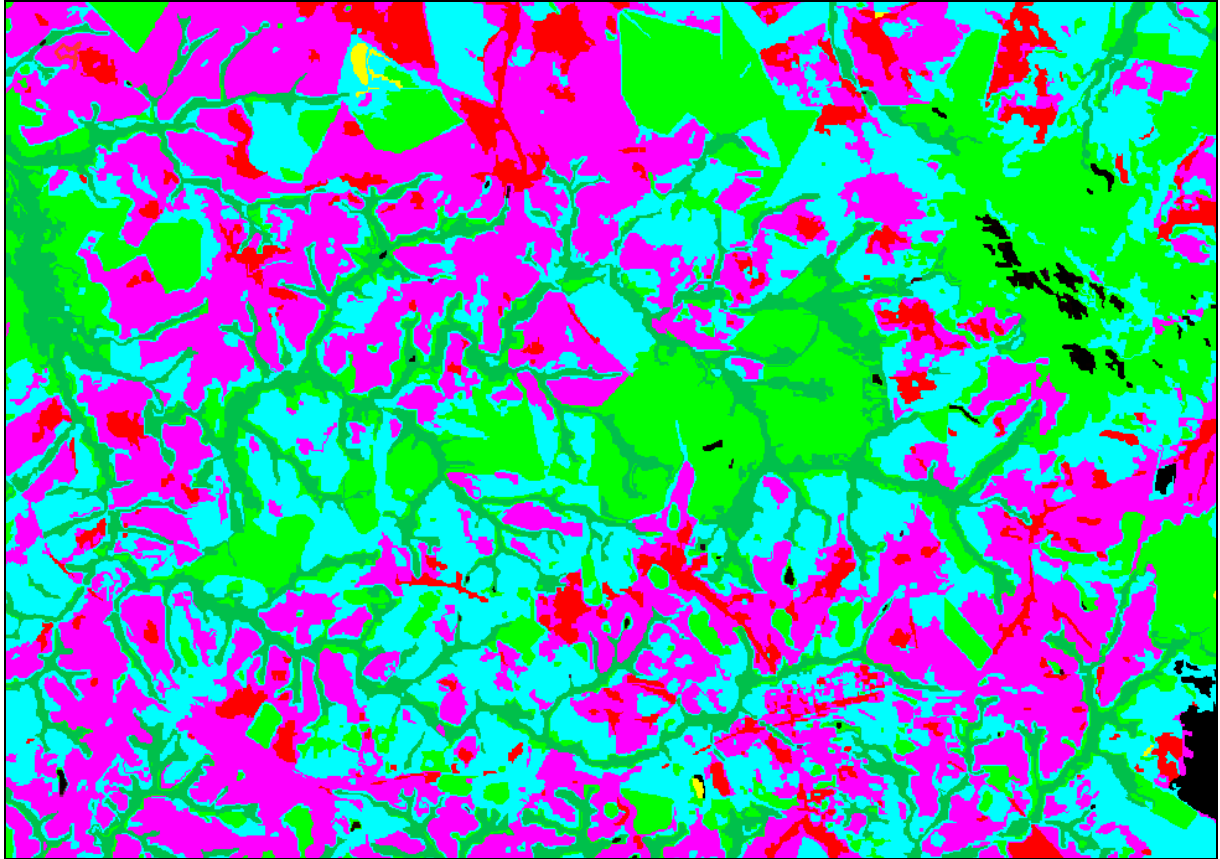
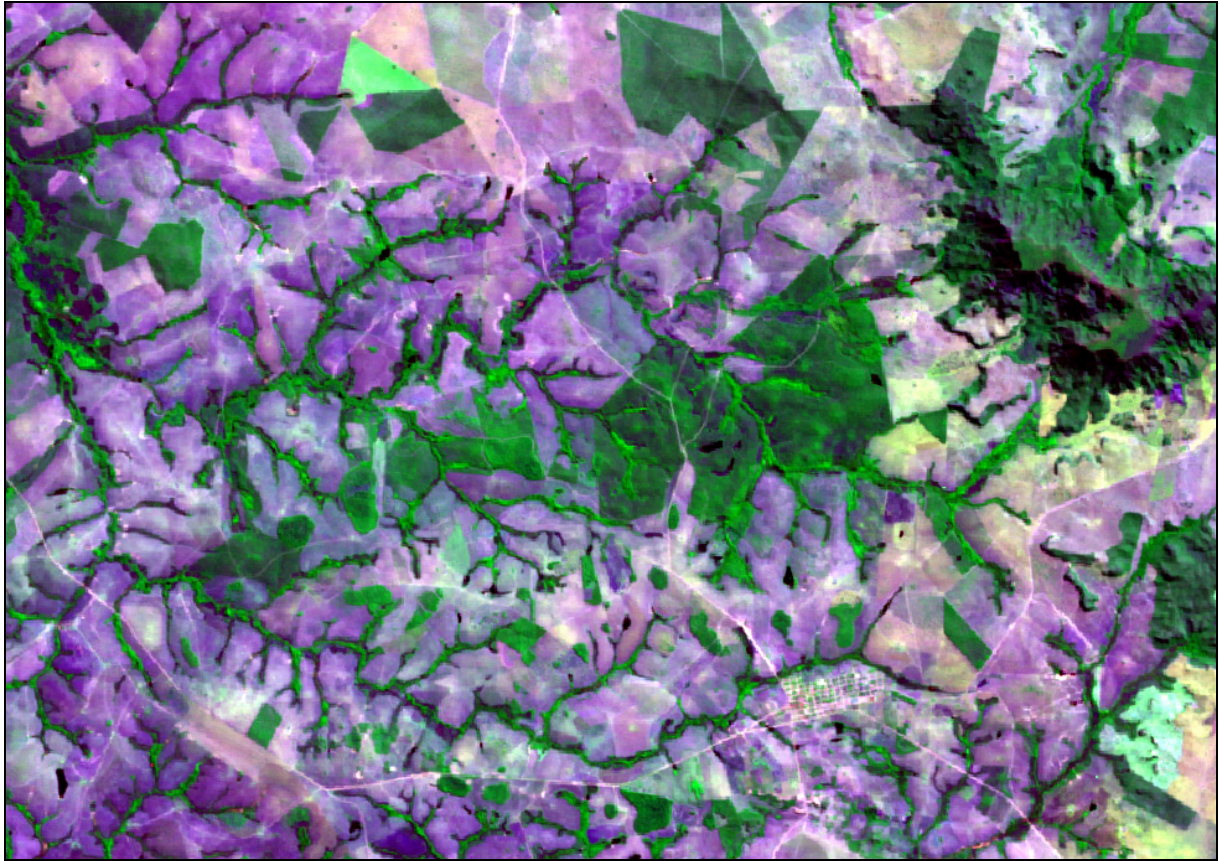


Figure 4: Multitemporal Interpretation Result of 2000

- dense savannah
- dense savannah in regeneration
- riparian forest
- green pasture
- dry pasture
- bare soil
- other