The use of Remote Sensing Imagery in support to Participatory Natural Resources Management
Progress in a case study in the indigenous reserve of Humapo and La Victoria

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Abstract

This report describes how Remote Sensing imagery is being used as a support to participatory Natural Resources Management with the inhabitants of an indigenous reserve containing two villages, Humapo and La Victoria. Its aim is to provide an example of the application of a simple methodological framework to use of Remote Sensing technology in local development processes This itinerary includes participatory envisioning and action planning, analysis of actors, definition of indicators and image processing, the latter being complemented with other sources of data.

This 4158 ha site has been chosen because it is composed of communal lands. Its communities therefore have a high level of responsibility in the management of their natural resources. Their inhabitants greatly value the forest and other natural environments within the reserve because their diet is based on fish and game, and because they rely on materials from plants and trees for their crafts and the roofs of their houses. However, they feel that their resources have been greatly depleted, and want to manage them in order to recuperate their potential. Forest protection and regeneration also calls for an adjustment in agricultural practices, where improved varieties of pasture and cassava can play an important role.

The Remote Sensing imagery is being used in two contexts, both as a cartographic support for planning meetings and also for the quantitative monitoring of the forest cover within the reserve. In this latter context, very simple image processing procedures applied to temporal series of Landsat images allow to identify areas where the forest cover has changed over the last 13 years. They also help identify areas of forest regeneration which were burned during the last dry season, the general burning practices and agricultural activity. Visualisation of these images and the products of the image processing allow the inhabitants as well as the Municipal unit of Agricultural Technical Assistance (UMATA) to focus efforts of fire protection as well as reforestation. They also allow to plan and to monitor agricultural rotation and intensification efforts.

This document is not a final report, because the project it describes is not yet finished. It is meant to report on the progress of the project, but also to serve as an example for others who would like to use the same methodological framework. This report will be updated in 2002 and translated into Spanish.

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1. Introduction

1.1. Justification

More and more efforts of Natural Resources Management use participatory approaches. Through different types of exercises with moderators, members of communities describe their resources, who use them, the links between actors, who benefits from their commercialisation and how much. Also, envisioning approaches are more and more popular to describe desired futures at short, medium and long term (Lightfoot, 2001). These approaches often give an approximate evaluation of the availability of resources and their spatial distribution, based on local perceptions, which are often sufficient for action planning. However, in order to be able to later determine if these actions lead to an improvement of the situation, the local perceptions of resource availability should be supported by quantitative estimations made in the field, combined with spatial distributions determined from aerial photographs or satellite images.

However, satellite images and aerial photographs are rarely used in such initiatives. Reasons for this include the cost of the data, unavailability of technical personnel to process it, but maybe most importantly a lack of correspondence between the offer and the demand of spatial data, as is also often the case with other types of data. Sometimes, land cover maps that are produced by consultants from remote sensing images are not used for decision making because the themes of interest for the planners were not distinguished in them. Any data should analysed with the objective of answering questions posed by planning. Conversely, planning has to result in well formulated questions, or request indicators that are relevant. We should also always be able to compare the indicators to some kind of desirable objective, just like a doctor knows what the desirable temperature or cholesterol level is for a patient. Natural Resources Management approaches are sometimes very descriptive and lack a direction of "how we would like the conditions to be". In those cases, it is difficult to make any data, including Remote Sensing data, useful for diagnostic and monitoring. To be able to make a judgement during diagnosis and monitoring, it is necessary to compare present conditions and tendencies to desirable conditions.

The present methodology was designed and tested in response to the frustrations felt by many professionals working in Natural Resources management. These include planners who experience difficulty drawing conclusions from very descriptive diagnosis, and who sometimes don't know when to stop the quantity and level of detail of data to acquire. They also include producers of data and information who feel that their products are not being used in decision-making.

1.2. General and particular objectives of this study

The practical objective of this study is to help the village communities of Humapo and La Victoria to organise their actions towards their development goals. However, the study also has scientific objectives which are to better understand how these actions can be helped by data, in to guide other users in their use of remote sensing images for participatory natural resources management. In particular, this article aims to improve the link between the data offer and demand in local development processes through a simple "methodological itinerary". This report shows detailed results of the proposed methodology, in a form that would not be sufficiently synthetic for a scientific article. We hope that this level of detail will be useful for other users who wish to adapt and apply the methodolgy in their case studies.

2. Methodological overview

The methodology that we used is illustrated in figure 1. It is composed of two major frameworks, the planning framework, represented by the horizontal set of boxes, and the data analysis framework, represented by the vertical set. The concepts of the planning framework are discussed in more detail in Beaulieu *et al.* 2001. This includes acquisition of basic, preliminary data on the study area, analysis of actors, participatory envisioning and action planning, the definition of indicators to respond to questions relative to monitoring and evaluation and the definition of action planning questions. With the help of data analysed in function of these questions, we are presently conducting a more formal description of the initial and present conditions[1], focusing actions in space and time and will be following up the implementation of actions with the actors. The data analysis framework, which is oriented by the two types of questions mentioned above, produces results that allow the formal description of initial and present conditions as well of the focusing of actions in space and time. In this study, the image analysis techniques that were used were very simple. We are focusing more on the planning aspects of the method, and showing how the image analysis can fit in.

In addition to their use in the assessment and monitoring of environmental dynamics, the images were used in community meetings as a cartographic base to represent the territory of the reserve and point out features of interest to the community. The analysis of actors followed guidelines by Ravnbörg and Westermann, 2000, and Ravnbörg *et al*, 1999/2000. Parts of the methodology developed by INRA to analyse the role of spatial modelling in territorial development were also used here, namely in the analysis of actors and the information content of spatial representations. This methodology can be found in Moquay *et al.* (2001) and in Lardon (2001). The participatory method

[1] which will be repeated in time during monitoring

to establish vision of future conditions, conduct a preliminary diagnosis from local perceptions, and define actions and potential requests is described in Beaulieu *et al*, 2000.

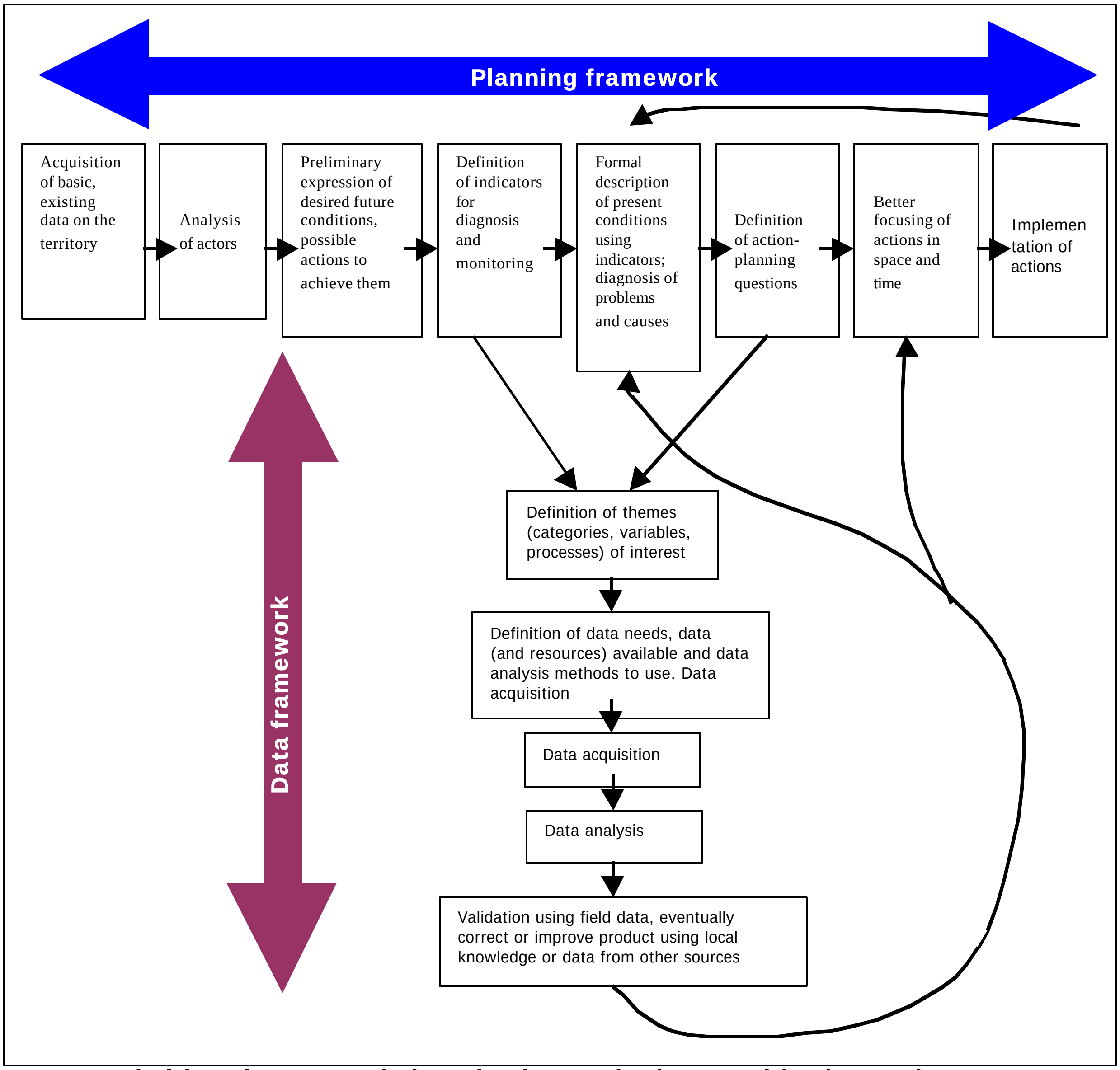

Figure 1: Methodological overview and relationships between the planning and data frameworks.

3. The application

This 4158 ha site has been chosen to illustrate this methodology because it is composed of communal lands. Its communities therefore have a high level of responsibility in the management of their natural resources. Their inhabitants greatly value the forest and other natural environments within the reserve because their diet is based on fish and game, and because they rely on materials from plants and trees for their crafts and the roofs of their houses. However, they feel that their resources have been greatly depleted, and want to manage them in order to recuperate their potential. Forest protection and regeneration also calls for an adjustment in agricultural practices, where improved varieties of pasture and cassava can play an important role. The Plan Básico de Ordenamiento Territorial of the municipality of Puerto López (Alcaldía de Puerto López y CIAT, 2000) includes municipal support to the management of natural resources in this reserve, and the municipal employees most suited for this support are those of the municipal unit of agronomical UMATA.

This site also presented the advantage of having a large enough area for low cost, medium resolution imagery to give relevant information. Many other villages also presented an interesting problematic of natural resources management and poverty alleviation, but they were too small to allow their resources to be quantified with medium resolution satellite imagery, and adequate aerial photographs were not available. We did not have the funding necessary to acquire high resolution imagery, nor do we think actors in similar cases in Latin America would, whereas medium resolution are much more affordable.

3.1. Basic information about the reserve

The indigenous reserve of Humapo and La Victoria has an area of 4158 ha, centered at 4d18'13"latitude and 72d18'38" longitude. It was created in the year 1979, in the context of the law 065. It is part of the municipality of Puerto López, and is located 80 km East of this municipal capital along the highway between Puerto Lopez and Puerto Gaitán. Its location is shown on figure 2, showing a Landsat ETM colour composite of March 3, 2001, on which the limits of the municipality are drawn in blue. The northern part of the reserve, covering 1280 ha, belongs to the village of Humapo, located at 3 km north from the highway, with 44 families (292 persons) of the Achaga ethnic group. It has direct contact with the Meta river, in which the inhabitants go fishing. Over a distance of about 500 m from the Meta river, the geomorphology is composed of river terraces with relatively rich soils. On the remaining part of the Humapo portion of the reserve, the geomorphology is composed of the high plains or "altillanura". These are older soils formed on sediments, with a typical lateritic profile. The altillanura in this portion is not very dissected (*altillanura plana*), but is drained by streams that are bordered by relatively narrow strips of riparian forest. The Humapo portion of the reserve is bordered by the Humapo and caño de los Indios streams, respectively to the East and to the West. Towards the South, it is crossed by the Puerto Lopez – Puerto Gaitan highway.

The larger southern part of the reserve, 2878 ha, belongs to the village of La Victoria, inhabited by 22 families of the Piapoco ethnic group. All of its area is composed of the geomorphologic unit of the high plains or "*altillanura*" in different grades of dissection. Only a small part of it presents a very slightly dissected landscape (*altillanura plana*) while the rest is mediumly dissected (*serranía*), with soils that are more sandy than in the plateaux of the *altillanura plana*. Its territory is drained by a large number of streams, bordered by riparian forests.

The land in both portions of the reserve is collectively owned and managed by the community. Individual families have built and own their houses. The village leaders are called *capitán* and the leader of the reserve is the *gobernador*. The activities of the reserve are co-ordinated by the board (or *junta*) of the *cabildo*, which is composed of the *gobernador*, both *capitanes* and a treasurer. In addition to this, the reserve has a representative to the municipal council of Puerto López, a *consejal*.

The diet of the inhabitants is traditionally based on fish, game, and bitter cassava from which they make large round and flat bread (*manioco*) and a toasted granular meal that is sprinkled in soups (*casave*). They usually cultivate the cassava in moist depressions and on river banks, replacing natural shrub or tree vegetation with their crops. However, they recently have started some agricultural projects with the financial help of the UMATA and the *Instituto de Bienestar Familial*, principally in the *altillanura plana*. Both villages share a tractor for their agricultural activities. They also collectively manage a herd of cattle. They raise this cattle on native grasses or "savannah", which is managed by burning. The animals eat the digestible young grass shoots that grow after burning. The village of Humapo recently planted an area of introduced pasture in 1991, which they use to complement the savannah grazing.

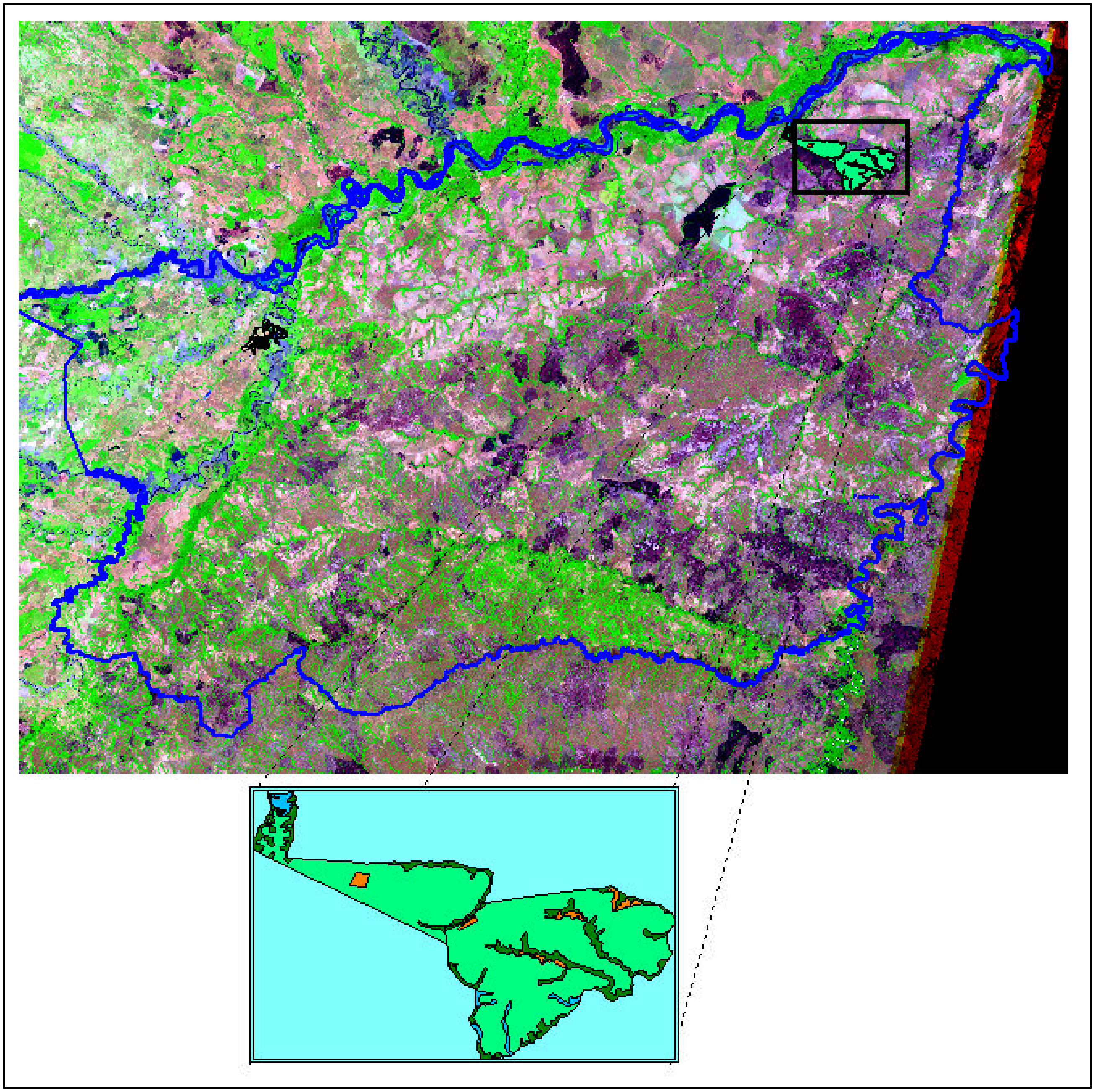

Figure 2 : General location of the Humapo/La Victoria reserve (close-up in the frame below), within the Puerto López municipality surrounded by a blue line

The distance between both villages is of 8 km. There is a lot of communication between both communities, inhabitants travel the distance on their bicycles or small motorbikes.

Both villages have access to electricity (since year 2000) and running water, but there is no telephone line. The community leaders can be joined by cellular phone. A public phone is available in a restaurant near by. There is the building for a common health centre between both villages, but it is not being used because there is no water. There is a small school in both villages, where local teachers teach in the local language and in Spanish. Most inhabitants practice the evangelist religion.

3.2. Establishment of a common vision of future conditions, local perceptions of present conditions, actions and requests to other actors

In April 2000, CIAT and the UMATA conducted participatory planning workshops in five villages in the municipality of Puerto López. The summary of the notes taken in the joint workshop with the inhabitants of the villages of Humapo and La Victoria is presented in table 1, translated into English.

During the description of the desired conditions, inhabitants expressed the desire to live in a richer natural environment, where they can hunt and fish and raise wild animals. In this richer natural environment, they also find the necessary trees and plants to make their crafts, build their houses and renew their roofs. They complement these natural resources with fruit and vegetable crops as well as with bovine livestock. However, in the present, they have very unsatisfactory hunting and fishing, and most of the useful plants have disappeared from the gallery forests. They rely on neighbouring farm owners for permission to collect the palm leaves necessary to change their roofs. They rely on state grants for part of their food needs, and they would like to be more independent.
Among the causes of this difference between desired and present conditions, the inhabitants identified their lack of experience with cropping systems. Their traditional cropping system is bitter cassava, which they plant on the border of streams in *canucos*, a rotation of cassava and fallow, but sometimes replacing mature gallery forest . They also occasionally use agrochemical on these crops, which can contaminate the streams. They have problems managing their livestock and their animals do not reproduce themselves as they should. They burn extensive areas of native savannah land to feed this reduced amount of bovines (about 50 cows).

Among the planned actions, they identified the possibility of cultivating a greater diversity of crops, planting improved pasture to restrain their cattle on smaller areas, planting improved cassava varieties that produce well in the acid soils of the *Altillanura* landscape, protecting the savannah land from fire to allow the gallery forest to spread out on the valleys, reforesting with useful trees and re-introducing useful plants, and raising wild animals like *Chiguiro*.

Since that time, they have planted test plots of cassava in the *altillanura*. They have also discussed a project for raising *Chiguiro* and would like to make a plan for reforesting and fire protection. It is to support this latter initiative that the following steps of the methodology were conducted.

Table 1 : Notes taken during the participatory envisioning of desired future conditions

<table>
<tr>
<td rowspan="2">1-Dream for in 5 years
• We produce enough food to meet our needs
• Rich natural environment (forest, moriche, palms etc…)
• We can hunt lapas, chiguiros, iguanas, pescado, micos, galapagos, babillas, patos, gavanes, perdices
• We have enough water and reforested watersheds
• We raise chiguiros, pigs and chickens
• We cultivate rice, corn, bitter and sweet cassava, outside depressions
• We sell agricultural produce to be able to buy goods (fertilizer, clothing)
• We only have 2 or 3 children per family
• Our houses are made of solid material so we don't have to change roofs every year
• We have pasture and cows
• We have home gardens
• We know how to cultivate and we like it
• We have a health center that works well
• We have cultural identity but selective (ej: we don't want to keep the guayuco!)
• Intern school for indigenous children from farther villages</td>
<td rowspan="2">2-Present conditions
• We do not produce enough food (we finished the plantain, we only cultivate cassava, children receive food from the ICBF)
• There is hardly anymore real forest, only fallow. We cut forest when we plant cassava
• There is no more chiguiro, we rarely are able to catch animals
• There is less and less fish
• We consume water from the streams but there is less and less.
• We don't have any animal raising facilities
• We cultivate cassava in the depressions and streambanks and we have a trial of 23 Ha of cassava planted on the plateaux
• We only commercialize manioco y casave but that does not pay much
• We do family planning and families only have 2 or 3 children
• We don't have home gardens
• Some houses are made of pressed mud bricks, most houses have their roofs in palm given by the neigbouring farms, but palm trees are disappearing
• Umapo has 20 cows and 1 bull. La Victoria has 30 cows. They feed in the savannas and we don't give them supplements
• We would like to cultivate but we don't know how
• The health center is abandoned, there is no water.
• A health promotor visits the village regularly.
• There are not health probems in children children
• They are the last group of achabas and they are loosing traditions
• There is a school in each village but no intern shool.</td>
<td>3a)-Causes controlable within the group
• We hardly cultivate and we are destroying the forest
• We over-exploit fish and game</td>
<td>3b)-Causes not controlable within the group</td>
</tr>
<tr>
<td>4-a) Things to do
• Let the forest rest
• Learn to cultivate in the savannahs
• Cultivate varied crops
• Give food supplements to cows
• Make home gardens and organic fertilizer
• Plant trees: ceje, moriche, palma real, cabui, ciruelos
• Construct facilities to raise chiguiros, curi, iguanas, etc
• Sow introduced pastures
• Establish controled hunting
• Find out about alternative materials for roofs
• Name cultural coordinator
• Write project for intern school</td>
<td>4b) Things to ask for
• Technical assistance for agriculture and livestock, home gardens
• Seeds for trees
• Water pump for the health center
• Funding for the intern shcool</td>
</tr>
</table>

3.3. Analysis of Actors

In March 2001, the governor of the reserve organised a workshop with CIAT and the UMATA of Puerto López, with the participation of CORPOICA and a biology student from the Universidad Javeriana. This workshop had the objective of focusing the actions for forest conservation, and to present advances in the other actions and requests that were evoked during the first workshop. In preparation for this meeting, we made large prints of a Landsat ETM image acquired on December 13th, 2000. The meeting started with a recapitulation of the exercise done the year before, and the different actions that were done by the participants, the villagers, UMATA and CIAT, mostly with respect to agricultural development and technical assistance on markets and soils. We then followed with a discussion on what needed to be done next with respect to forest conservation and regeneration. This discussion started with an analysis of the different actors, using a simplified version of the grids proposed by Moquay *et al.* (2001) as a framework.

We prepared the list of actors presented in table 2 simply by brainstorming. Many of the actors were present (villagers, community leaders, school teachers, UMATA, CIAT, CORPOICA, Universidad Javeriana) and they were able to explain their possible role to the rest of the participants. This served as an informal engagement for action. We also named all other possible actors that could play a role in forest conservation, either in regulation, incentives or technical assistance. Each of us found out about the existence of at least one actual or potential actor, before unknown to us. The results of this exercise are given in table 2. We then set out to establish the links between these actors, drawing arrows on extra pieces of large papers. It became obvious that no specific actor was responsible for the links between all of these actors. Somebody or some group was necessary to co-ordinate these relationships, to co-ordinate the actions, ask for technical assistance, present projects for incentives. It was decided that a committee should be formed, and that at first this committee would be under the supervision of the governor of the reserve. We then added this committee to the list of actors, in table 2. The results of this analysis of relationships are shown in figure 3. This committee remains to be created, and the actions of all other actors depend in large part on the leadership that will take place within it. Many external actors could be involved if solicited.

Table 1 : List of actors

ACTOR	TYPE	GROUP	ISSUES (and tasks)
Administrative systems of communities and reserve	Administration	Direct actor/regulator	Make internal regulation with respect to tree cutting, burning, applying agrochemicals and agriculture on the border of streams
Farmers and other villagerrs	Villagers	Direct actors	Cultivate land and use trees for fire wood and construction
School teachers	Teachers	Direct actors	Provide environmental education to the children
CORPORINOQUIA	Administration	Regulators/possible funding agency	Should enforce the application of state regulation (for example, protection of gallery forest on stream banks) but do not intervene. Can apply fines if regulation is not respected but can also provide incentives for reforestation. (*Certificados de incentivo forestal*)
UMATA	Public organisation	Resources persons, links with other actors	Agricultural technical assistance, and will help in the development of greenhouses for trees
Agricultural secretariate of the *Gobernación*	Administration	Resource persons/ - possible funding agency	Could provide incentives for reforestation (for example, they have a program on bamboo)
CIAT	International organisation/scientists	Resources persons/research	Assistance in NRM, moderating planning meetings, provide maps, crop requirements, soil information,
CORPOICA	National research corporation	Resources persons/research	Provide seeds for better adapted varieties of cassava and pasture
Primary school students	villagers	Direct actors	Participate in the collection of seeds and branches for reproduction, help in the reproduction and planting of trees and plants
Universities (eg:Javeriana, Unillanos)	Institution of Higher education	Resources persons/research	Assistance in the choice of species for reforestation, fire protection strategy and to develop wildlife raising projects (eg :Chigüirros)
Forest management Committee or local group (to be formed)	Civil society	Direct actors/co-ordinators	Co-ordinate tree reproduction activities; maintain links between the community and the other actors

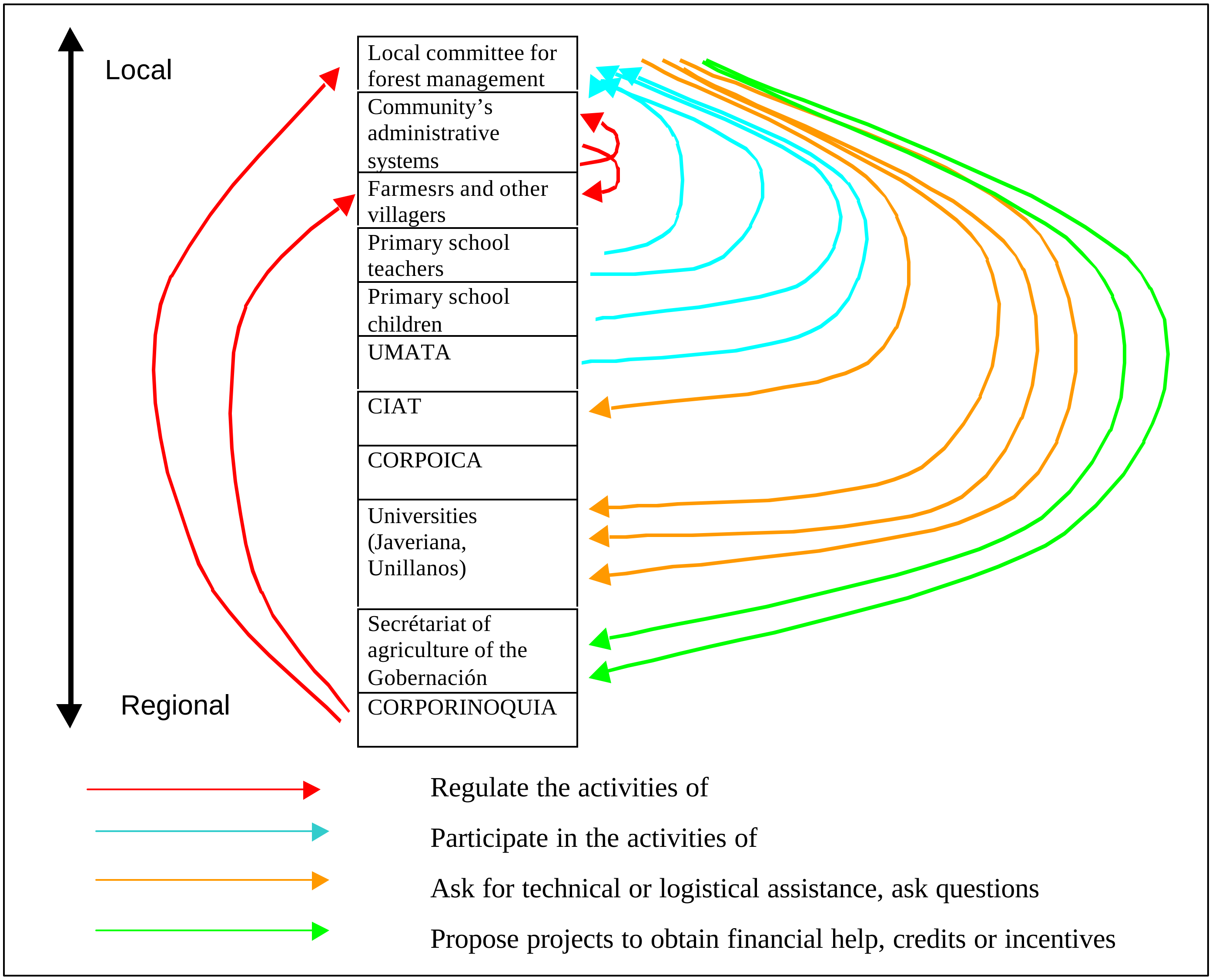

Figure 3: Relationships between actors

3.4. Use of the satellite images in the community meetings

In preparation for this meeting in March 2001, we printed out a portion of Landsat-TM image acquired in December 2000, just three months before. We made separate prints of the panchromatic band in Black and White (with a pixel size of 15m) and of a colour composite of three of the multispectral bands (bands 5,4,3, displayed respectively in the red, green and blue channels, with a pixel size of 30m). We also made a print of a fusion between the panchromatic image and the same three multispectral channels, which presents the structure seen in the panchromatic image, coloured with values calculated from the other images. This latter was the one preferred by the participants, because more detail could be seen on it. On all of the prints, a yellow line represented the limits of the reserve. All the prints were left to the community leaders after the meeting.

As seen in figure 4, we briefly explained the meaning of the colours on the images. On the 5, 4, 3 band combination, water with sediments appears blue, vegetation appears green, clouds appear white, and burned fields are black. The only odd colours correspond to bare soils and very sparse vegetation, which appear in different tones of purple and pink. The participants rapidly understood and were able to then take over the discussion, showing the different features that are distinguishable on the image, in particular the fields that were recently destined to pasture or crops. Other features visible on the image are the river courses, forests, burned areas (recent and older, with ashes washed away), pasture plots, roads. The drainage network, which is lined with riparian vegetation, is also visible. Dissection of land is visible through the drainage network and also partly through the observation of different shades in the burned areas. When more mountainous, our appreciation of relief is helped by the different intensities related to the more or less direct illumination by the sun. Table 3, adapted from the grids presented in Moquay *et al.* (2001), summarises the characteristics of the spatial representations seen in this image.

When participants were asked to describe what they would like the same image to look like in ten years, they unanimously replied "green!". However, we all agreed that the whole reserve could not be reforested because land is needed for agriculture. We discussed the different types of agriculture that are possible in the different landscape types (*vegas, terrasses, altillanura, Serranía* and depressions within the latter two) and that intensive agriculture should be concentrated only in the *altillanura plana*, although cassava could continue to be planted in rotations with fallow on the border of streams in dedicated *conucos*. Stream banks and the *Serranía* were identified as the priority areas for forest recuperation and reforestation. However, we decided to conduct a later meeting with experts in the field, once the forest management committee would be organised, about the which measures to take, which species to reproduce and where to plant what. The image prints were of great use in community planning meetings. They were more or less used as a base map, where one can point at the location of passed or future actions. They can also help develop a shared vision of the present conditions of the territory being planned, by providing a representation that is more neutral than many thematic or topographic maps. It also helps motivate people to act by making them understand that they will be able to see the effects of many of their actions in images that will be taken later. However, an analysis of images of different dates is necessary to support or refute the local perception stated in the participatory envisioning step ("the forests are disappearing") and to see where changes have occurred. This will also help locate where measures to protect forest from burning, for example, are most important.

a) b)

Figure 4: use of the images in community meetings. a) the meaning of colours is explained to participants. b) they take over the discussion, pointing to the features of interest, particularly to recently developed agricultural land.

Table 3: Characteristics of the spatial representations present on the image prints

Spatial representation Characteristics	1 Landsat TM colour composite	2 Limits of the reserve
Type	Satellite image colour print	Digital vectors, lines overlaid on the image print
Spatial scale and coverage	1 :10000 (print) Coverage : 10 km x 10 km	1 :10000 (print) Coverage: 10kn x 10 km
Temporal scale and coverage	Instantaneous, 13 December 2000 (3 months before the workshop)	
List of spatial objects	Pixels, texture, structures, shapes Spatial objects visible: • Gallery Forests and drainage network • Meta River • Burned areas • Area planted in improved pastures • Areas planted in cassava (not on stream banks) • Areas prepared for corn	Limits of reserve
List of variables represented		
Themes represented		Limits of reserve
Involved actors	Villagers, CIAT, UMATA, Universidad Javeriana	Villagers, CIAT, UMATA, Universidad Javeriana
Mean of appropriation by actors	Paper prints produced by CIAT (they were left with the community leaders) Use of the images in community meeting to illustrate the agricultural activities, forest cover, burned areas, landscape types Imagining how the community would like to see the image in 10 years	

3.5. Determination of indicators for diagnosis and monitoring

The following indicators were defined for diagnosis and monitoring. (The ones with one * can be estimated from the images. The one with ** can be estimated from the images combined with field checking). We chose to define indicators of state, pressure and response, as described in Winograd (1995) and Winograd and Farrow (2001):

- <u>Indicators of state</u>: Forest cover*, population of useful species (flora and fauna), cultivated surface**, yields of crops, benefits from crops
- <u>Indicators of pressure</u> : Extension of cassava on stream banks, burned areas in savannah*
- <u>Indicators of response and action</u>: Fire protection initiatives, reforestation**, new surfaces in well-managed forage crops**, Surfaces cultivated in varieties of cassava that are well adapted to the conditions in the “altillanura”**, other crops**, Ghigüirros raising areas.

3.6. Determination of questions to focus actions

We determined the following questions for focusing the actions :

a) for fire protection

- **Where should we be completely protecting land from fire?
- **Where should we conduct preventive burning practices? [2]

b) for reforestation

- Which species should we plant?
- Where should we plant them?
- **Where are the areas where natural regeneration would be sufficient, and where we should not bother to reforest?
- **Which areas were recently deforested for agriculture and could be reforested once the agriculture activities can be transferred elsewhere?

c) For adjustment of agricultural and livestock activities

- In which areas should we confine cows?
- Which forage crops should we cultivate, and where?
- Which varieties of cassava should we cultivate and where?

3.7. Use of the images to monitor forest cover

After conducting the workshop in March 2001, we were able to purchase an image that was acquired on March 3rd, 2001. We also had purchased an image of January 11th 1988, to be able to support or contradict the local perception that forest cover had been depleting in the last years. These two images were geo-referenced to the same cartographic projection as the image of December 13th 2000. All three images were processed with a very thresholding approach in order to extract forest cover. Pixels having a lower red (band 3) digital number than a given threshold and a higher Near-infrared (band 4) digital number than another threshold were assigned to the forest class, and all others were assigned to the class "other". The threshold values were determined separately for all three images by observing profiles of the digital numbers for these two spectral bands in cross sections of the gallery forest and its transition (usually quite clear) with native savannah. We created a new image of forest and non-forest for each date, with a digital number of 255 where we have forest and 0 for non-forest.

Figure 5 shows an image of the changes in of forest cover between the dates. In red, we display the areas that were forest in 88 and that were not in December 00 but then were forest again in March 00. Areas in yellow indicate areas that were forest in 88 and that were neither forest in December 00

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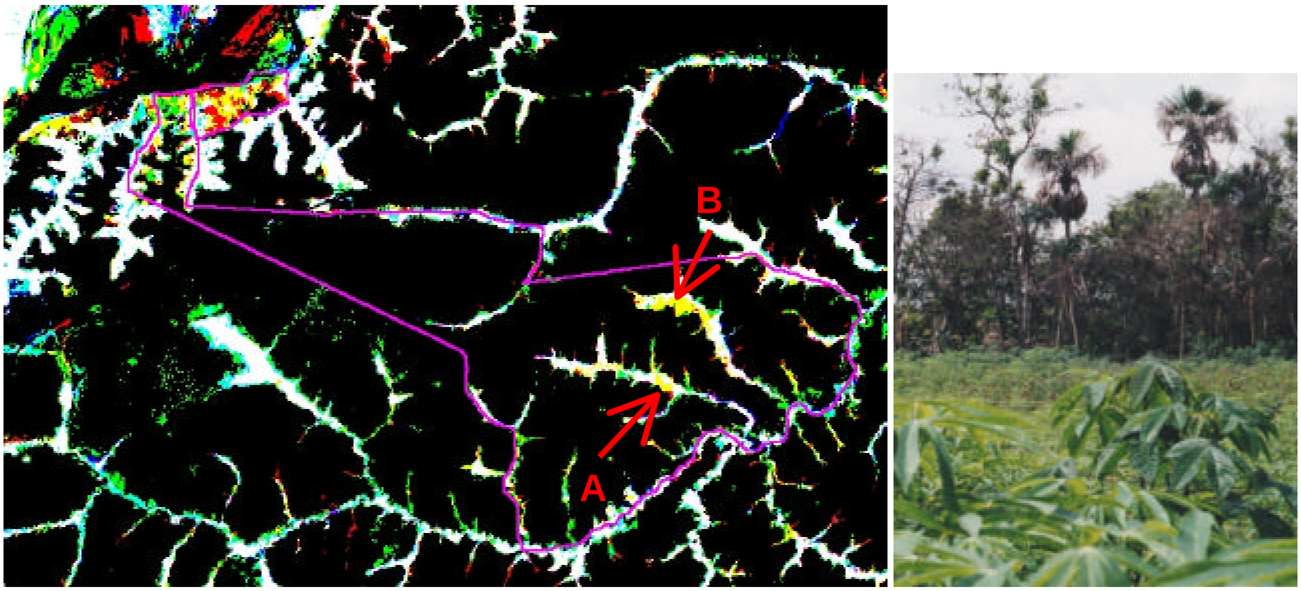
[2] To prevent trees and shrubs from being affected by fire, one can conduct preventive burning at the end of the wet season, just a few days after rain. Since ligneous take longer to dry out than do grasses, grasses burn but trees and shrubs are not very much affected. A periodical preventive burning can be prevent the accumlation of grass biomass beneath regenerating forest, preventing a catastrophic effect of accidental fire during the dry season (Kellman, personal communication, 2000)

nor in March 01. Areas in blue indicate areas that were forest in December 00 but that were neither in 88 or in March 01 and areas in cyan indicate areas that were forest in 88 and December 00 but that were not in March 01. The areas shown with the red arrows were visited in the field with members of the community. The areas of forest were cut down during the dry season between December 2000 and March 2001 to plant cassava.



a) b)

figure 5: a) image of changes in forest cover between dates. b) photograph of a cassava plantation established during the dry season of 2000-2001, indicated by arrow A.

What is even more interesting is to observe the areas in green, which were classified as forest at the end of the wet season and as non-forest at the end of the dry season. These can reveal the areas where forest regeneration (or at least important vegetation growth) occurs during the wet season but is burned during the dry. These are areas where preventive burning could be used successfully to encourage natural forest regeneration. Within the reserve, it is necessary to nmanage some of the native savannah area for grazing. Fires tend to spread from these burned areas or from neighbouring farms. This is why preventive burning would be such an important practice.

Figure 6 shows zooms onto the portions of the images shown by arrow B. Frames a, b and c show the 5,4,3 composite for January 88, December 00 and March 00. Frames d, e and f show the thermal band for the same three dates. The brightness of the same areas in the thermal band confirms that these areas are bare, possibly burned soil, and not flooded with water. The lines displayed in yellow are the contour of the forest areas in 88, the cyan lines are the contours of the forest in December 00 and the orange lines are the contours of the forests in March 01. These contours were obtained by first filtering the images of forest cover with a modal filer of kernel size 3x3 and then by eliminating all isolated groups of 3 pixels or less. The contours were then automatically generated using the image processing software.

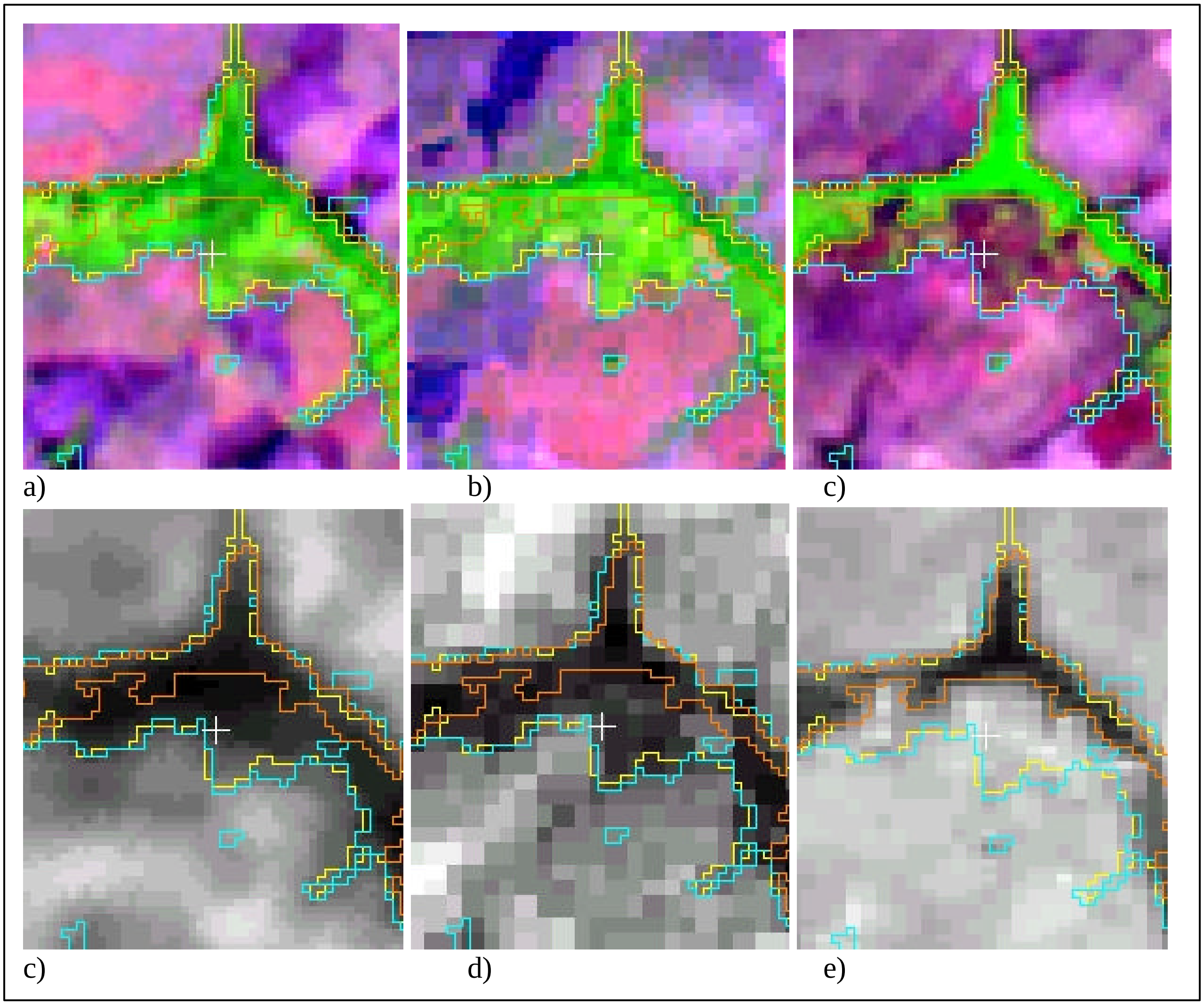


Figure 6: Frames of image close-ups taken at location of arrow B. Frames a, b and c show the 5,4,3 composite for January 88, December 00 and March 00. Frames d, e and f show the thermal band for the same three dates.

3.8. Follow-up with the community

A meeting was conducted with members of the Cabildo board and several members of the community to discuss various aspects of their agricultural development in the reserve. Considerable effort is made by community leaders and villagers to shift the cultivation of cassava from the forest-covered moist and fertile depressions to the less fertile and acid *altillanura* soils. However, the deforestation that was observed earlier in the year had been motivated by the lack of funds to buy the fertiliser necessary to plant the cassava in the *altillanura* soils. The board of the *cabildo* discussed the necessity to encourage its internal regulation prohibiting the replacement of forest by cassava with a more aggressive agricultural production strategy. To support this agricultural strategy, trials to evaluate improved varieties of cassava, better adapted to the acid soils of the *altillanura*, will soon be initiated by the UMATA. The wisdom of keeping part of the benefits from a harvest to cover inputs of the next crop is helpful only when there is some commercial activity.

A comparison of the images taken at the beginning and end of the same dry season enabled us to identify areas where forest could be regenerating during the wet season but that are burned during the dry season. These areas could benefit from the application of preventive burning in relatively moist conditions, to avoid the accumulation of grass biomass that can cause more intense fires, which are much more damaging to small trees during the dry season (Kellman and Thackaberry, 1997). The visualising of images in the future will allow inhabitants to appreciate the results of their management efforts, and the fact that these efforts will be visible from above brings additional motivation.

Once the cultivated areas near stream banks lose their natural fertility and become unsuitable for cultivating cassava, they should be the object of preventive burning or reforestation.

Next steps are the following:

a) For the work in the reserve, the community will
- continue with the actions planned in table 1,
- create forest management committee
- plan and execute preventive burning, fire protection, reforestation, environmental education

b) the UMATA will
- Provide technical assistance with agricultural activities and follow-up monitoring

b) To finish this study and for methodological development in Land Use Planning, CIAT will
- Complete quantitative analysis of land use changes within the reserve
- Make the image processing more usable by end-users like UMATA and NGOs, by including image processing algorithms within the SPRING software.
- Test the entire methodological framework in other case studies
- Provide training

d) Other actors
- Provide technical assistance with forest management (U.Javeriana)
- Provide forest incentives if projects accepted (CORPORINOQUIA)
- Provide images to the UMATA in the future (Municipality or other institution)

3.9. Discussion

3.9.1. "Extrapolability" of this methodological framework to other sites

This site has specific characteristics, and we might argue that the approach presented here could not be applied to other sites. In deed, large community areas managed by smallholder native populations is an unusual situation in the Colombian llanos, where smallholders are usually concentrated in very small areas and very large areas are owned by individual, richer farmers. This situation is only made possible by the indigenous reserve, and some other similar can be found where communal lands have been given to villagers by municipalities, such as the case of Puerto Guadalupe. However, there are many other places in the world where peasants manage large, communal lands. Also, in many cases, villages are sufficiently large to allow medium resolution images to give relevant information. In smaller villages, high resolution images can be used, although it is more costly.

This methodology can also be used in the context of municipal planning, but using a multi-level planning methodology. The participatory envisioning and action planning can be conducted with the individual groups of actors (villages, farmer associations, industries, other groups, NGOs, etc…) and then repeated at the municipal level. It can be especially useful for the planning of actions and monitoring of natural parks, where forests and river dynamics are relevant information that can be provided by satellite images.

The approach of designing data acquisition and process data in function of the questions addressed by planning, through the determination of desired future conditions and the definition of indicators, is applicable to any strategic planning situation, regardless of scale or theme.

3.9.2. Limitations of the Remote Sensing technology used

Limitations of the images are many and must be taken into account. The ones we used, Landsat TM and ETM with a spatial resolution of 28.5m, allow the mapping of the extension of relatively dense vegetation, which we classify as forest, but give little information on the species composition of these environments. The decline in population of useful tree and plant species, as well as in fauna, would go unsuspected (and undetected) if they had not been described by the villagers. In his study in Mexico, Casalegno (2001) found that degraded tropical forest was very difficult to identify with multispectral imagery because it did not necessarily present lower green biomass. Different types of forest could maybe be distinguished through more research, and higher resolution imagery (and an order of magnitude more expensive) could eventually be exploited. However, no imagery to date seem to be in a position to replace field observations of species present in the forest. A ground monitoring program will therefore be designed with the *cabildo* board, with the help of the ecology department of the Universidad Javeriana, along with the action plan.

There is another limitation of the imagery that is specific to very irregular environments such as the *llanos* and its gallery forest. Since the perimeter to area ratio of this forest is very high, classification errors committed on the border between forest and other uses can become significant with respect to the total forest area. The use of different re-sampling methods during geocoding will produce distinct results at the border between two different environments. Images of different dates, if to be compared, should always be submitted to the same pre-processing methods and be classified with the same approach, but even then, successive values of the indicator “total area of forest” should be considered with great care, if not at all. The period of the year in which the images are acquired (moist or dry) will also influence the estimate of forest coverage. Estimates made with images of different resolutions will also differ from each other. We chose to use the images mainly to point out areas of interest to be checked in the field, and also to document the dynamic processes.

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