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A Proposed Framework for Using Remote Sensing Imagery to monitor environmental dynamics in support to local planning efforts

Nathalie Beaulieu[(1)], Grégoire Leclerc[(1)] Mauricio Alvarez[(2)], Gérard De Wispeleare[(3)], Jaime Jaramillo[(1)], Yolanda Rubiano[(1)], Adriana Fajardo[(1)], Ovidio Muñoz[(1)], Noemí Peñuela[(4)]

[(1)]Centro Internacional de Agricultura Tropical, CIAT, Land Management project,
[(2)] Corporación Colombiana de Investigación Agropecuaria, CORPOICA,
[(3)] Centre de coopération international en recherche agronomique pour le développement, CIRAD-EMVT,
[(4)]Unidad municipal de Asistencia Técnica Agropecuaria, UMATA, Puerto López

Abstract

Despite its potential for monitoring environmental dynamics, the adoption of Remote Sensing technology for local planning has been low, which leads us to think of a new paradigm for its role and application. Our experience has showed that local actors take ownership of this technology when it allows them to effectively answer questions that arise during the planning process, either during diagnosis and monitoring or in action planning. When these questions are not well defined, much effort is spent in descriptive collections of data from which it is difficult to draw useful conclusions. In those cases, remote Sensing images simply add to the quantities of confusing data acquired. Through ongoing case studies in the Colombian Eastern plains (or *llanos*), we propose a framework for using remote sensing images in community-based natural resources management. Community goals are expressed as “desirable future conditions”, determined in a participatory way and based on an envisioning process. Using carefully chosen indicators, present conditions and trends are described with respect to the desired conditions and progress towards these goals is monitored. Remote sensing imagery play a fundamental role in the estimation of some of these indicators in a timely, low-cost, and intuitive manner. They also help certain actors focus their actions in space and time.

In the two examples presented, we apply very simple analysis techniques to time series of multispectral images, to identify possible areas of deforestation, forest regeneration or pasture degradation. These areas are then further investigated in the field. Our ongoing research with other organisations aims at developing reliable methods to assess pasture conditions, combining satellite image analysis and field surveys. We have very encouraging preliminary results using various multispectral images within a year, which allow us to identify areas that present a persistently low vegetative cover. The image analysis techniques that we developed are being adapted to software that can be freely distributed to users. This framework could be widely adopted by local planners and agricultural extension agents but this requires adequate networking between providers and users of data and technical support.

1. Introduction

Aerial photographs and, more recently, satellite images, are available on the market in a range of spatial resolutions (or scales) and spectral characteristics (panchromatic, multispectral, radar, thermal, etc…). They give a synoptic view of a territory and therefore present obvious usefulness for the management of natural resources. Remotely Sensed imagery can be effectively used in participatory processes related to local development as it can help actors develop a common representation of the territory (Adell et al, 2001). It can be used as a cartographic reference for peasants to map the characteristics of their land (Imbernon, 2001, Maurel and Moity-Maizi, 2001) and therefore presents a support on which to collect and structure local knowledge. Other studies have shown the use of Geographic Information Systems (GIS) as a cognitive tool in participatory planning (Talen, 2000), which can also integrate Remote Sensing imagery. Time series of images can bring relatively objective[1] pictures of the trends in the extent and quality of natural resources and help us map dynamic processes such as modifications of river courses, deforestation, reforestation, agricultural migrations, etc…. In addition to all the information that can be derived from their visual interpretation, digital images can also be analysed through automated or semi-automated procedures to provide rapid assessments of the distribution or state of certain natural resources. However, the aim of this article is not to convince the reader of the potential of Remote Sensing imagery but to provide approaches to help natural resources managers fully exploit this potential to reach their development goals, while also considering limitations of the technology.

Indeed, the potential of satellite imagery has probably even been oversold, and many planning professionals have been disappointed, finding the resulting maps inaccurate or of very limited usefulness for their purposes. Financial and human resources as well as technological know-how remain determinant factors, although the associated costs can be shared through appropriate networking. However, satellite imagery, just like any other data source, should be used to fulfil a well-defined need, and not as an end per se. They must respond to well-defined and relevant questions, but when describing a territory, an infinity of questions arise. However, planning goes much beyond describing, it involves defining actions, projects and rules leading to a desired future. We must therefore define the right strategic questions in order to define data needs and analysis techniques.

2. The diagnosis syndrome

Most planning methodologies involve an iterative sequence of diagnosis, action planning and implementation (FAO, 1993,UNESCO, 1997, Ministerio del Medio Ambiente, Colombia, 1997/1998), although diagnosis is in some cases referred to as "problem definition". Monitoring can consist in a series of diagnostics made during and after the implementation of actions. However, too many planning efforts remain persistently in the diagnostic phase. Diagnostic activities are often extremely descriptive, and when descriptions have no reference there is no limit to the quantity of information required. Large quantities of information can be compiled, gathered, systematised, without necessarily allowing any useful conclusion to be drawn from them. However, a diagnosis should consist in the comparison of the actual conditions with the desired ones (Ministerio del Medio Ambiente, Colombia, 1997/1998), not only in a description of present conditions and trends. Descriptions should be made in order for the comparison to be possible. For example, when a medical doctor takes a patient's temperature or has cholesterol measured in a blood sample, it is to compare it with the ranges of values corresponding to a healthy individual. He or she also knows

[1] Un-interpreted, un-classified photographs or satellite images can be less suggestive than maps, which "must offer a selective, incomplete view of reality in order to avoid hiding critical information in a fog of detail" (in "How to Lie with Maps", Monmonier, 1996). Although maps and images always distort reality, as do any type of representation, the distortions created by images are determined by the limitations of the sensors and display devices, whereas maps can convey intentional or non-intentional human distortions, that depend on perceptions or opinions of particular actors. However, we can turn limitations of satellite imagery into "lies" just as we can with maps. For example, if satellite imagery do not pick up degradation processes that actually do exist, they can be used to convince the population or decision-makers that the perceived problems are not founded.

that temperature and blood cholesterol content can serve as indicators of the presence and level of specific health disorders. Winograd (1995) and Winograd and Farrow (2001) explain how indicators can be used in Natural Resources management.

To continue with this medical analogy, we call the diagnostic syndrome a state of anguish that affects planners (or the persons charged with planning[2]) when they try to make a diagnosis without having a set of "desired future conditions" to which to compare their descriptions. GIS and Remote Sensing specialists can provide and organise data to help the descriptions, but the actual diagnosis requires a prior definition of those desired conditions. Different participatory approaches can help planners develop a concerted version of them with citizens, through discussions of a common vision of the future among actors (Beaulieu et al., 2000, Lightfoot, 2001, Leclerc and Narvaez, 2001). Kelley and Becker (2000) state that "a plan to fulfil a vision can be one of the most exciting plans to develop" but also mention that a true vision is usually associated with strong (often informal) leadership and is often not developed in a participatory manner. Whichever the type of planning, an expression of the desired future conditions will help guide data analysis towards extracting meaningful information.

3. Proposed approach

We propose that the planning process be organised around a series of steps during which planning questions will emerge and guide data acquisition and analysis. However, it is necessary to acquire a minimum amount of information at the beginning of the process to gain a general understanding of the socio-economical and biophysical contexts of the territory or study area[3]. These steps are the following:

1. Gathering and compiling of basic, existing information over the territory or study area.
2. Analysis of actors[5] and stakeholders as well as their respective roles in the territory or study area.

[2] Whereas in certain countries "planning" is a well defined profession and practice, accompanied by unions and faculty departments, it is not in many others. In these, planning is a practice that is often adopted spontaneously by different types of professionals in response to a great demand created by national de-centralisation policies. This is not necessarily negative, but the diagnosis syndrome tends to affect planners during their first experiences.

[3] We will use the word "territory" either in the context of "comprehensive planning" (see Kelly and Becker, 2000), where a person or organisation plans over the area it is responsible for, integrating all sectors of activity, or sectorial planning, involving only one sector. We will talk about a "study area" when a specific problem or issue is to be addressed and all geographical areas contributing to this problem or issue are considered.

[5] Ravnborg et al. (1999/2000) and Ravnborg and Westerman, 2000 present a stakeholder analysis method. Part of he framework presented by Moquay et al. (2001) and Lardon (2001) can also be used for the analysis of actors. To deal with different terminology, we will define an "actor" as any person, group, institution or natural agent whose actions, policies, rules or decisions will affect conditions within the territory or study area. We will define "stakeholder" as any person, group, institution or natural agent whose well-being will be affected by the conditions in the territory or study area, and therefore by the actors. In many cases, actors are also stakeholders, but there are some differences. For example, future generations are stakeholders but are not actors because they are not yet able to act or make decisions regarding the territory. On the other hand, some actors might not be conscious and might not even care about the effect that their policy or activities have in a given location. In the rest of the text we will talk about actors because they will either be involved in the planning process or their effects absolutely need to be considered. Stakeholders who participate in the planning process automatically become actors. An actor group such as an NGO can represent the interests of stakeholders such as flora, wildlife and future generations.

3. With actor groups, considering the study area or territory: statement of the desired future conditions, preliminary description of present conditions and tendencies, preliminary assessment of the actions and rules necessary to achieve the desired conditions
4. Definition of questions for diagnosis and monitoring and definition of indicators of state, pressure and response, potentially useful for the different actors. When possible, objective values or ranges should also be given for the indicators.
5. Formal description of present conditions[6], tendencies and actions through indicators developed in step 3, using existing data as well as new data from surveys, field measurements and remote sensing imagery
6. Formal comparison of present conditions with desired future conditions, evaluation of causes of these differences.
7. Definition of action planning questions, and definition of the data necessary to answer these
8. More precise definition of actions and rules in function of data acquired, consulting with experts (this can include the elaboration of scenarios that can be compared with each other in terms of the defined indicators)
9. Implementation of actions and rules by actors

These steps do not follow a rigid, linear sequence, but rather form an iterative, successively refined, learning process. For example, steps 5 to 9 form the basis of the well-known evaluation-action loop. Also, the analysis of actors in step 2 will be very much improved during step 3, as actor groups express the actions they request from others. The description of the desired future conditions can greatly evolve as we learn more about the territory and as actors communicate with each other. The indicators to be used will also evolve with time.

Steps 4 and 7 correspond to two types of questions, the first referring to diagnosis or monitoring-and-evaluation, the second to action planning. The first type includes "How far are we from the desired conditions? Are we getting better or worse? Is the situation intolerable, tolerable or just fine? Given the existing external forces, how are we likely to progress? What is being done about it? ". These questions will lead to the definition of indicators, and we suggest the State, Pressure and Response indicator model described by Winograd (1995) and Winograd and Farrow (2001). The second type includes "We have an idea of what we should be doing, but which are the best options? Are these actions feasible? Where should we apply them? Over how large of an area? When is the best time to act? Which would be the best combination of actions?". These are on a more direct path to action, so we will simply refer to them as "action planning questions".

It is clear that this framework promotes integration of many disciplines, which will benefit from improved communication and networking. Forester (1989) sees the planning practice mainly as communicative action. Engel (1997) insists on the importance of "applied networking" as a discipline to support agricultural innovation. Planning in rural areas also involves disciplines like rural sociology, agronomy, economics, hydrology, ecology, geology, transportation engineering, geography and health. It can also involve a range of skills, techniques and technologies such as mediation, facilitation, field surveys, field measurements, mapping, GIS and Remote Sensing. Planners have the responsibility of being co-ordinators of a planning process, and link professionals of the different disciplines and skills.

[6] This formal description can stem from local perceptions, which can themselves be quite well formalised. See Ait Alhayane (1998) and Clouet (2000) for methodologies and examples of local-perception based mapping.

It also becomes clear that Remote Sensing imagery can only bring a small portion of the information necessary to estimate meaningful indicators and answer action-planning questions. It will not give an answer to all questions. However, in certain cases such as the ones where dimensions of space and time must be integrated, it can help make assessments that could not be made reliably otherwise. This is discussed in the next section.

4. Two case studies in the Colombian *llanos*

The proposed framework is presently being followed by our team in the Puerto López municipality, in the Colombian *llanos*, and two specific cases have emerged where remote sensing play a key role. One case addresses forest management in the indigenous reserve of Humapo and La Victoria (Beaulieu et al, 2001); in this case remote sensing was used for monitoring of forest resources. The other case addresses improving productivity in pasture areas across the municipality; in this case remote sensing was used for identifying pasture areas that are potentially degraded . Table 1 summarises our results for the various steps addressed during the planning process. These are very simple examples where there are no conflicting views of desired future conditions between actors and where we identified the need to use time series of satellite images to answer specific questions.

Note that these case studies are spin-offs of a more exhaustive comprehensive planning process in the municipality of Puerto López (Alcaldía de Puerto López and CIAT, 2000). Indeed, in Colombia, the recent legal obligation imposed to municipalities to develop master plans (in Spanish: *planes de ordenamiento territorial*), created a demand for generic and robust approaches. During the design of Puerto López master plan, satellite imagery was used in numerous community meetings and was distributed to persons active in planning and technical assistance. In addition to allowing the general monitoring of land use in the municipality, the imagery is allowing certain actors to focus and monitor their actions.

4.1. Forest management in the Humapo/La Victoria indigenous reserve

In this 4152 ha reserve, inhabitants depend greatly on their natural resources, their diet being mainly composed of fish, game and cassava. The materials necessary for the construction of houses, roofs and crafts are provided by the gallery forest and have become extremely scarce in the reserve. Since the municipal exercise of *Ordenamiento territorial* conducted in 1999 and 2000, which involved all the villages composing the municipality, the board of the "*cabildo*" continued the effort of managing their natural resources, with the help of the Colombian ministry of agriculture extension service (UMATA) and CIAT.

This planning was focused on a discussion of future desired conditions by the population for the reserve, from which they made a description of present conditions, a preliminary diagnosis consisting in an analysis of the differences between these conditions and their causes, and a list of possible actions by the present actors and by others. During the description of desired future conditions, villagers insisted on a healthy and extensive natural environment, for the reasons mentioned above. Following this exercise, and concentrating on the objective of increasing the surface of forest and the concentration of useful species, present and planned actions are being focused more and more precisely. These include protection against fire, preventive burning, the displacement of agricultural practices, agricultural intensification in selected areas, and the raising of wild animals. For the focusing of these actions, questions are raised, as shown in table 1.

Image classifications were made in CIAT from satellite images of 1988, 2000 and 2001 and were compared to identify areas where forest was eliminated during the last decade and discuss the causes of these changes. These classifications were derived using a very simple rule based algorithms, using thresholds of digital numbers in the red and near-infrared bands. Areas with low red digital numbers and high near-infrared digital numbers were classified as forest. The thresholds were different for all three images. Figure 1 a) shows the result of the superposition of all three binary classifications (forest/non-forest) in a colour composite (January 1988, December 2000 and March 2001 respectively displayed in Red, Green and Blue). White areas indicate areas classified as forest in all three the three dates, black areas were not classified as forest in any of the dates, yellow areas have been deforested only since December 2000 and red areas were deforested after January 1988, or correspond to changes in the river course. Cyan areas represent possible forest regeneration and green areas represent areas that were classified as forest only after the wet season.

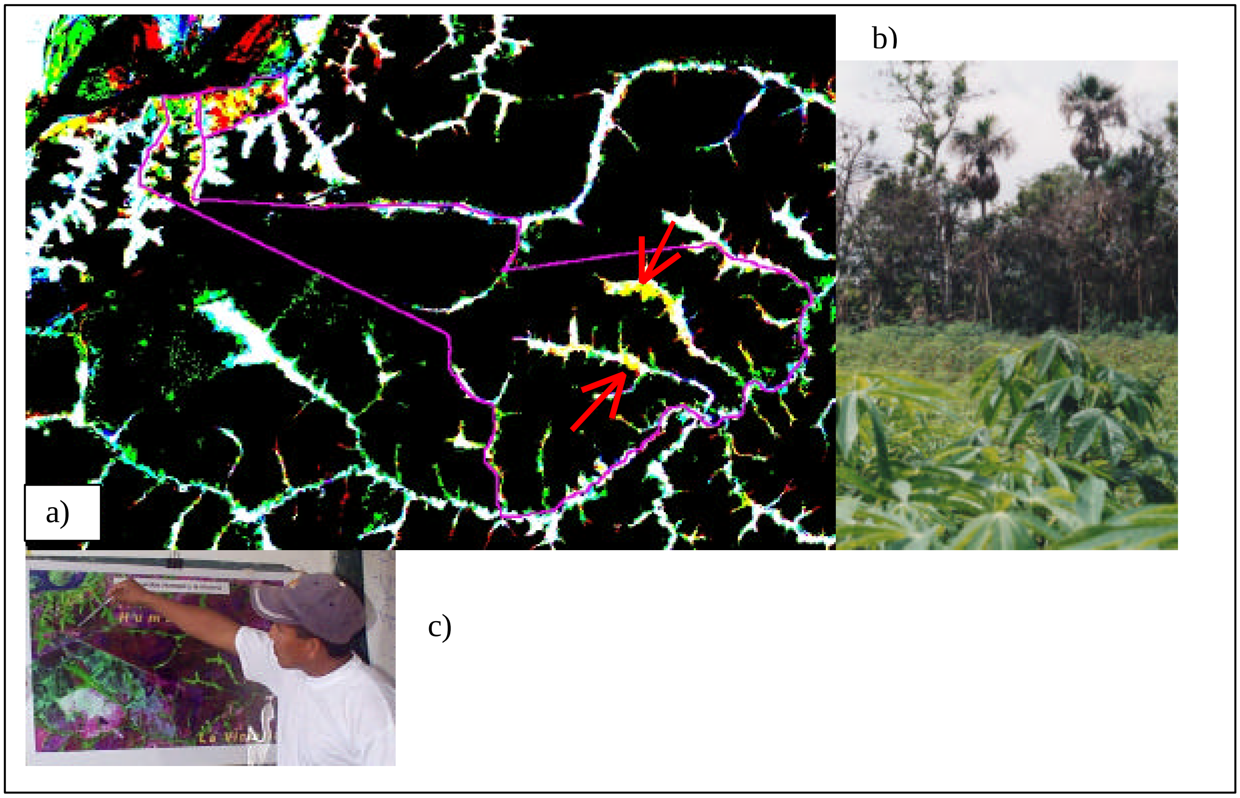


Figure 1: Humapo/La Victoria indigenous reserve. a) Colour composite of three binary images resulting from classifications of forest/non forest. In red, Green and Blue (RGB), respectively: forest in January 1988, December 2000 and March 2001. The magenta line represents the limits of the reserve. b) cassava plots recently planted in the forest, in the area showed by the lowest red arrow. The higher red arrow indicates an even larger cassava plantation. c) José Carben Rui Arrepiche, former head of the *cabildo*, points to a plot of introduced pasture that is cultivated to reduce burning in the native savannah areas.

Although 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, the recent deforestation of two considerable forest patches was detected on the images, and were verified in the field (see figure 1 b). The board of the *cabildo* (community leaders) discussed the necessity to encourage its internal regulation prohibiting the replacement of forest by cassava with a more aggressive agricultural production strategy. Indeed, this deforestation had been motivated by the lack of funds to buy the fertiliser necessary to plant the cassava in the *altillanura* soils. 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.

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.

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.

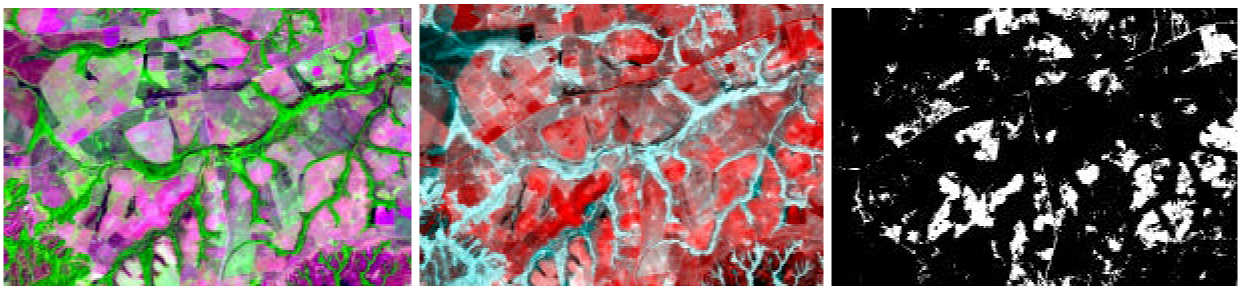
4.2. Improving pasture conditions in the Puerto López municipality

The main actors of this example are subsistance farmers and cattle ranchers, who respectively receive technical assistance from the UMATA and the cattle ranchers association (in Spanish: *asociación de ganaderos*). The desired future conditions for these actors regarding their pastures are not ambiguous or conflicting: they all want healthy, productive pastures. We will define *pasture degradation* as the change of pasture conditions that reduces the profitability of livestock activities, affecting pasture quality and/or quantity. Possible causes of it are inadequate fertilisation or nutrient recycling, soil compacting, overgrazing, undergrazing, poor drainage, pests, rainfall regime changes and, in the case of cultivated pastures, invasion by weeds (Rincón, 1999). The actions to achieve the desired conditions are mainly in the domain of agronomic management. However, the political and economic context, influenced by political and economic actors, will affect the farmers' actions. For example it might be more advantageous for a landowner to convert more pristine land into cultivated pastures than to manage or reclaim existing cultivated pastures. Maybe some of the existing pastures have been established in response to incentives, agricultural development programs or for land speculation, and now livestock is not among the land owner's priorities.

Other actors are also interested in bringing solutions to pasture degradation. For example, the municipal government of Puerto López, who declared two linked municipal parks within the territory, is not interested in having more pristine land converted to agriculture. They, as well as the departmental government, are on the other hand interested in stimulating production and economic growth. A new corn hybrid, which was developed for the acid soils of the *altillanura* of the Colombian *llanos*, has great potential to be used in agropastoral systems for the reclamation of degraded pasture land. Technical assistance in the use of this crop, as well as any other adequate management techniques, could be focused to areas where pastures are degrading. Farmers are also interested in prioritising the management actions on their land.

Through this study, we examine the possibility of using Landsat and SPOT imagery as a support to managing pastures or focusing technical assistance. CORPOICA's experimental farms in La Libertad and Carimagua (not within the Puerto López municipality) are used as control sites. We have observed that satellite images can advantageously support monitoring efforts by local actors who have knowledge of the local production systems, and who have the possibility of ground-checking any assessments made from the images. Infestations by spittlebug or locust can be fairly obviously detected on a single image, if it is acquired at the right moment. A lower than expected vegetation index (or vegetation-related colour on the colour composite display) can indicate fertility loss or soil compaction. In any case, the cause and nature of the degradation must be verified in the field. Moreover, it is important to consider the pasture's management in any diagnosis made from satellite images. If not, recently grazed plots in a rotating management practice could be mistakenly identified as degraded in comparison to resting plots.

To avoid drawing possibly misleading conclusions from a single image, we decided to use a series of three images acquired within a year and to identify areas showing persistently low ground cover in all three images. This approach is being tested in Carimagua, with two SPOT images and one Landsat ETM image, in the Puerto López municipality and in the La Libertad station, with three Landsat ETM images. The class "persistently low vegetative cover" is assigned to pixels having a minimum brightness value, in the three dates, that is higher than a pre-defined threshold and a maximum value of the vegetation index that is lower than another threshold. This class can also correspond to roads and any other permanently bare area, therefore final results need to be edited by the user. Thresholds were defined using samples of known degraded pasture plots in the Carimagua station. Figure 2 shows results of this analysis for an area in the Puerto López municipality. The vegetation and brightness indices are calculated through a linear combination of reflectance values in the red and near-infrared bands, as explained in Beaulieu and De Wispeleare (2001). The co-ordinates of the data are determined with respect to new axes, an estimated "soil line" and its perpendicular. The brightness index corresponds to the co-ordinate along the axis of the soil line and the vegetation index corresponds to the co-ordinate along the perpendicular axis. The latter is akin to the Perpendicular Vegetation Index (PVI) proposed by Richardson and Wiegand (1977). Relative atmospheric corrections are applied to planetary reflectance values calculated from the digital numbers in the images of the various dates, in order for the indices to be consistent in time.



a) b) c)

Figure 2: A small area (13,3 km wide) within the Puerto López municipality, where many plots are cultivated with introduced pastures. a) Colour composite of one of the three images used, acquired at the end of the wet season (13 December 2000), with bands 5, 4 and 3 respectively displayed in Red, Green and Blue. Bare areas appear in pink and light purple tones, while healthy vegetation appears green. b) Colour composite with, in red, the minimum brightness index of the three dates (16/03/00, 13/12/00 and 3/03/01), and in blue and green, the maximum vegetation index of the three dates. c) In white, areas to check in the field, having a high minimum brightness index and a low maximum vegetation index, likely to have a persistently low ground cover (thus potentially degraded). These correspond to the bright red areas on frame b).

We are also developing an image-based indicator for plots potentially invaded by weeds, but this one requires knowledge of the types of pastures cultivated in each plot. Since *Brachiaria humbidicola* and *B. dictyoneura* are competitive with regards to weeds, and they usually present good ground coverage because of their stolonic growth, these species do not tend to suffer from weed invasion. This type of degradation mainly occurs in *B. decumbens*. Preliminary results indicate that *B. decumbens* plots, even healthy ones, present higher brightness indices than the *B. humidicola*, *B. dictyoneura* or mature, native grasses. Our hypothesis is that if a *B. decumbens* plot presents a persistently low brightness index, it is likely to be either invaded by weeds or overgrown. We will soon be testing this hypothesis using a GIS coverage indicating the cultivated species in the control sites.

In this case, as in the case of the previous application, we are using image analysis to point out areas that need to be visited in the field. The actual decisions about management will be made on the basis of field observations. We are not yet at the stage where we can use the images to produce maps of "degraded pastures" to give municipal or departmental officials figures of "degraded pasture area" for different years. Although this is an indicator requested by many officials at the municipal and departmental levels, the definition of degradation is so complex (and varies so much) that we could not pretend to provide such figures at the moment. Through field validation and successive improvement of our method, we however hope to be able to provide reproducible figures in the near future.

Table 1. Summary of results for the planning processes for the two applications.

Issue	Main Actors	Desired future conditions (only relative to stated application)	Indicators of state, pressure and response	Questions for action planning	Data to be extracted from images, Methodology being used
Forest management in the Humapo/La Victoria indigenous reserve	**Core**: Villagers of Humapo and La Victoria **Coordination**: board of the *cabildo* **Technical assistance:** UMATA, CIAT, CORPOICA, Universidad Javeriana **Policy/regulation**: Municipality, CORPORINOQUIA **Possible funding of projects or incentives**: CORPORINOQUIA, Gobernación del Meta	Extensive natural areas with abundant fish and game, palms for roof construction, wood, and the plant and tree species used in traditional crafts. Forest fauna is raised in controlled natural areas and productive crops and pastures are cultivated outside the forest	**State**: forest cover (and changes in this cover over time), abundance of useful or ecologically important species **Pressure**: surface burned, areas of cassava planted in gallery forest areas **Response**: Preventive burning efforts, Planting improved varieties of pasture and cassava outside the valleys (in the *altillanura*) to reduce the pressure on the forest, reforestation	Where are the areas where natural regeneration is occurring during the wet season and is being burned during the dry season? (these areas could benefit from preventive burning) Where should reforestation be focused, and with which species?	Mapping of forest in January 1988, December 2000 (end of dry) and March 2001 using a simple threshold of a vegetation index. The areas of change between forest and non-forest in the three dates were displayed on the screen and discussed with the forest management committee and villagers. We identified Areas of fire-suppressed natural regeneration as well as areas of continuing cassava cultivation within the gallery forest. Mapping of areas burned during the dry season of 2000-2001, using a rule-based classification. Mapping of agricultural areas as well as cultivated pastures using rule-based classification, complemented with visual interpretation with villagers.
Improving productivity of pasture areas in the Puerto Lopez municipality	**Core**: Land owners (of small and large operations) Municipality: Declared natural parks in its master plan. Degrading pastures create pressure on pristine land (savannah and forest) **Coordination**: UMATA, asociación de ganaderos **Technology providers:** CORPOICA, CIAT, Unillanos **Policy and regulation**: Municipality **Possible funding/credits**: banco ganadero	Productive pastures that maintain healthy cattle (good ground cover, green plants, very few weeds, in the case of cultivated pastures) Degrading cultivated pastures are reclaimed or better managed, rather than converting more pristine land.	**State**: Green vegetation cover, plant productivity, percentage of phytomass composed by weeds **Pressure**: animal stocking rate **Response**: Maintenance, adjustments in stocking rate, rotative management; policy that encourages management rather than converting pristine land, land reclaimed using acid tolerant crops such as the new corn hybrid.	Where are the degrading areas where we should focus technical assistance for management and reclamation? (Within the farm, for the land owner, within the municipality, for the UMATA)	Pastures with consistently low ground cover: Areas having a consistently high brightness index and a consistently low vegetation index are mapped as areas with low ground cover. These areas could be crossed with a land use map to obtain statistics of areas of degraded pastures. Weed invasion (mostly occurring in *B. decumbens*) could be identified using the Brightness index. Plots of *B. decumbens* are usually brighter than *B. humidicola* and mature savannahs.

5. Discussion

5.1. Could this framework be repeated elsewhere?

As we mentioned before, the applications presented here have been conducted with the support of research institutions, with the objective of developing methods that can be applied elsewhere. Through this methodological development and through an on-going training program, we aim at helping networks of actors become able to develop functional applications on their own. But in order for the framework to be adopted, the benefits of the planning process should largely outweigh the investments made. The proposed framework can increase the return on planning investments by allowing goal setting among actor groups to converge faster and by focusing data acquisition towards strategic questions (therefore avoiding the diagnosis syndrome). The Remote Sensing component of this framework is still in development, and before we start training a great number of people in it, we need to test its user-friendliness with the target end-user, in our case the UMATA. Scientists in CIAT expect to conduct this testing and start extensive training within six months.

The villages of Humapo and La Victoria, as well as the other villages in the municipality, will benefit from the fact that the municipal government is following up its master plan using satellite imagery. This imagery will be available for consultation by farmers, farmer associations and citizens at the UMATA office. For these purposes, we are presently adapting our image processing methods, including rule-based classifications, to the SPRING freeware developed by INPE in Brazil, which is available over the internet. We will therefore be training personnel of the UMATA in the use of this software and our particular applications.

We however do not expect all municipal agricultural extension agents to become Remote Sensing technicians. We therefore need to establish which portion of the analysis are likely to be assumed by the end-users and which should be assumed by some other, more specialised institution. In a hypothetical model of data analysis task sharing, the purchase, geocoding and preliminary processing could be conducted by national or regional institutions. The images (when there is no copyright restriction) and their derived products could then be distributed in a ready-to-use form to the departmental planning, environmental and agricultural management agencies and to the municipalities, and then be consulted by farmer associations and individual farmers, NGOs and all citizens. There are still some methodological challenges for this to be possible, as we will see in the next section, but the biggest challenges are organisational. If a country wishes to make this technology available "at large", some institutions need to organise networks of data providers and users and create national data infrastructures. For examples of such national efforts in Central America, see Hyman et al, 2001.

There is also an obvious debate to which this responsibility should be taken by the public or private sectors. In the first case, the costs would be shared by agencies of various administrative levels but the products would be free to the end-users. In the second, the cost would be concentrated on the end users but can still be shared and reduced if the end-users are many and are organised in a network, or if the private companies have many clients among which to distribute the costs.

5.2. What methodological challenges remain in the field of remote sensing?

Many challenges remain to improve the adoption of remote sensing in local planning. They motivate to pursue research through collaborative projects between CIAT and CORPOICA. They have catalysed the formation of a working group around this topic at La Maison de la Télédétection in Montpellier. An informal network of researchers in Colombia, Brazil, France and Japan is now working on the theme of monitoring pasture conditions with remote sensing. Rather than making image processing techniques more sophisticated, we are aiming at simplifying and finding methodological shortcuts that facilitate the use of the images by natural resources managers in developing countries while preserving a strong learning component. There are some freely available GIS software that can be distributed to end-users (for example, SPRING, developed by INPE in Brazil, and MapMaker Popular, developed by MapMaker Limited, Dudley, 1999) that are compatible with more sophisticated but costly image processing software used by national or regional agencies. Still, we need to adapt presently available image processing techniques to:

- Allow end users to more easily integrate local knowledge into image classifications
- Allow reliable intermediate (land cover type) results to be obtained in a relatively automatic way, which can then be transformed into an accurate land use or land characterisation map by the end-user
- in areas where the land conditions are very dynamic (agricultural areas, land managed by burning, seasonally flooded areas), integrate images of different dates in the same year to evaluate land use and land degradation
- Decrease the boundary errors that become important in fragmented forest environments because of the large perimeter to area ratio of patches.

6. Conclusions

This article presents a simple framework of planning where remote sensing, together with other sources of information, play a role in answering two types of questions posed by the actors. The first type of question occurs in diagnosis or monitoring can lead to the definition of indicators of state, pressure and response. The second type corresponds to action-planning questions. We have described two simple and on-going applications of Remote Sensing imagery in the context of local planning and monitoring efforts. In order to make remote sensing technology broadly available to local planners and their collaborators, there are many organisational and methodological challenges to address. We are learning how to do this in collaboration with our partners in the Colombian *llanos*, and one aspect of this collaboration touches affordable image analysis techniques and their validation. We hope to have contributed to establish a possible action-research frame for the development puzzle, in which remote sensing practitioners, along with professionals of various practices, can all place their pieces.

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