5. ASSESSING VEGETATION COVERAGE AT THE SAO PAULO STATE SCALE: "A TOOL FOR AIDING THE DECISION MAKING PROCESS"

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5.1. Relevance and importance of the application

The availability of reliable information of the agricultural production data is increasingly a fundamental demand in the decision making process, both for national and international scenarios (Pino, 1999; Epiphanio et al., 2002; Dronin & Bellinger, 2005; Epiphanio, 2007; Castillejo-González et al., 2009).

The operational methodology currently applied to perform agricultural forecasting in Brazil is done through extensive, prolonged, expensive and subjective surveys based on the opinion of technical agents involved in the agricultural segment (Instituto Brasileiro de Geografia e Estatística, 2002) and therefore the analysis is biased, due to the errors and uncertainties involved and renders this methodology less practical.

Therefore, an increasing demand is observed for agricultural forecasts derived from remote sensing data, which allow faster results, with higher accuracy and lower costs than the traditional techniques (Food and Agriculture Organization of the United Nations, 1998; Prasad, 2006).

In the same way, there is also a great gap with respect to information about the degree of conservation of the remaining natural vegetation coverage. Global demand for agricultural products is now a major driver of cropland and pasture expansion across much of the developing world. Whether these new agricultural lands replace forests, degraded forests or grasslands greatly influences the environment. While the general pattern is known, there is still no definitive quantification of these land cover changes (Gibbs, 2010).

Conservation of biodiversity within managed landscapes calls for a strategy that includes increasing the conservation value of the agricultural matrix both in terms of providing viable habitat for forest-dependent species, as well as increasing connectivity between protected areas and forest fragments (DeClerck et all, 2010).

The identification, mapping and monitoring of the land use changes is an important tool to support decision making, both for public managers and for agribusiness investors. At the same time, recovery and utilization of degraded areas and restoration of native vegetation could prevent the advance of deforestation in areas of agricultural expansion.

In this context, the Vegetation instrument on board the SPOT satellite deliver measurements specifically tailored to monitor land surface properties with a frequency of about once a day on a global basis and at a spatial resolution of one kilometer (in fact 5 times over 6 days at the equator, once a day at 30° latitude, and twice a day at latitudes higher than 60°). These characteristics allow monitoring large extents of land in a continuous way.

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5.2.   Objective of the application

The main objective for this application is to assess the vegetation coverage at the municipalities from the Sao Paulo State (Brazil) using data from a temporal set of S10 NDVI images, acquired by SPOT Vegetation instrument, which are available from the DevCoCast project. After the validation of this methodological approach in a near future, it would be useful to implement a monitoring system using the vegetation cover and make it available to decision makers and for the society.

5.3.   Methodology and study area

5.3.1.   Methodology adopted

A flow chart of the followed methodology is presented in figure 5.1 below.
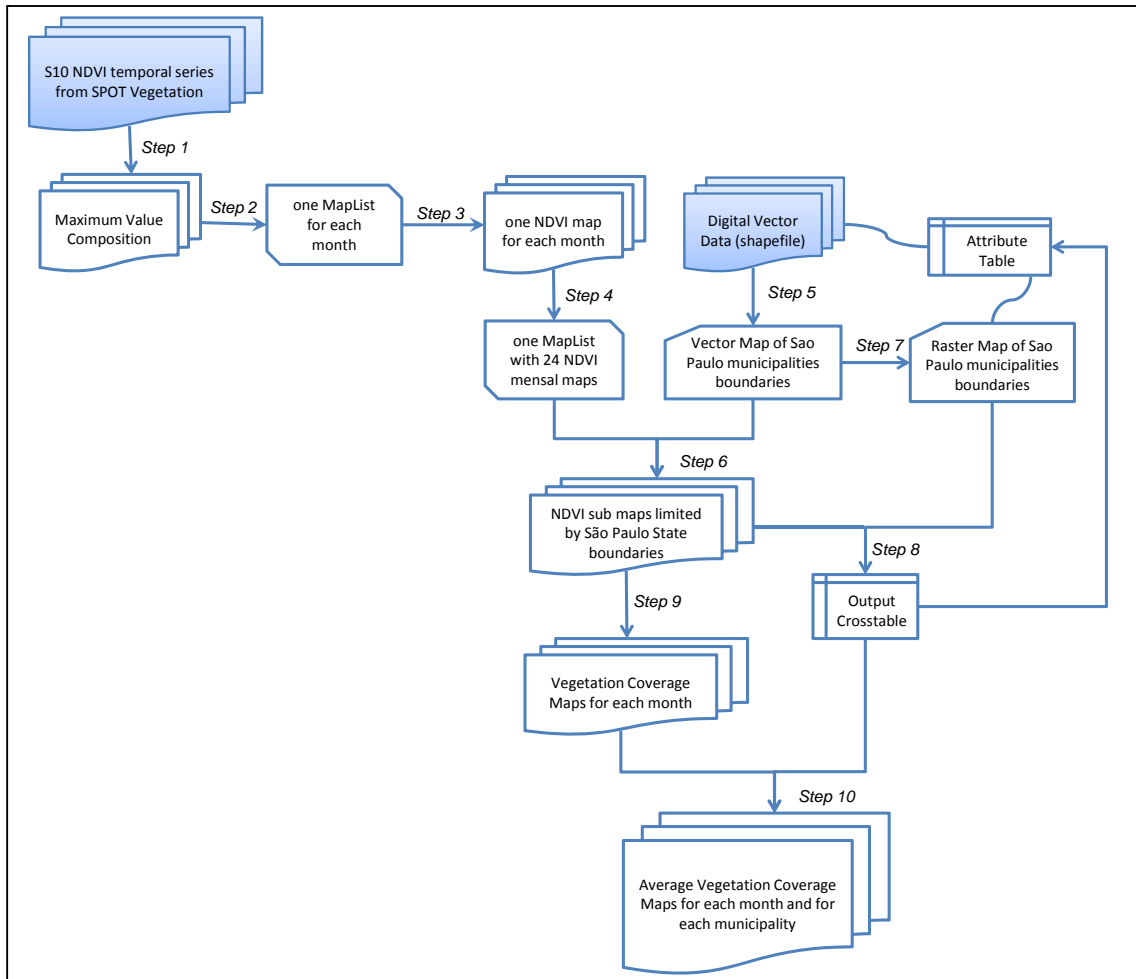

Figure 5.1 Flowchart of the adopted methodology

5.3.2. Study Area

The study area covers the São Paulo State, Brazil, consisting of 645 municipalities, see also figure 5.2.
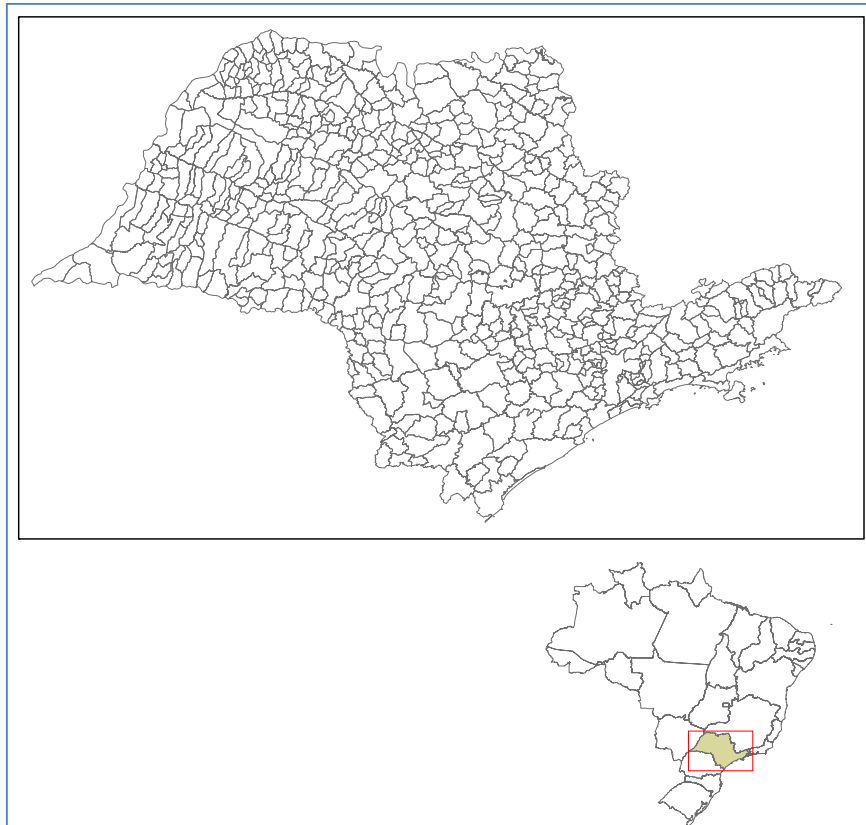

Figure 5.2 Sao Paulo State with the municipal boundaries and its location in Brazil

5.4. Data pre-processing

For this application, a temporal data set is used of S10 NDVI images. The 10-day SPOT Vegetation S10 synthesis products are a combination of daily atmospherically corrected data of all VEGETATION segments (measurements) of the given decade (10-day period) into a single image using the Maximum Value Composite (MVC) algorithm, which selects the pixels with the best ground reflectance values (Bartholomé, 2006). Here a temporal data set is used from the years 2008 and 2009. Not all time steps need to be pre-processed, as example of the necessary pre-processing required, the month of December 2009 is used.

5.4.1. Importing the S10 NDVI images

A temporal series of S10 NDVI images derived from the SPOT Vegetation Instrument, for the years 2008 and 2009, available within the GEONETCast data stream should be imported into the Integrated Land and Water Information System (ILWIS), using the GEONETCast Toolbox (see figure 5.3). Ensure that you have unzipped the exercise data, open ILWIS and move using the ILWIS navigator to this active working directory. You will note that there is a sub directory "gnc_data". The directory is containing the raw data from GEONETCast-DevCoCast. Once close ILWIS and Open ILWIS again to ensure that the directory settings are correct.

Ensure that the GEONETCast toolbox plug-in is installed, open from the main ILWIS menu the option "Operations => Geonetcast" => "toolbox", now select the option "Configuration" => Folders". Specify the folder settings for "SPOT VGT4 Latin America", set the appropriate input and output folders, note that the input folder is your active working directory and add here the sub-directory "\gcn_data".

From the ILWIS Main Menu, import the NDVI images for the 3 decades of December for the year 2009, select from the ILWIS menu: "Operations => Geonetcast => Toolbox => SPOT VGT Products => SPOT VGT Latin America => NDVI". Use as "Date" stamps: "20091201", "20091211" and "20091221" respectively.
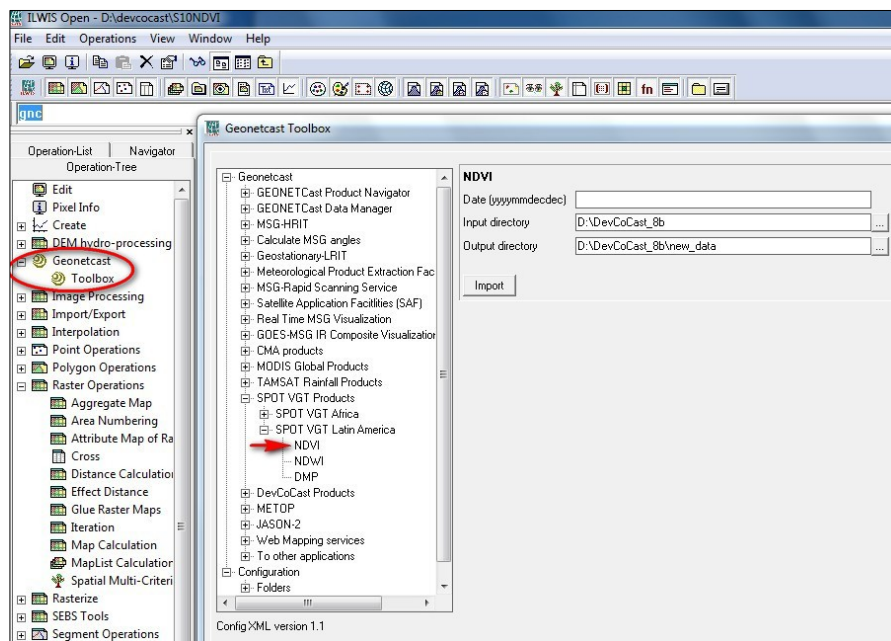

Figure 5.3 Importing S10 NDVI images using the Geonetcast Toolbox plug-in

Open the imported maps "ndvi20091201", "ndvi20091211" and "ndvi20091221", use as Representation "NDVI1", browse with the left mouse cursor pressed over the map and inspect the values. Note that also a status map, (*_SM) is created. This status map is going to be applied to select only those pixels that meet the following criteria: cloud free, land pixel and having good radiometry in the red and near infra red channels. For further explanation on the procedure, see also Maathuis et al (2011). Type the following map calculation formula on the command line in the main ILWIS menu:

Status_ok:=iff(((((ndvi20091201_SM div 1)mod 2)+((ndvi20091201_SM div 2)mod 2)=0) and (((ndvi20091201_SM div 8)mod 2)+((ndvi20091201_SM div 32)mod 2)+((ndvi20091201_SM div 64)mod 2)=3),1,0)

Leave all other options as default and execute the operation. Inspect the resulting map and now apply the mask, showing the pixels meeting the selection criteria, to the NDVI map by entering the following map calculation statement on the command line in the main ILWIS menu:

ndvi_ok20091201:=iff(Status_ok=1,ndvi20091201,?)

Again use all other settings as default and execute the operation, check the results, use as Representation "NDVI1". Repeat this procedure for the other two decades as well. Use the command line history from the main ILWIS menu and change the date string portions!

5.4.2. Creating a Map List for the imported NDVI images

Create one map list for each month, with the three decades from its corresponding month (see figure 5.4). From the ILWIS Main Menu select "File => Create => Map List" and make for the month of December 2009 a map list consisting of the 3 corrected decadal maps "ndvi_ok200912*". Specify as output map list name "122009"
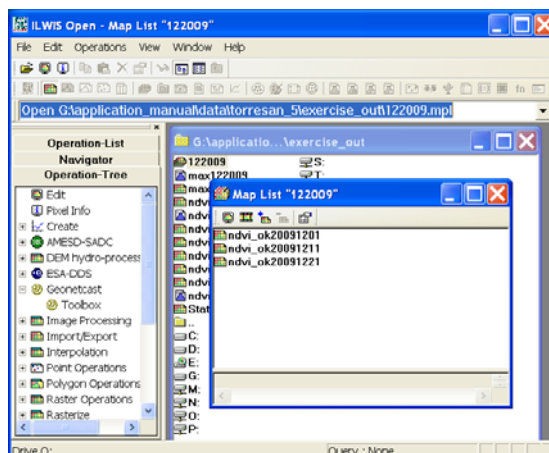
Figure 5.4 Example Map List created with the three decades from December 2009

5.4.3. Extracting the Monthly Maximum Value Composition

From the map list created, the three NDVI images will be merged into another raster map, resulting in the maximum NDVI value for each month. Right click with the mouse the map list "122009", from the context sensitive menu select "Statistics => Maplist Statistics", as Statistic Function select "Maximum", specify as output map "max200912" and press "Show" to execute the operation. To display the map use as Representation "NDVI1" and press "OK". Now add the polygon file "spnovo", select from the active map window the options "Layers => Add Layer" and select "spnovo". From the menu "Display Options – Polygon Map", unselect the option "Info" and activate the option "Boundaries Only". The polygon boundaries are now draped over the raster NDVI map, use the "Zoom-in" option from the active map window and select the area of interest. Next, from the active map window, select the option "File => Open Pixel Information" and move the mouse cursor over the map to see the corresponding table attributes. Your results should resemble those of figure 5.5.
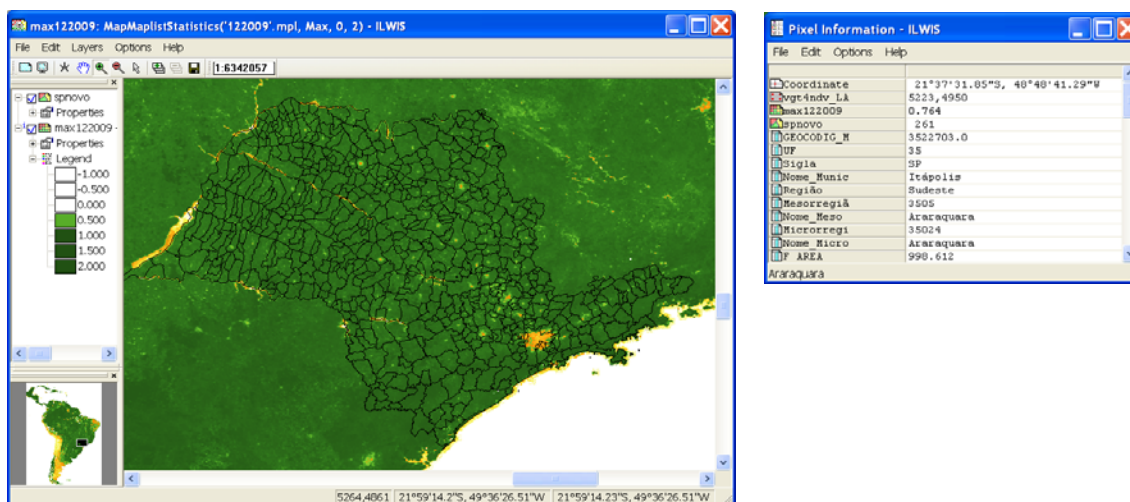

Figure 5.5 Monthly NDVI maximum value composite with Sao Paulo State political vector map

In order to calculate the operations only for the study area it is necessary to create a "Sub map". To create a sub map it is necessary to select using the right mouse button the "max200912" map and choose from the context sensitive menu the "Spatial Reference Operations => Sub Map" options. The details to select only the Sao Paulo State are provided in figure 5.6 and press "Show" to execute the operation and display the sub map using the Representation "NDVI1".
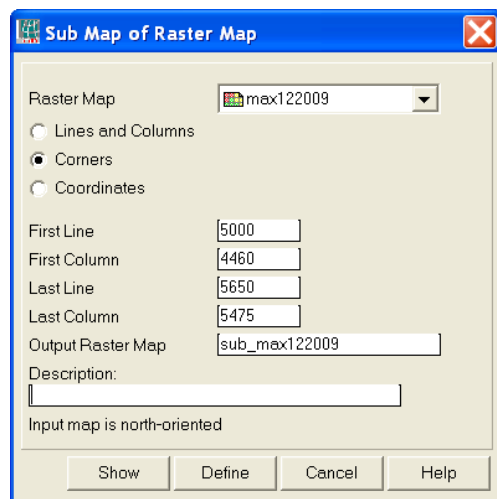
Figure 5.6 Sub map settings to select the Sao Paulo State region

Most of the analysis in ILWIS is based on raster data. Therefore, conversion from vector to raster format (rasterize) is often a necessary step preceding the analysis. Right-click with the mouse the polygon file "spnovo", from the context sensitive menu select the option "Polygon to Raster", as Georeference select "submax2008_1" and type for the Output Raster Map: "municipios", press "Show" to execute the operation. Press "OK" to display the map using the default settings. Close the map and right-click with the mouse the newly created raster map "municipios", select "Properties" and note that the Attribute Table "spnovo" is attached to this map. Double click with the left mouse button the table "spnovo" to display it and inspect the content. Its content is identical to the record that is displayed when using Pixel Information (see also figure 5.5).

5.5.   Data analysis

In order to conduct the full pre-processing chain, as indicated in chapter 5.4, for the whole time series requires a lot of time. Therefore a full pre-processed sub set of NDVI data of the Sao Paulo region has been prepared. The methodology used to create this time series is identical as described above. The time series NDVI maximum value composites are provided in the map list "submax2008_2009". Double click with the mouse the map list name, use the option "Open as Slide Show", select as Representation "NDVI1" and press "OK" twice to see then animated sequence of this time series. After the content is inspected close the visualization.

5.5.1.   Statistical analysis on the NDVI values for each municipality

An important tool for data analysis in ILWIS is the Cross operation, which calculates the frequency of occurrence of all possible combinations of two maps. The Cross operation performs an overlay of two raster maps by comparing pixels at the same positions in both maps and keeping track of all the combinations that occur between the values or classes in both maps. The input maps used in a Cross operation should be raster maps that have the same georeference. During the Cross operation, combinations of class names, identifiers or values of pixels in both maps are listed, the number of pixels occurring as this combination is counted, and the areas of the combinations are calculated. The results are stored in an output cross table and optionally an output cross-map can be created. The output cross-table and the output cross-map obtain an ID domain with the same name as the output cross-table. The domain contains items, which are combinations of the class names, IDs, group names or values of the first input map and those of the second input map.

You are going to cross a raster map with an identifier domain called "municipios" (created before, containing the municipal areas of the State of Sao Paulo) and the NDVI maximum monthly value map for each month of the years 2008 and 2009. The result is a large cross-table which contains the combinations of the municipality names - codes and the number of pixels with a certain NDVI value.

Open from the main ILWIS menu the option "Operations => Raster Operations => Cross". Select the raster map with the maximum monthly NDVI values for the 1st month of 2008, here called "submax2008_1" as 1st Map. Select raster map "municipios" as 2nd Map. Type "avg_01_2008" as Output Table and press "Show". From the menu of the newly created table, select the option "Columns => Aggregation". The Aggregate Column dialog box is opened and now select the Column: "submax2008_1", as Function "Average" Group by "municipios", as Output Table specify "spnovo" and type for the Output Column "avg2008_1". Click "OK" in the Aggregate Column dialog box, see also figure 5.7.
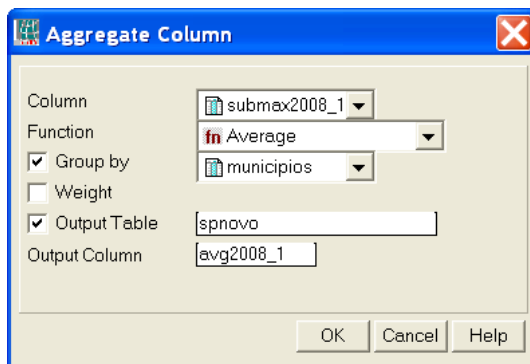

Figure 5.7 Column aggregation and adding resulting column to external table

Open the cross table and open the table "spnovo". Inspect the newly created column "avg2008_1". This procedure should be repeated for all maps in the time series. If you do not want to do this another 23 times, open the table "spnovo_ndvi" and inspect the content of this table.

5.5.2. Estimating vegetation cover

For this step, the methodology proposed by Gao et al. (2006) is adopted, which uses vegetation cover (VC) to calculate the rate of degradation and the result can be applied to establish a system for assessment and monitoring of the environment using remote sensing. In this application, the following expression will be used to estimate the vegetation coverage (VC):

$$VC = \frac{(NDVI - NDVI_S)}{(NDVI_V - NDVI_S)} *100 \qquad \text{(Eq 1)}$$

Where:

VC   the vegetation coverage

$NDVI_S$ the average of the minimal NDVI value of the study area (here 0.192)

$NDVI_V$ the average NDVI value of pure vegetation or the average of the maximum NDVI value in the study area (here 0.671)

Note that $NDVI_S$ and $NDVI_V$ values specified above can be obtained from the table (e.g. the table "spnovo", using the aggregated minimum and maximum statistical values of the 24 "avgyear_month" columns). Select from the main ILWIS menu the option "Operations => Raster Operations => MapList Calculation", see also figure 5.8. Select the NDVI time series map list "submax2008_2009" as input MapList and as Output MapList specify "vc2008_2009". Here only "1" Input MapList is used. In the expression field, type the following expression:

     (((@1-0.192)/0.671)*100

and press "Show" to execute the operation. Now 24 new maps are calculated, representing the vegetation coverage for each month. After the calculation is finished open the newly created maplist "vc2008_2009", double click one of the map layers and display the map using a Representation "vgcover". See a resulting example of January 2008 with the municipality boundaries in figure 5.9. Close the map and now display it as an animated sequence, using the same Representation. Close the animation when finished.
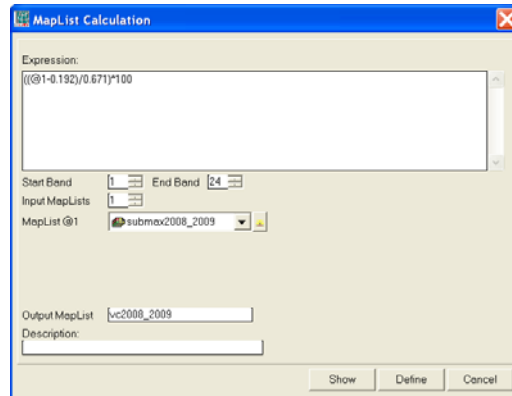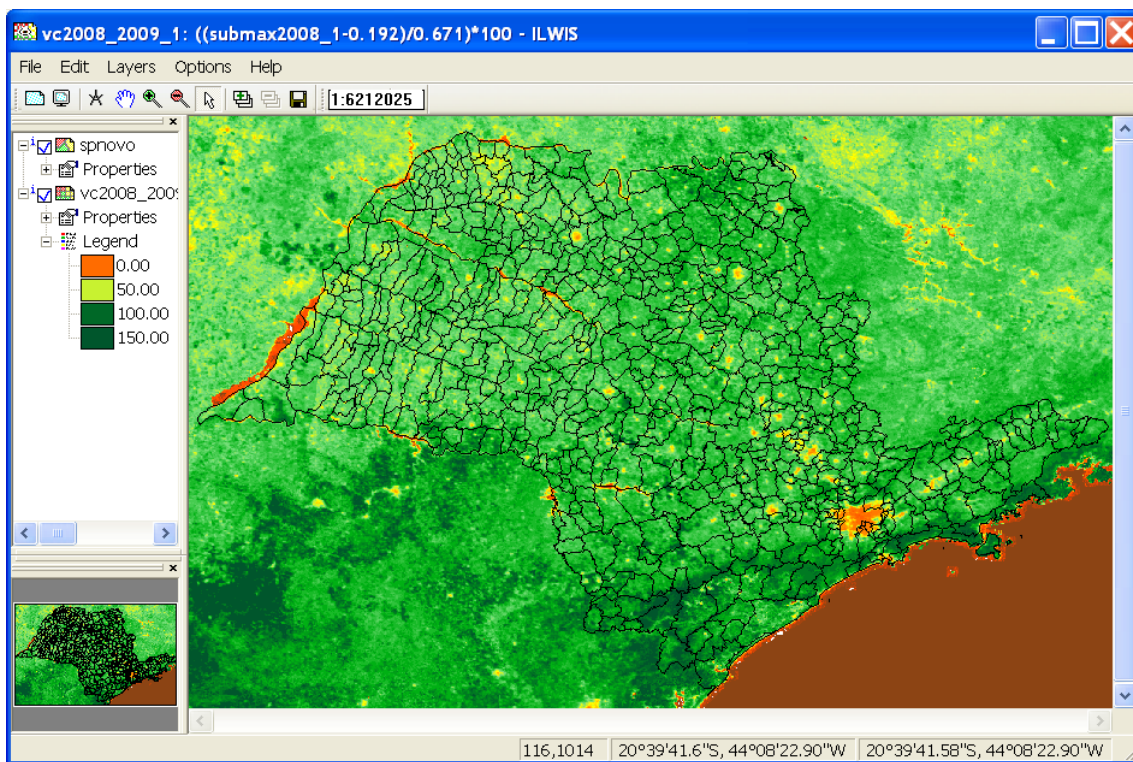
Figure 5.8 MapList Calculation

Figure 5.9 Vegetation coverage for January 2008

Now the monthly average vegetation cover maps have to be crossed with the municipality raster map. Repeat the same procedure as described in chapter 5.5.1 but now cross the vegetation cover maps for each month with the raster municipality map. This will result in 24 new columns in the table "spnovo", use as column prefix name "vc_". If you don't want to repeat the procedure 24 times, open the table "spnovo_ndvi_vc" and inspect the content.

5.5.3. Municipal Vegetation Cover maps

Having calculated the average vegetation cover per municipality in the table, this information is now going to be spatially represented. First select, by right clicking the mouse over the raster map "municipios" the Properties Dialog Box. Ensure that from here the Attribute Table "spnovo_ndvi_vc" is selected and press "Apply" and "OK". Again, right click with the mouse, the map "municipios" and select "Raster Operations => Attribute Map", as Attribute select the column "vc012008" and as Output Raster Map specify "muni_vc012008", press "Show" to execute the operation and display the resulting map using a Representation "vgcover". The result is also given in figure 5.10.
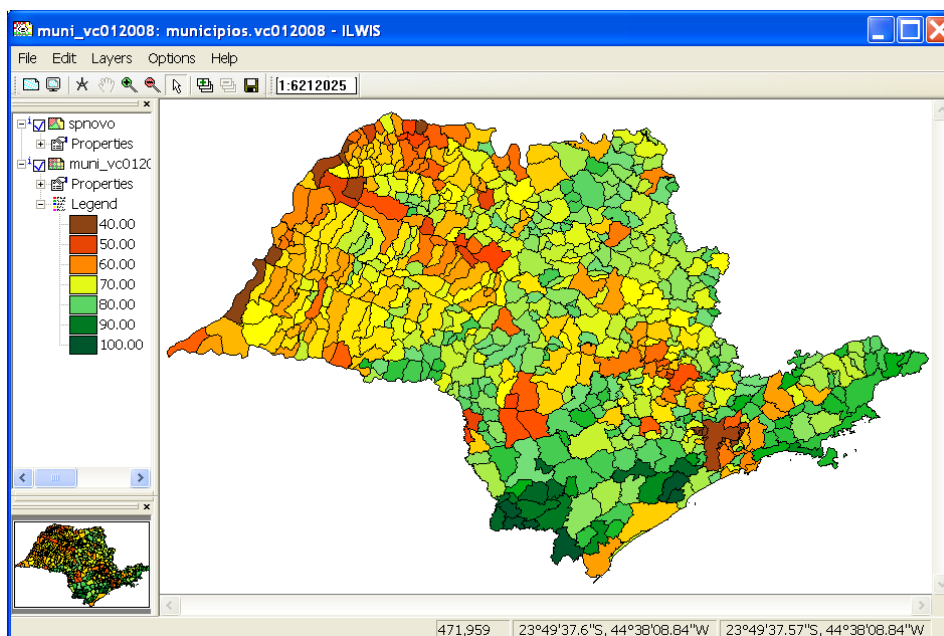
Figure 5.10 Vegetation cover aggregated per municipality, Sao Paulo State, January 2008

Check the command line string from the main ILWIS menu, use the drop down icon on the right hand corner of the command line. The expression generated to execute the operation can be adapted and a new map can be calculated. The string that was used to calculate the attribute map is:

muni_vc012008.mpr{dom=value;vr=4.28:94.79:0.01} = MapAttribute(municipios,vc012008)

To calculate a new map the output map name needs to be changed and the attribute column. Open once more the table and note that the attribute column for the vegetation cover of February 2008 is called "vc_fev2008". Now change the expression given in the command line history following:

muni_vc022008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_fev2008)

Press enter (from the active command line) to execute this operation and "OK". Keep on changing the input attribute column and output map name to obtain a time series of 24 VC municipality aggregated maps. All command line expressions are also presented in appendix 1.

When all 24 muni_vc* maps are created, open from the ILWIS main menu the options "File => Create => MapList", specify as MapList name "muni_vc", select all 24 muni_vc* maps and use the ">" icon to transfer them to the right hand map listing, press "OK". Display the newly created maplist as an animated sequence, using as Representation "vgcover", and press "OK" twice. In the active map window, select the option "Layers =>Add Layer", add the polygon file "spnovo", from the menu "Display Options – Polygon Map", unselect the option "Info" and activate the option "Boundaries Only".

Once more open the maplist "muni_vc" and display the map "muni_vc012008". Add to this map the vector layer showing the municipalities and use the option boundaries only for display of this vector layer. Now from the main ILWIS menu, select "Operations => Statistics => MapList => MapList Graph" In the maplist graph window, select as MapList "muni_vc", use a fix stretch of 0 to 100, activate the options "Continuous" and "Always on top". Activate the map window showing the previously opened map layer "muni_vc012008". Browse with the mouse cursor over the map. Note the aggregated vegetation cover time series values in the graph window, see also figure 5.11. You can also change the maplist, e.g. use submax2008_2009 to see the maximum monthly NDVI values. Note that you have to change the fix stretch from 0 to 1!
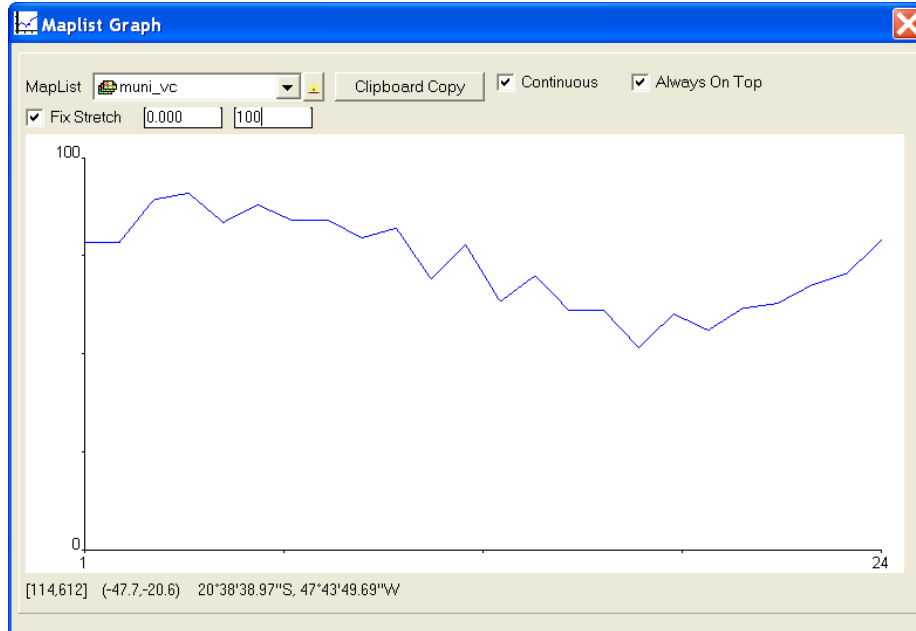
Figure 3.11 Aggregated Vegetation Cover and time series graph of a pixel

5.6. Conclusions

This methodology needs to be validated with in-situ data. The thresholds of the NDVI values used to calculate the vegetation cover ($NDVI_S$ and $NDVI_V$) may be changed depending on the length of the time series available and also on the area of interest.

This methodology can be adapted to different objectives, like crop and biomass monitoring and for biodiversity monitoring and environmental management of protected areas. In this case, other geographical limits of analysis need to be adopted, like the extents of a certain land use regions, the boundaries of watersheds or of parks and protected areas.

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APPENDIX 1

Listing op map calculation statements to compute the aggregated VC per municipality.

Type the expressions below on the command line in the main ILWIS menu to calculate the vegetation cover (VC) for each month of the year 2008 and 2009.

```
muni_vc012008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc012008)
muni_vc022008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_fev2008)
muni_vc032008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_mar2008)
muni_vc042008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_abr2008)
muni_vc052008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_mai2008)
muni_vc062008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_jun2008)
muni_vc072008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_jul2008)
muni_vc082008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_ago2008)
muni_vc092008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_set2008)
muni_vc102008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_out2008)
muni_vc112008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_nov2008)
muni_vc122008.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_dez2008)
muni_vc012009.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_jan2009)
muni_vc022009.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_fev2009)
muni_vc032009.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_mar2009)
muni_vc042009.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_abr2009)
muni_vc052009.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_mai2009)
muni_vc062009.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_jun2009)
muni_vc072009.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_jul2009)
muni_vc082009.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_ago2009)
muni_vc092009.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_set2009)
muni_vc102009.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_out2009)
muni_vc112009.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_nov2009)
muni_vc122009.mpr{dom=value;vr=0.00:100.00:0.01}:=MapAttribute(municipios,vc_dez2009)
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