Mesoamerican Reef Alliance, ICRAN-MAR Project

# Land use change modelling for three scenarios for the MAR region

## Technical Report

*Technical report on the collection of geographic data, the regression analysis of explanatory factors of land use patterns, the development of a set of three alternative scenarios, and the modelling of land use changes using the CLUE-S model. This work was carried out as part of the ICRAN-MAR project's sub-result 1.2, "Trends in land use integrated with spatial, hydrological and oceanographic models for use in modelling".*

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# Summary

Mesoamerica – the region in which the Mesoamerican Barrier Reef Systems fall – is recognized internationally for its biodiversity. For example, Conservation International has identified the area as a biodiversity hotspot, with a high proportion of endemic species (Myers *et al*. 2000). The area's natural ecosystems are also recognized to be threatened. The World Bank-funded Central America Ecosystems Mapping Project, which concluded in 2002, estimated that 49% of Central American land had been converted to agriculture (Vreugdenhil *et al*. 2002).

With a focus on the Mesoamerican Reef, the International Coral Reef Action Network's Mesoamerican Reef Alliance (ICRAN-MAR) project is focusing its attention on how changing land use affects the health of the region's reef ecosystems. The project region includes southern Mexico, and all of Belize, Guatemala, and Honduras.

This report details the steps undertaken to map current and potential future land cover for this ICRAN MAR region. Geographic data was collated, three alternative land cover scenarios for 2005 to 2025 were developed, a regression analysis was undertaken to identify the strength of different factors affecting land use patterns and land use changes under these scenarios were modelled.

The land cover maps for the present day and for 2025 were used as a key input to a hydrological model of watersheds discharging adjacent to the Mesoamerican Reef, prepared by the World Resources Institute (WRI). A hydrologic modelling report is also available on this CD.

A workshop was held in August 2006 to disseminate project results and to provide training in the use of the models. A preliminary version of this report was distributed to workshop participants.

# 1 Data collection and preparation

## 1.1 Outline of methodology and preparation steps

To identify drivers of deforestation, a regression analysis was undertaken in SPSS. The method involves a comparison of land use with the explanatory factors on a cell-by-cell basis within a raster map. Consequently, it is important that all raster data associated with the explanatory factors are prepared consistently: all raster maps must have exactly the same extent, same cell size, and the same numbers of grid cells that are not Null (NoData). A difference of just one cell will cause an offset in the order in which the statistical analysis are carried out and results will be meaningless.

To assure consistency across the raster inputs, the same preparation and conversion procedure was applied to every dataset. The data preparation involves two stages as follows.

### 1.1.1 Stage 1: Creation of ASCII grids with identical number of value cells

Stage 1 involves the creation of the raster datasets in Arc/Info ASCII format so that they can be used (i) by the CLUE-S model and (ii) for the subsequent Stage 2 processing steps.

1. Identify and acquire the best available and most suitable data, in vector or raster formats. Different data from different sources will be used.
2. Review the quality of the dataset, and edit the dataset to resolve any data errors or other problems (areas with missing data; non-adjacent polygons; misclassification of data). If necessary reclassify the data into a more appropriate system.
3. Create any derived datasets, if applicable. An example of this is the creation of a dataset for the number of dry months from monthly precipitation data.
4. Convert vector data or resample raster data to the same raster grid resolution and spatial extent (see Section 1.2).
5. Apply a focal mean filter (continuous data) or a focal majority filter (categorical data) to fill any occasional *Null* cells[1] and “add a few grid cells width” of data on the edges of the maps. This critical step ensures that when data are clipped in the next step, there are absolutely no Null cells within the watershed boundaries. An Avenue script was developed for use in ArcView 3.3 (Appendix 1).
6. Clip all rasters to the MAR extent, and then clip them further to the individual extents of the countries (Table 1-1). This step can be carried out using the *Raster Calculator* in ArcMap.
7. Export all data from GRID to ASCII text format. This can be carried out using the conversion tools in ArcToolBox (Conversion Tools > From Raster > Raster to ASCII[2])

[1] IThe conversion of vector data to raster data sometimes results in *Null* cells where they would not be expected. This reason for this appears to be non-adjacency of polygons in the vector data. Grid cells are assigned as *Null* when their centre points fall in the empty area between the two polygons.

[2] Step 7 – 10 required several Gigabytes of disk space because the ASCII files were quite large and there were many of them.

### 1.1.2 Stage 2: Conversion to a text file for use by SPSS regression module

Stage 2 involves the further processing of the output datasets from stage 2 into a number of different formats to obtain plain text files that can be imported by SPSS. The CLUE-S user manual and exercises (Verburg 2004, Verburg *et al*. 2004), offer a more detailed explanation.

8. Separate grids must be created for every land cover type because binary logistic regression analysis is used. This can be carried out using the *Raster Calculator*. For the ICRAN MAR region, there were 4 countries * 10 land use types = 40 different grids. Each grid is then converted to ASCII format, as in step 7.
9. Using the *File Converter* program that is supplied with CLUE-S, convert the ASCII grids to text files in which all raster values are listed in a single column, with no header. This must be undertaken for all land use types and all explanatory factors, creating a large number of files. For example, for 10 land use types and 15 explanatory factors, there are 4*(10+15) = 100 single-column files. A consistent file naming convention should be used to avoid confusion and mistakes.
10. Copy the contents of the single-column files into an overall file that can be loaded in SPSS (this file is called stats.txt by the CLUE-S *File Converter*). The total number of columns in this file must equal the sum of the number of land use types and the total number of explanatory factors. This file was created using the TextPad text editor (the option to create this file using the CLUE-S *File Converter* resulted in a runtime error, possibly as a result of the large grid size. Record the order of the data columns.

## 1.2 Grid extent and grid resolution

### 1.2.1 Creation of watershed boundaries shapefile

WRI provided a base watershed boundaries shapefile. This illustrates that not all the watersheds in the four MAR countries drain to and have a direct impact on the Mesoamerican Reef[1], and is a vital component in analysing the impacts of land cover change on the reef system. A version delineated from the 90 m DEM was completed on 4 August 2005 and a version based on the 250 m DEM on 24 January 2006. Neither shapefile was readily usable in this exercise because WRI had removed watersheds less then 80 ha in size. This had resulted in an erratic boundary that did not correctly represent the water/land boundary. Furthermore, to retain flexibility in the final resolution used for modelling, it was considered undesirable to restrict the boundaries to a particular DEM extent.

Several edits were carried out to create an improved and more flexible boundaries shapefile for preparation of data for the regression analysis and the land use modelling. The overall area of WRI's 90 m and 250 m shapefiles (for inland boundaries) was combined it with the best land/water/country boundary shapefile (*land_country_20july05.shp*, used for the mask's coastline). Next, the combined shapefile was improved in January 2006 by extensively editing the coastline of Mexico and Honduras so that it better matched the coastline from the Ecosystem map and the Landsat TM colour composites. The final MAR watershed shapefile **`MAR_BASIN_3B_RECLASSMASK_5FEB06.SHP`** was created.

The shapefile was converted to a raster at 250 m resolution as **`BASIN250`**. This raster has *NoData* values outside the catchment area and has four different grid values: 1 for Mexico, 2

[1] GIS analysis (using the WRI watershed delineations and the administrative boundaries provided by CCAD) reveals that all of Belize's six districts, fourteen of Guatemala's twenty-two departments, sixteen of Honduras' eighteen departments and three of México's thirty-two states possess lands in the hundred or so watersheds draining to the reef.

for Belize, 3 for Guatemala and 4 for Honduras. These values are used later on in the modelling process.

### 1.2.2 Conversion to raster masks

As mentioned above, it is critically important that all input data associated with the land use and the explanatory factors are prepared consistently, meaning that all grids must have the same extent, cell size and NoData area. A difference of just a single cell will render the results of the statistical analysis meaningless.

In cooperation with the hydrological modeller, a grid cell size of 250 m was chosen[1]. The extent of the grids for the MAR watershed and every country is given in Figure 1-1.

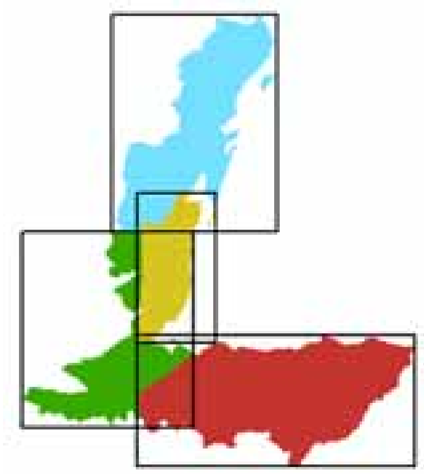

*Figure 1-1: Spatial extents and data area for raster datasets for the counties within the MAR region.*

The regression analysis was carried out at 250 m. It should be noted that explanatory factors of land use changes can be scale dependent. That is, certain spatial relationships that may be observed (i.e., are statistically significant) at a certain scale, but may be less or not all significant at other scales. However, Kok and Veldkamp (2001) and Kok (2004) have concluded that changing the spatial resolution does not lead to major changes in the set of variables composing the equation that explain land use patterns in Central America.

*Table 1-1: Spatial extents for the raster datasets, by country. The coordinates are based on Universal Transverse Mercator (UTM) projection for zone 16 with the NAD 1927 Central American datum.*

| Country | West (xmin) | East (xmax) | South (ymin) | North (ymax) | # Rows | # Columns | # Cells (not Null) |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| All of MAR | 40 000 | 794 000 | 1 519 000 | 2 390 000 | 3 484 | 3 016 | 3 046 407 |
| | | | | | | | |
| Belize | 261 500 | 412 500 | 1 757 500 | 2 045 250 | 1 151 | 604 | 349 762 |
| Mexico | 213 250 | 528 750 | 1 971 250 | 2 389 750 | 1 674 | 1 262 | 886 433 |
| Guatemala | 41 250 | 368 750 | 1 596 500 | 1 972 250 | 1 503 | 1 310 | 542 309 |
| Honduras | 260 250 | 793 000 | 1 521 000 | 1 772 250 | 1 005 | 2 131 | 1 267 903 |

[1] A minimum polygon size of about 150 ha was applied during the creation of the 2003 Central American Ecosystem map, and a minimum of 10 ha was used for the more detailed 2004 Ecosystem Map for Belize. A resolution of 250 m (6.25 ha grid cell) is thus small enough to preserve the data resolution.

From the raster **BASIN250**, a separate raster mask was created for each of the four countries. This involved three steps:

1. Set the appropriate analysis extent and cell size in the Spatial Analyst options menu. Use the values as specified in Table 1-1.
2. Use the raster calculator and the expressions below:

   For MX, `Con([basin250] == 1, 0 ,setnull([basin250]))`
   For BZ, `Con([basin250] == 2, 0, setnull([basin250]))`
   For GT, `Con([basin250] == 3, 0, setnull([basin250]))`
   For HN, `Con([basin250] == 4, 0, setnull([basin250]))`

3. Save the output of the raster calculator permanently, using the names: **MASK_MX_250, MASK_BZ_250, MASK_GT_250** and **MASK_HN_250.** Each of these grids only has zero values and can be used as analysis mask for further data preparation.

## 1.3 Land use/land cover classification

### 1.3.1 Reduced number of land cover classes

A reduced land cover classification with ten classes (Table 1-2) was developed for use by the CLUE-S land use model and the scenario analysis. The need for such a classification was outlined early in the project and a proposed classification in principle agreed upon during a conference call on 16 September 2005. The dataset was derived from the 2003 Ecosystem Map dataset for Central America and the 2004 update for Belize. Appendix 4 gives the legend used for the original and reduced classifications.

*Table 1-2: Land use classes used for the land use change modelling. The original Ecosystem Map dataset had a more detailed classification that was reduced.*

| | |
|---|---|
| 0 – Other/Unknown[1] | 5 – Savanna |
| 1 – Broad-leaved forest | 6 – Wetland/Swamp |
| 2 – Pine forest | 7 – Mangroves |
| 3 – Agriculture/Pasture | 8 – Urbanized |
| 4 – Scrub | 9 – Water |

The ten land use classes represent different production systems that are distinctly different in terms of (i) natural and spectral characteristics, (ii) relevant national policies and key drivers of land use change in the past and future, and (iii) management practices and possible changes in those practices as they relate to the overall objective of the project.

The proposed classification changed over time, during a total of four revisions:

- In September, a seven-class system was proposed: Forest, Pasture, Scrub, Cropland/Agriculture, Wetland, Savanna, and Other (includes urban, water bodies).
- During the 16 Sept 2005 conference call we agreed that mangroves should be added as a separate class and that forest should be split in two forest types (broad-leaved and pine forest). This brought the total to nine classes.

[1] The “Other/Unknown” land use class includes any land cover types that cannot be reclassified as any other types. For the scenario simulations it is assumed that “Other/Unknown” remains constant over time (i.e., neither the total area, nor the spatial distribution changes over time. The Other and Water classes were not included in the statistical analysis of land use factors and the associated areas were not changed by the CLUE-S model.

- During the creation of the first reclassified raster, it was noticed that neither the 2003 Ecosystem Map nor the 2004 Belize Ecosystem map contained pasture as a separate category. Pasture may be included within the agricultural land class. Pasture was therefore dropped from the classification, resulting in a total of eight classes.
- Having reviewed the first reclassified dataset, Lauretta Burke suggested that urban and water should be included as two separate classes rather than be grouped in the "other" class. The final version is therefore composed of ten classes.

*Table 1-3: Total area ($km^2$) of each land cover type in the reclassified and rasterized Ecosystem map data (final version 4 created on 6th February 2006)*

| | Mexico | Belize | Guatemala | Honduras |
|---|---|---|---|---|
| 0. Other/Unknown | 251.7 | 13.5 | 8.3 | 232.9 |
| 1. Broad-leaved forest | 31 760.9 | 12 684.2 | 17 322.6 | 20 555.3 |
| 2. Pine forest | 0.0[1] | 771.8 | 840.4 | 12 198.9 |
| 3. Agriculture/pasture | 3 398.0 | 4 235.1 | 10 505.9 | 43 720.4 |
| 4. Scrub | 14 990.6 | 274.8 | 4 292.3 | 151.6 |
| 5. Savanna | 62.3 | 1 886.4 | 0.3 | 1 114.7 |
| 6. Wetland/Swamp | 1 921.0 | 931.8 | 13.4 | 472.1 |
| 7. Mangroves | 2 316.8 | 720.0 | 0.8 | 82.7 |
| 8. Urban | 145.4 | 189.4 | 118.3 | 130.5 |
| 9. Water | 555.4 | 153.2 | 792.2 | 584.8 |
| TOTAL | *54 402.06* | *21 860.13* | *33 894.31* | *79 243.94* |

### 1.3.2 Sources of land cover data

For Mexico, Honduras and Guatemala, data were derived from the revised 2003 Ecosystem Map. For Belize: data were derived from the revised 2004 Ecosystem map for Belize.

Both datasets contain a mangrove class. Emil Cherrington shared a separate mangrove dataset for Belize that is arguably more up-to-date. While this dataset appears more detailed (there are many more smaller polygons), it does not include all the mangrove areas within the 2004 Ecosystem map. As substituting the mangroves from the 2004 Ecosystem map with the improved mangrove data would result in data gaps, for which the land cover is unknown, this has not been undertaken.

The 2003 Ecosystem map had various data quality problems, in particular non-adjacent polygons along the Belize/Mexico and Belize/Guatemala border and in locations where rivers form national boundaries. For example, an area of about 75 km long and just 400 m wide along the straight border was not classified. This resulted in some visible reclassification errors and gaps in the first version of the reclassified land cover raster.

The 2003 Ecosystem map was extensively edited to fix these errors and improve polygon adjacency with the 2004 Belize ecosystem data (which was not edited). After review, it appeared that the second reclassified land dataset still contained errors, mostly in the form of single NoData cells. The original 2003 Ecosystem map was extensively edited (half a day) to fix these remaining problems via: better edge-matching of polygons along rivers; addition of numerous missing water bodies, particularly along the Mexican coastline; development of a script in Avenue to iteratively apply a 3x3 neighbourhood majority filter (Appendix 1). This script was applied to the ecosystem raster dataset, prior to clipping.

[1] Total absence of a particular land use type, here pine forest in Mexico, is a special case that requires some tweaks/workarounds in the CLUE-S model to avoid runtime errors. See section 4.2.6 for details.

The known unresolved data quality issues with the land cover map are as follows:

1. In the 2003 ecosystem map, a very large part of Honduras has been classified as '*Sistemas agropecuarios'*, and in the 2004 Belize dataset there is a class '*Agricultural uses*'. As this is likely to be a mixture of cropland and pasture, this class has been named "*Agriculture/Pasture*" to avoid confusion.
2. The errors that could be observed near the Belize/Mexico border in the first reclassified raster have been fixed. However, some other abnormalities in the Mexican Yucatan —the sudden land use changes at the 19th and 20th parallel and the 90th meridian— have not been resolved as these are problems with the source data, not the reclassification.

### 1.3.3 Output extent and cell size

A cell size of 250 m was chosen. Earlier in the project, it had been assumed that the entire country of Honduras would be included. WRI's latest watershed shapefile (*mar_basin_3b.shp*, 4 August 2005) showed that not all of this country would be included, so the raster analysis extent was adjusted to avoid unnecessarily large grids. The final analysis extent is:

`West:  40 000` (no changes)
`East:  794 000` (was 920 000 but eastern part of Honduras now excluded)
`North: 2 390 000` (was 2 400 000)
`South: 1 519 000` (was 1 430 000 but southern part of Honduras now excluded)

### 1.3.4 Reclassification methodology using ArcGIS

#### 1.3.4.1 Step 1: Creation of clip/mask shapefile and grid

An overall MAR watershed shapefile **`MAR_BASIN_3B_RECLASSMASK_4FEB06.SHP`** was created, based on the WRI version. It includes both sets of watershed boundaries that WRI delineated from the 90 m and 250 m DEM, which were completed on respectively 4$^{th}$ August 2005 and 24 January 2006, and also all smaller watersheds excluded by WRI. The coastline has been extensively edited to better match the coastline from the Ecosystem map data and the Landsat colour composites.

The shapefile was converted to a raster at 250 m resolution: **`BASIN250`**, as described in section 1.2.1. This raster has *NoData* values outside the catchment area, and values inside the catchment area according to country: 1 for Mexico, 2 for Belize, 3 for Guatemala and 4 for Honduras.

#### 1.3.4.2 Step 2: Creation of land cover reclassification tables

Two reclassification tables (dbf files) were created for the ecosystem datasets: **`ECOMAP2003_RECLASS.DBF`** (Table 1-4) and **`ECOMAP2004BZ_RECLASS.DBF`** (Table 1-5).

#### 1.3.4.3 Step 3: Reclassification & rasterization of the Ecosystem Map data

The two reclassification tables were linked to their corresponding vector datasets in ArcMap. Next, the *Feature to Raster* tool was used to rasterize the ecosystem data (see Fig. 1-2).[1]

#### 1.3.4.4 Step 4: Combining the rasterized 2003 and 2004 Ecosystem datasets

The next step was the combination of the two grids created in the previous step in such a way that the **`ECOMBZ04_V3`** values takes priority over **`ECOMAP03_V3`**. This was carried out using the following *Raster Calculator* expression, and the result saved as grid **`COMBRAW_V3`**.

```
Con(IsNull([ecombz04_v3]),[ecomap03_v3],[ecombz04_v3])
```

*Table 1-4: Reclassification table for the 2003 Ecosystem map using field DESCRIPTIO*

| **DESCRIPCIO** (ecomap2003_reclass.dbf). | **NEWCLASS** | **NUM** |
|---|---|---|
| Arbustales de coniferas | Scrub | 4 |
| Arbustales de latifoliadas | Scrub | 4 |
| Arbustales mixtos | Scrub | 4 |
| Arbustales xeromorficos subdeserticos | Scrub | 4 |
| Areas con escasa vegetacion | Other | 0 |
| Arrecifes coralinos | Other | 0 |
| Bosques deciduos de latifoliadas | Broad-leaved forest | 1 |
| Bosques manglares | Mangroves | 7 |
| Bosques semideciduos de latifoliadas | Broad-leaved forest | 1 |
| Bosques semideciduos mixtos | Broad-leaved forest | 1 |
| Bosques siempreverdes de coniferas | Pine forest | 2 |
| Bosques siempreverdes y semisiempreverdes de latifoliadas | Broad-leaved forest | 1 |
| Bosques siempreverdes y semisiempreverdes mixtos | Broad-leaved forest | 1 |
| Cuerpos de agua | Water | 9 |
| Otros | Other | 0 |
| Pantanos y humedales | Wetland/Swamp | 6 |
| Plantaciones forestales | Broad-leaved forest | 1 |
| Paramos | Other | 0 |
| Sabanas | Savana | 5 |
| Sin datos | Other | 0 |
| Sistemas agropecuarios | Agriculture/Pasture | 3 |
| Sistemas productivos acuaticos (camaroneras, salineras) | Other | 0 |
| Urbano | Urbanized | 8 |

*Table 1-5: Reclassification table for the 2004 Belize Ecosystem map using field ECOSYSTEM*

| **ECOSYSTEM** (ecomap2004bz_reclass.dbf) | **NEWCLASS** | **NUM** |
|---|---|---|
| Agricultural uses | Agriculture/Pasture | 3 |
| Coral reef[2] | Water | 9 |
| Lowland broad-leaved dry forest | Broad-leaved forest | 1 |
| Lowland broad-leaved moist forest | Broad-leaved forest | 1 |
| Lowland broad-leaved wet forest | Broad-leaved forest | 1 |
| Lowland pine forest | Pine forest | 2 |
| Lowland savanna | Savanna | 5 |
| Mangrove and littoral forest | Mangroves | 7 |
| Open sea | Water | 9 |
| Seagrass | Water | 9 |

[1] It should be noted that these conversions could not be successfully completed in ArcGIS 9 (it hung the application). The reason for this is unknown. ArcView 3.3 was used instead.

[2] Coral reef, sea grass and open sea are included in the original source data and were reclassified as *Water*, but these ecosystem types are not relevant to the land cover change analysis.

| | | |
|---|---|---|
| Shrubland | Shrub | 4 |
| Sparse Algae | Other | 0 |
| Submontane broad-leaved moist forest | Broad-leaved forest | 1 |
| Submontane broad-leaved wet forest | Broad-leaved forest | 1 |
| Submontane pine forest | Pine forest | 2 |
| Urban | Urban | 8 |
| Water | Water | 9 |
| Wetland | Wetland/Swamp | 6 |

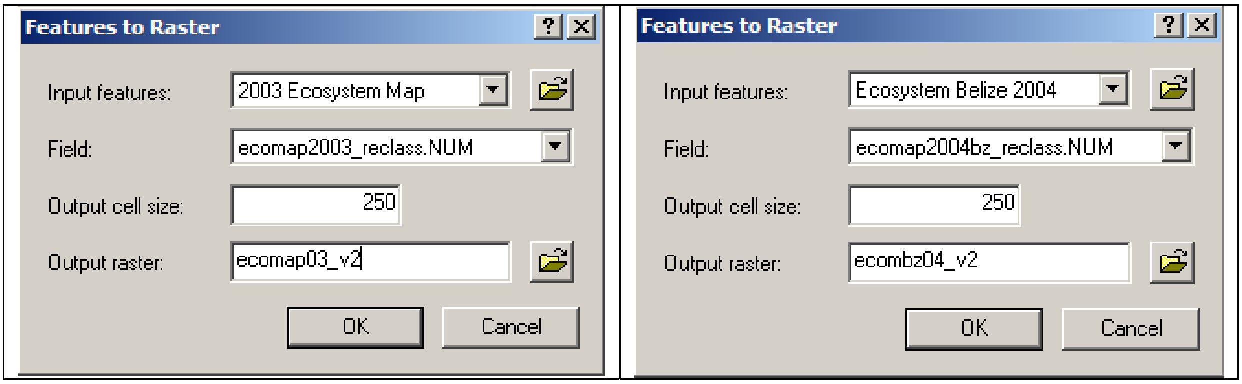


*Figure 1-2: Rasterization of the Ecosystem map vector data on linked field NUM for the 2003 Ecosystem Map data (left) and the 2004 Belize Ecosystem Map (right)*

#### 1.3.4.5 Step 5: Application of a hole-filling majority filter

The raster **ECOMRAW_V3** had some imperfections. First, some apparently randomly located grid cells were Null where they would not be expected to be Null. This was traced back as the result of non-matching polygons in the original vector data, where the centre point of the grid cells fell exactly in the empty area between the two polygons. Even a grid cell that had >95% of its area covered by the vector data could still become NoData in this way. Second, the coastline of the Ecosystem Map dataset did not exactly match the coastline of the clip/mask shapefile. For the statistical analysis it is crucial that all datasets contain exactly the same number of value grid cells (not NoData cells).

A hole-filling Avenue script (GRIDTOOLS, *Fill NoData Holes in Grid*) was used. This iteratively applies a majority filter. This script not only fills any single NoData cells, but also buffers the raster as described in section 1.1.1. A 1-cell thick buffer is added in each iteration and a total of five iterations were carried out. The resulting dataset was **ECOMFILTER_V3**.

#### 1.3.4.6 Step 6: Clip to the watershed extent and coastline

Lastly, the **ECOMFILTER_V3** was clipped to the extent of the watershed using the mask grid **BASIN250** and the result saved as **ECOMAPFINAL_V4**. This is the final land cover grid.

```
Con(IsNull([basin250]), SetNull([ecomfilter_v3]), [ecomfilter_v3])
```

### 1.3.5 <u>Calculation of area by country and land cover type</u>

This was easily carried out in the Raster Calculator using **BASIN250** and **ECOMFINAL_V4**. Recall that **BASIN250** has four different values for each country values (1=MX, 2=BZ, 3=GT and 4=HN) and the final land cover grid has values from 0 to 9. The expression below produces a grid that has unique values for each land cover type in each country.

```
([basin250] * 10) + [ecomfinal_v4]
```

The resulting grid was saved as **CLS4CNTRY_V4**. This grid's attribute table lists the number of cells per land cover per country (Table 1-1). The grid values range from 10 (Other/Unknown in Mexico) to 49 (Water in Honduras). As each grid cell is 250 m, the area in $km^2$ was calculated by dividing the Count value by 16.

#### 1.3.6 Land cover for use in N-SPECT

The combined & reclassified land cover grid **ECOMFINAL_V4** was developed for use as the "current" land cover by both the CLUE-S model and the N-SPECT model. It is important that the same land cover grid is used in by both models to allow accurate evaluation of the impacts of the land cover change simulated by CLUE-S on the results of the N-SPECT model. For N-SPECT, it is necessary to reclassify/remap the 10 different land cover types to 10 corresponding ones from the set of 22 land cover types supported and hard-coded into the N-SPECT model.

## 1.4 Explanatory factors of land use patterns

A set of potential explanatory factors was compiled on the basis of a literature review and other knowledge about the dominant factors that have affected the directions of land use changed in the past and/or affect the prevailing land use patterns. CLUE-S operates by extrapolating the current land use pattern and driving forces of change to the future (Kok & Veldkamp 2001, Wassenaar *et al*. 2005, Kok & Winograd 2002, Kok 2004, Cherrington 2005). Table 1-7 lists the factors that have been identified and for which data are available at this time.

Each location factor is represented in the form of a grid that is clipped to the boundaries of the country based on the extents listed in Table 2. There is a separate grid for each country because the regression analysis and CLUE-S model runs are performed on a country basis. The main categories of explanatory factors are described below. It has been assumed that only factors on this list have to be accounted for; on the other hand, some of these factors may not be significant.

#### 1.4.1 Topographic factors - elevation and slope

##### 1.4.1.1 Data source

The Shuttle Rader Topography Mission (SRTM) data provided the most consistent and highest resolution elevation data for Central America. CIAT has processed the original 90 m resolution STRM data to fill any *NoData* holes using digitized contours from topographic maps and other elevation products. These processed data were used in this project.

##### 1.4.1.2 Data processing

CIAT data were available in 5 x 5 degree tiles. A total of eight tiles covering 10-25N and 80-95 W (Fig. 1-3) were required to cover the entire MAR catchment .These were merged into a seamless mosaic, **SRTMFULL**, in geographic coordinates and WGS-1984 datum. This DEM was projected to UTM zone 17 using a modified Raster Project tool to a 250 m DEM, **SRTM250_BL_CC**. This name reflects the discovery that the bilinear and cubic convolution resampling methods both gave the same result as the grid resolution was increased from

0.0008333° (approximately 90 m) to 250 m. The factor grids for elevation and slope (degrees) were computed from this DEM.

In the early stages of the project, a comprehensive accuracy assessment of the SRTM data was conducted along with a review of relevant geographic transformations and tools for projecting raster datasets in ArcGIS. The out-of-the-box Raster Project tool in ArcToolbox is that it cannot perform geographic transformation of raster datasets. This is a known issue with ArcGIS 9.0/9.1. Consequently, a modified, functional version of that tool was developed by Joep Luijten.

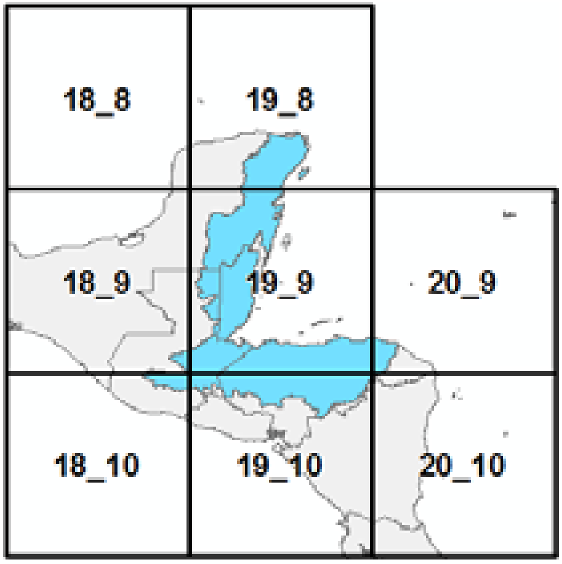


*Figure 1-3: SRTM tile numbers that were downloaded. Tile 20_10 was included as the earlier versions of the watersheds boundaries indicated that it extended more to the east and southeast.*

*Table 1-6: Potential explanatory factors that will be included in the regression analysis and simulated of land use changes. The number (#) has been used for numbering of the CLUE-S regression results parameter files and therefore starts at 0. Cost of access to roads was eventually left out from the analysis because it is strongly correlated to cost of access to markets. There weare no categorical explanatory factors.*

| # | Explanatory factor | Data source | Reference/suggested by | Type | Dynamic | File prefix |
|---|---|---|---|---|---|---|
| | | | | | | |
| | **Demographic** | | | | | |
| 0 | Population density | GPW v3, CIAT LAC | Kok & Veldkamp 2001, Wassenaar 2005 | Float | Likely | POPDEN |
| | | | | | | |
| | **Soil / geology** | | | | | |
| 1 | Soil depth | SOTER LAC | Wassenaar 2005, Kok & Veldkamp 2001 | Float | No | SDEPTH |
| 2 | Soil drainage | SOTER LAC | Wassenaar 2005, Kok & Veldkamp 2001 | Float, 0-1 | No | SDRAIN |
| | | | | | | |
| | **Climate** | | | | | |
| 3 | Mean annual rainfall | CIAT WorldClim database | Wassenaar 2005, Kok & Veldkamp 2001 | Int | No | RAINYR |
| 4 | Length dry period (consecutive months with < 60 mm rain) | Derived from Worldclim | Wassenaar 2005, Kok & Veldkamp 2001 | Int (0-7) | No | DRYMON |
| | | | | | | |
| | **Topography** | | | | | |
| 5 | Altitude | SRTM DEM | Kok & Veldkamp 2001 | Int | No | ELEVAT |
| 6 | Slope | SRTM DEM | Wassenaar 2005; Kok & Veldkamp 2001 | Float | No | SLPDGS |
| | | | | | | |
| | **Contextual** | | | | | |
| 7 | Cost of access to markets (cities with population > 10 k) | Friction surface | CIAT; Kok & Veldkamp 2001 | Float | Possibly | ACSMKT |
| ~~8~~ | ~~(Cost of) distance to roads~~ | ~~Friction surface~~ | ~~Wassenaar 2005, Cherrington 2005~~ | ~~Float~~ | ~~Possibly~~ | ~~ACSRDS~~ |
| 9 | Coastal, tourism hotspots | Selva Maya; WWF experts | Cherrington 2005; http://www.selvamaya.org | Int (0/1) | Likely | TOURIS |
| 10 | Protected areas (full protection) | WDPA (Jan 06) | Wassenaar 2005, Kok & Veldkamp 2001 | Int (0/1) | Possibly | WDPAR1 |
| 11 | Protected area (partial protection) | WDPA (Jan 06) | Wassenaar 2005, Kok & Veldkamp 2001 | Int (0/1) | Possibly | WDPAR2 |

### 1.4.2 Demographic factors – population density

#### 1.4.2.1 Data sources

There was a choice of two population density datasets, as follows: (i) CIAT and colleagues completed the third version of the Latin American and Caribbean (LAC) Population Database in March 2005 (CIAT *et al*. 2005). It contains vector population maps (population per administrative unit) and raster surfaces created with an accessibility model; (ii) CIESEN released the latest Gridded Population of the World (GPW) database v3, together with the Global-Rural Urban Mapping Project (GRUMP) data (Balk *et al*. 2004) in December 2005. A third dataset, Landscan 2004, was produced by the Oak Ridge National Laboratory, USA, but the project team was not able to obtain this dataset.

When overlaying on a Landsat image, the LAC dataset is visibly less accurate than GPW v3. GPW's actual population density for 1990, 1995 and 2000, estimated density for 2005, 2010 and 2015, and population density grid appears more accurate. This may be because CIAT used comparatively coarse road maps and urban areas data for population modelling. However, the GPW data do not show much spatial variation in population density in Belize, and to a lesser extent in the Mexican Yucatan. Belize City does not stand out at all in the GPW dataset, probably because population densities are averaged across administrative areas, of which there are only six in Belize (compared to 3 696 in Honduras). The LAC dataset is slightly better for Belize, although it still does not look accurate in the vicinity of Belize City.

#### 1.4.2.2 Data processing

The LAC dataset was selected for Belize and Mexico, and the GPW v3 dataset for Guatemala and Honduras. The original data at 1-km resolution were resampled to 250 m. No other processing was carried out. For actual (1990-2000) population data, the GPW3 "**AG**" grids (adjusted population density to match UN totals) were used.

### 1.4.3 Demographic factors – location of settlements

#### 1.4.3.1 Data source

As there was no available consistent urban point dataset with associated population information, a dataset was pieced together from four different sources data. Many of these were identified by Emil Cherrington. For Honduras, a dataset (**HN_SETTLEMENTS_IGN-CCAD.SHP**) from CCAD was used. For Belize a dataset (**BZ_SETTLEMENTS_BTFS.SHP**) from the Belize Tropical Forest Studies was used. For Mexico and Guatemala the settlements from the Selva Maya CD (see Table 1-6) were used (**BZ-GT-MX_SETTLEMENTS_SELVA_C2000.SHP**). El Salvador was included because it closely borders the MAR catchment; the GRUMP v1 settlement data were used here, even though they were not very accurate.

#### 1.4.3.2 Data processing

Each dataset was projected to UTM16 and the fields in the attribute table that contained the city/settlement name and population size were renamed, respectively, NAME and POPSIZE. The datasets were then merged. The Selva Maya data appeared quite inaccurate and so, where possible, alternative data were used. Guatemala City was missing and was added manually, with its location based on the ESRI and GRUMP settlements and ESRI world cities. The resulting shapefile **MAR_SETTLEMENTS_POP.SHP** has a field SOURCE that indicates were the point features originated from. It should be noted that the GRUMP dataset is very small scale, but was useful for comparison to indicate whether any key cities are missing, rather than for precise pinpointing of locations.

### 1.4.4 <u>Soil and geology factors</u>

#### 1.4.4.1 Data source

The highest quality consistent soil dataset for Central America is the 'Soil and Terrain database for Latin America and the Caribbean' (SOTERLAC) and its associated SOTER-based soil parameters estimates (version 1). Both datasets were downloaded from http://www.isric.org/UK/About+Soils/Soil+data/Geographic+data/Regional/. The soil parameters dataset contained everything that was needed - shapefiles, legend files and a large MS Access database that contained all parameters for every soil profile ID (*PRID*) and unique SOTER unit (*NEWSUID*).

#### 1.4.4.2 Data processing

Essentially, the entire area has been characterized using 1585 unique SOTER units, corresponding with 5855 polygons, and the soils described using 1660 profiles. Each SOTER unit is associated with one or more profiles, each given a relative weight and totalling 100%. Each profile and its soil parameters are specified by up to five different layers (*D1* = 0-20 cm; *D2* = 20-40 cm; *D3* = 40-60 cm; *D4* =60-80 cm and *D5* = 80-100 cm), but the deepest layers can be less than 20 cm thick. The soil parameters vary between soil profiles. The attribute data of the shapefiles only contained the soil parameters for the top layer (*D1*).

To calculate the average soil depth and average drainage (over all soil layers), an aggregation had to be made across soil profiles and soil layers, as follows:

<u>For soil depth and drainage:</u>

◊ Opened **`SOTWIS_SOTERLAC_1.MDB`** and exported table *SOTERsummaryFile* to a **`SOTER_SUMMARY_FILE.DBF`**.

◊ Edit **`SOTER_SUMMARY_FILE.DBF`** and add a field *ProfDepth* (Number, 2 decimal places) to store the effective depth of that profile within a SOTER unit.

◊ Calculated the *ProfDepth*, in cm, as: `0.01 * ([BotDep] – [TopDep] * [Prop]`.

◊ Added a field *ProfDrainage* (Number, 4 decimal places) to store the effective drainage rates of that profile within a SOTER unit.

◊ Calculated the ProfDrainage, in cm, as: `0.01 * [Drain2] * [Prop]`.

◊ Summary on the *Newsuid*, taking the <u>Sum of *ProfDepth*</u> (which will be in between 0 and 100 cm) and the <u>Average of *ProfDrainage*</u> (which will be in between 0 and 1). The file was saved as **`CUMULATIVE_BY_NEWGUID.DBF.`**

◊ Linked **`CUMULATIVE_BY_NEWGUID.DBF`** to **`SOTERLAC2_SOTWIS.SHP`** and created a legend based on the cumulative soil depth (*Sum_Cum_Depth*).

◊ Convert feature to raster on the cumulative depth field and drainage field. The resulting grids were saved as **`SDEPTH`** and **`SDRAIN`**.

◊ Applied the majority filter 20 times to each grid (so many times to fill major gaps near the islands) and saved grid as **`SDEPTHFT20`** and **`SDRAINFT20`**.

◊ Mask and clipped a total of 8 grids using the raster calculator:

| | |
|---|---|
| `Con([BASIN250] == 1, [SDEPTHFT20])` | Saved as **MXSDEPTH** |
| `Con([BASIN250] == 1, [SDRAINFT20])` | Saved as **MXSDRAIN** |
| `Con([BASIN250] == 2, [SDEPTHFT20])` | Saved as **BZSDEPTH** |
| `Con([BASIN250] == 2, [SDRAINFT20])` | Saved as **BZSDRAIN** |
| `Con([BASIN250] == 3, [SDEPTHFT20])` | Saved as **GTSDEPTH** |
| `Con([BASIN250] == 3, [SDRAINFT20])` | Saved as **GTSDRAIN** |
| `Con([BASIN250] == 4, [SDEPTHFT20])` | Saved as **HNSDEPTH** |
| `Con([BASIN250] == 4, [SDRAINFT20])` | Saved as **HNSDRAIN** |

### 1.4.5 Climate factors - precipitation and length of dry season

#### 1.4.5.1 Data source

CIAT's WorldClim database (http://biogeo.berkeley.edu/worldclim/worldclim.htm) was used. The database contains grids of monthly mean temperatures and precipitation in several resolutions (30 degree-seconds and 2.5, 5 and 10 degree-minutes). The finest resolution, 30 degree-seconds (about 1-km x 1-km), was considered more than sufficient for land use modelling.

#### 1.4.5.2 Data processing

WorldClim data at 30 degree-seconds resolution were downloaded for tiles #22 and #23 (the MAR catchment covers a small part of each tile). These monthly grids were mosaicked and stored as **PREC_1, PREC_2, …, PREC_12.** Each grid was then projected to UTM 16 NAD 1927 and clipped to the extent of the MAR. A bilinear interpolation was used. The resulting grids are stored as **PRECIP1, PRECIP2, …, PRECIP12.** A grid of annual precipitation **ANNUALRAIN** was computed by adding the 12 grids.

The calculation of dry season length was more complex. Based on existing literature, a month with less than 60 mm of precipitation is considered a dry month. An inspection of the range of values of the monthly grids showed that November through May are generally the drier months. While the minimum value in both July and August is also below 60 mm, the much shorter period and very few grid cells with a value < 60 makes this insignificant compared to the other seven months.

A short Avenue script was written as follows, to calculate a grid that indicates whether each of these seven months is a dry month. Note that the script is hard-coded to use the precipitation grids from months 11, 12, 1, 2, 3, 4 and 5.

```
theProj = av.getProject
theView = theProj.finddoc("view1")

r1 = theView.FindTheme("precip1").getGrid
r2 = theView.FindTheme("precip2").getGrid
r3 = theView.FindTheme("precip3").getGrid
r4 = theView.FindTheme("precip4").getGrid
r5 = theView.FindTheme("precip5").getGrid
r11 = theView.FindTheme("precip11").getGrid
r12 = theView.FindTheme("precip12").getGrid

' Only Nov-May are potentially dry months so leave out other months.
g = 20000000.asgrid +
  (((r11 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 1000000) +
  (((r12 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 100000) +
```

```
    (((r1 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 10000) +
    (((r2 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 1000) +
    (((r3 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 100) +
    (((r4 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 10) +
    (((r5 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 1)

  gthm = gtheme.make(g)
  theView.addTheme(gthm)
```

The output grid has 8-digit numbers only. The first digit is always 2 and has no meaning: it exists solely to make sure that the first digit is not a 0 (resulting in a number less than 8 digits long). The 2nd through 8th digit indicate whether, in exactly the following order, the month of November, December, January, February, March, April, and May is a dry month (value=1) or not (value=0). A reclassification table was manually created (Table 1-6).

Note that the number *Dry_Months* is the number of consecutive dry months. For example, a value of 20101010 is reclassified as 1 because there is a maximum of just one consecutive dry month (albeit it occurs three times), not three consecutive dry months. The resulting grid was saved as **DRYMONTHS** (Table 1-7).

*Table 1-7: Grid reclassification (resampling) scheme for the number of dry months.*

| Value | Count | DryMonths |
|---|---|---|
| 20000000 | 59136 | 0 |
| 20000010 | 10397 | 1 |
| 20000011 | 104 | 2 |
| 20000100 | 18129 | 1 |
| 20000101 | 142 | 1 |
| 20000110 | 42598 | 2 |
| 20000111 | 187 | 3 |
| 20001000 | 2164 | 1 |
| 20001010 | 4224 | 1 |
| 20001100 | 5290 | 2 |
| 20001110 | 67622 | 3 |
| 20010110 | 25 | 2 |
| 20011000 | 14 | 2 |
| 20011100 | 1320 | 3 |

| Value | Count | DryMonths |
|---|---|---|
| 20011110 | 34593 | 4 |
| 20011111 | 6 | 5 |
| 20101000 | 2 | 1 |
| 20101010 | 4 | 1 |
| 20101100 | 10 | 2 |
| 20101110 | 4406 | 3 |
| 20111000 | 57 | 3 |
| 20111100 | 6604 | 4 |
| 20111110 | 61067 | 5 |
| 20111111 | 29 | 6 |
| 21111100 | 10403 | 5 |
| 21111110 | 114659 | 6 |
| 21111111 | 6930 | 7 |

Next, the majority filter was applied five times and the grids saved as **ANNUALRAINFT** and **DRYMONTHSFT**. Lastly, the grids were clipped using the raster calculator

| | |
|---|---|
| `Con([BASIN250] == 1, [DRYMONTHSFL])` | Saved as **MXDRYMON** |
| `Con([BASIN250] == 1, [ANNUALRAINFL])` | Saved as **MXRAINYR** |
| `Con([BASIN250] == 2, [DRYMONTHSFL])` | Saved as **BZDRYMON** |
| `Con([BASIN250] == 2, [ANNUALRAINFL])` | Saved as **BZRAINYR** |
| `Con([BASIN250] == 3, [DRYMONTHSFL])` | Saved as **GTDRYMON** |
| `Con([BASIN250] == 3, [ANNUALRAINFL])` | Saved as **GTRAINYR** |
| `Con([BASIN250] == 4, [DRYMONTHSFL])` | Saved as **HNDRYMON** |
| `Con([BASIN250] == 4, [ANNUALRAINFL])` | Saved as **HNRAINYR** |

### 1.4.6 <u>Contextual factors – protected areas</u>

#### 1.4.6.1 Data source

The World Dataset of Protected Areas (WDPA) that is maintained by UNEP-WCMC has been used. Initially the 18-May-2005 WDPA version was made available. A comparison with similar data from both CCAD and MesoStor showed major discrepancies, in particular for Honduras. There were obviously missing data in the WDPA dataset. Revisions were started during Emil Cherrington's visit in December 2005 and an improved dataset for MX, GT, BZ and HN was made available in January 2006. A further revision was completed in May 2006, along with a hypothetical future protected area dataset for the scenarios. The only key difference between the Jan and May versions was the inclusion in May of a large area in Belize (Gallon Jug Estate). Table 1-8 lists the prevailing WDPA types in the four countries along with the number of polygons of each type.

#### 1.4.6.2 Data processing

The WDPA dataset contains protected areas with different types of designation (national parks, biological reserves, etc.). For the regression, the degree of protection from land use change is important. The IUCN category (IUCN 1994) was used to generate an estimate of protection level.

The following assumptions were made.

◊ The areas are legally protected from land use change if they are in IUCN Categories I to IV. There are some exceptions for category III (Natural Monument), but this general rule will be used in the CLUE-S model.

◊ The areas may be subject to some level of change (but certainly not complete change) if they fall in IUCN categories V and VI.

◊ Any area that does not have a category assigned (115 areas for the MAR countries), was treated as if it was fully protected from change.

Data processing steps:

◊ Two new fields named **PROTECTED1** and **PROTECTED2** were added to the WDPA shapefile **WDPA_MAR_SUBSET_UTM16.SHP**. The field were of type integer.

◊ All polygons of the categories I to IV and the "unset" ones were given a value of 1 for **PROTECTED1** (full protection). All polygons in categories V and VI were given a value of 1 for **PROTECTED2** (partial protection).

◊ The shapefile was rasterized on both fields and the resulted grids saved under the same name as the fields, **PROTECTED1** and **PROTECTED2**. Note that these grids have values only for the WDPA area, not for the entire country.

◊ Lastly, the following equations were used to created the final clipped grids:

`Con(isNull([protected1 – protected1]),0,[protected1 – protected1])`, saved as **WDPAR1**

`Con(isNull([protected2 – protected2]),0,[protected2 – protected2])`, saved as **WDPAR2**

*Table 1-8: Prevailing designation types of WDPA areas in Mexico, Guatemala, Honduras and Belize.*

| Designation Type | Areas [1] |
|---|---|
| Anthropological Reserve | 1 (1) |
| Archaeological Reserve | 12 (12) |
| Archaeological Site | 2 (1) |
| Area de Protección Especial | 13 (5) |
| Biological Reserve | 12 (8) |
| Biosphere Reserve | 47 (15) |
| Biosphere Reserve Core Zone | 89 (8) |
| Bird Sanctuary | 7 (3) |
| Crocodile Reserve | 1 (0) |
| Cultural Monument | 7 (3) |
| Fisheries No Take Zone | 11 (1) |
| Flora and Fauna Protection Area | 402 (4) |
| Forest Reserve | 18 (17) |
| Mangrove Reserve | 1 (0) |
| Marine National Park | 1 (0) |
| Marine Reserve | 29 (4) |
| Multiple Use Area | 10 (5) |

| Designation Type | Areas |
|---|---|
| Multiple Use Reserve | 1 (1) |
| National Park | 121 (40) |
| National Park - Buffer Zone | 1 (1) |
| Natural Monument | 10 (3) |
| Natural Resources Protection Area | 2 (0) |
| Nature Reserve | 4 (4) |
| Private Natural Reserve | 53 (16) |
| Private Reserve | 18 (18) |
| Protected Biotope | 6 (4) |
| Regional Park | 20 (8) |
| Reserva de Manantial | 2 (2) |
| Sanctuary | 28 (1) |
| Wildlife Refuge | 20 (11) |
| Wildlife Sanctuary | 9 (8) |
| Zona de Amortiguamiento | 27 (6) |
| Zona de Veda Definitiva | 24 (4) |
| Area Productora de Agua | 1 (0) |

### 1.4.7 <u>Contextual factors – access to roads and markets</u>

The accessibility of transportation links and markets are important explanatory factors of land use patterns and how land use changes. Accessibility is more than a measure of distance. It has been described as the ease with which a location may be reached from another location. The concept of accessibility has been used in rural development policy as an indicator or rural deprivation and as a variable in location analysis.

Farrow and Nelson (2001) and Nelson (2000) developed a raster GIS-based methodology for calculating accessibility grids using cost-distance functions. The same methodology was used here for calculating accessibility of roads and markets.

#### 1.4.7.1 Data source and data processing - roads

Numerous roads datasets of varying quality and ground year were identified (Appendix 2). The best quality regional dataset was the one from MesoStor (**`RED_VIAL_LINE.SHP`**). In addition, other datasets, thought to be more accurate, were available for Belize. A national map was created by Jan Meerman, as an update of the Land Information Centre's (LIC) roads dataset, using 2000-03 Landsat Imagery. Furthermore, Emil Cherrington made available a 2005 road dataset for southern Belize.

The processing of the road data was cumbersome for several reasons. First, while all three datasets included a road classification, these classifications were different and needed to be reconciled. Second, overlaying the data for Belize showed that they were all different, though no single dataset seemed superior to the others. Some existing roads were missing in the MesoStor data included in the more recent Meerman data, but the opposite was true for other roads. The Belizean datasets were also most detailed, including many tracks.

[1] Total number of WDPA areas in Mexico, Guatemala, Honduras and Belize. The number between parenthesis is the number of areas that are wholly or partially within the MAR catchment boundaries.

Thus, reconciling these differences and the creation of a single combined dataset was the first processing step. QuickBird Satellite imagery, viewed through Google Earth, was used to resolve discrepancies about the existence or precise location of roads. The combined dataset **MAR_ROADS_MODELLING.SHP** has the fields *TYPE* and *SOURCE*. The former field is used for symbology. For consistency between countries, tracks were omitted. The *SOURCE* field shows from shapefile each road originated.

#### 1.4.7.2 Data source and data processing - markets

It was assumed that markets exist in the larger cities, so a dataset of settlement locations with population data was needed. No such single dataset for the entire MAR or Central America existed, however, several other datasets that covered a country where available. The settlements data from the Selva Maya CD provided good coverage in Mexico, Belize and all but the southern part of Guatemala. Better data for Belize were available from the Belize Tropical Forest Studies project (http://www.green-hills.net/btfs/). Several datasets were available for Honduras and the one from IGN/CCAD was the most complete. The datasets were merged and reviewed, resulting in the combined dataset **MAR_SETTLEMENTS_POP.SHP**.

#### 1.4.7.3 Data processing - accessibility

The methodology described by Farrow and Nelson (2000) was followed, although their accessibility wizard (an Arcview GIS 3.2 extension) was not used, to retain control over all processes. Several new grids were prepared as an input to the cost-distance functions.

◊ To avoid edge effects that may be caused by the exclusion of roads that are just outside the MAR boundary, the catchment extent was buffered at 50 km and rasterized. This raster **MASK50K** was used as a temporary analysis extent (`Xmin=-10 000; Xmax=844 000; Ymin=1 469 000, Ymax=2 440 000`).

◊ The land cover raster was recreated to include the 50 km buffer zone. The resulting grid had the same 10 classes (Table 1-9) and was saved as **ECOMAP50K.** A value of 0 (unknown) was assigned to those areas that fall in the buffer zone and that do not have land. Note that the precise value doesn't matter.

◊ Slope affects travel time. Slope in degrees was calculated from the DEM. Any areas not covered by the DEM and oceans were assigned a slope of 0. Again, the precise value of the additional areas in the buffer zone doesn't matter. The resulting grid was saved as **SLOPE50K.**

◊ Roads were rasterized using four classes: 1=paved roads; 2=major roads; 3=major roads dry season only; 4=other roads (Table 1-10). Tracks were omitted. The source grid **SRC-ROADS** was reclassified to contain only zeros, **SRC_ROADS_0**.

◊ Settlements with a population of at least 5 000 and 10 000 were selected from **MAR_POP_BUF_75KM.SHP** and rasterized to **SRC_POP5K** and **SRC_POP10K**. The only grid value is 0.

◊ Next the friction surface was created. As the cell size is 250 m, friction values were expressed in seconds. This was a two-step process. First, three input grids (slope, land cover and roads) were reclassified to their friction values (see Tables 1-9 to 1-11), resulting in **FRIC_ROADS**, **FRIC_SLOPE** and **FRIC_LAND**.

◊ Next, the three reclassified "semi-friction" grids were combined into a single surface using the following expression. The output was saved as **FRICTION**, and had friction values from 8 to 2 700 seconds, indicating difficulty of passing through a 250 m grid cell.

```
FRICTION250 = ([fric_roads].isnull.Con([fric_land] *
[Fric_slope],[fric_roads] * [Fric_slope]))
```

The same friction surface, but expressed per map unit passed through:

```
FRICTION = FRICTION250 / 250
```

Accessibility in terms of travel time, in hours, was calculated using ArcView 3, as:

```
ACCESS_ROADS = [Src_roads_0].costdistance([friction],nil,nil,nil) /
3600
ACCESS_POP5K = [Src_pop5k].costdistance([friction],nil,nil,nil) /
3600
ACCESS_POP10K = [Src_pop10k].costdistance([friction],nil,nil,nil) /
3600
```

◊ Because of the strong interdependence between access to roads and access to market, only one of these factors (**ACCESS_POP10**) was ultimately included in the regression analysis. Lastly, the **ACCESS-POP10K** grid was masked and clipped to create four country-scale grids in the final format, using the raster calculator:

`Con([BASIN250] == 1, [ACCESS_POP10K])`, Saved as **MZACSMRK**
`Con([BASIN250] == 2, [ACCESS_POP10K])`, Saved as **BZACSMRK**
`Con([BASIN250] == 3, [ACCESS_POP10K])`, Saved as **GTACSMRK**
`Con([BASIN250] == 4, [ACCESS_POP10K])`, Saved as **HNACSMRK**

*Table 1-9: Friction values for land cover with 250 m grid cells. On land cover, average walking speed was estimated at 4km/hr, but reduced to 3 km/hr in forest and increase to 5 km/hr in urban areas.*

| **Land cover type** | **Speed (km/hr)** | **Friction value (sec per 250 m)** |
|---|---|---|
| | | |
| 0. Other/Unknown | 4 | 225 |
| 1. Broad-leaved forest | 3 | 300 |
| 2. Pine forest | 3 | 300 |
| 3. Agriculture/pasture | 4 | 225 |
| 4. Scrub | 4 | 225 |
| 5. Savanna | 4 | 225 |
| 6. Wetland/Swamp | 1 | 900 |
| 7. Mangroves | 1 | 900 |
| 8. Urban | 5 | 180 |
| 9. Water | 0 | 10000 |

*Table 1-10: Friction values for different road type with 250 m grid cells.*

| **Road type** | **Speed (km/hr)** | **Friction value (sec per 250 m)** |
|---|---|---|
| | | |
| 1. Paved road | 110 | 8 |
| 2. Major road | 60 | 15 |
| 3. Major road (dry season only) | 50 | 18 |
| 4. Other road | 30 | 30 |

*Table 1-11: Friction multipliers for slope. There is no accounting for slope direction; it is assumed that travelling both up-slope and down-slope incurs a reduction in travel speed.*

| Slope | | Friction value multiplier |
|---|---|---|
| | | |
| 0 – 5 degrees | | 1 |
| 5 – 10 degrees | | 2 |
| 10 – 20 degrees | | 3 |
| > 20 degrees | | 5 |

### 1.4.8 <u>Contextual factors – tourist hotspots and areas of coastal development</u>

#### 1.4.8.1 Data source

The most relevant dataset was the tourism threat layer from the Selva Maya data CD, covering the Yucatan, Belize and the Peten region of Guatemala (the northern half). It is composed of hexagonal polygons of 100 ha, with an attribute "Qualification" (*Calificacia*) that indicates what part of the polygon is under threat. Nearly all of the areas under threat are predominantly mangroves. In addition, WWF (email from Melanie McFreld) supplied the approximate location of tourism hotspots, drawn on maps in a PowerPoint file. This confirmed the accuracy of the Selva Maya dataset, though Honduras was not covered by either. The two main tourist areas on mainland Honduras are the cities of La Ceiba and Trujillo. These cities were added to the Selva Maya dataset.

While there is general consensus that urban development near tourist hotspots is a major threat to the land in those areas, its use as an explanatory factor in the statistical analysis difficult, because the impact of tourism is highly localized, whereas the statistical analysis and subsequent modelling is carried out at a national level.

The problem can be split in two. First, coastal development can never be an explanatory factor for (urban) developed land that is not near the coast, particularly in Honduras, which has major urban areas inland. Second, the available data for tourism hotspots point out the areas that are under the greatest pressure, rather than actual areas of tourism-induced urban development. Overlaying the Selva Maya tourism threat layer with the ecosystem map land cover data shows that nearly all of the areas under threat are mangroves.

Consequently, it is likely that a regression analysis between the land cover data and tourism hotspots will not show a significant relationship. However, the areas under threat from coastal development were included in the statistical analysis in order to confirm this suspicion.

#### 1.4.8.2 Data processing

- ◊ A field named *RECLASS* was added to the Selva Maya shapefile and all polygons with a qualification > 100 (out of 1000) were given a value of 1. All other polygons were given a value 0. The shapefile was rasterized on the field and the resulted grid saved as **`COASTD`**.
- ◊ The following equation was used to created the final clipped grid:

  `Con(IsNull([coastd]),0,[coastd])`, saved as **`TOURIS`**.

# 2 Analysis of drivers of land use change

## 2.1 Land Use Change Adjacent to the Mesoamerican Reef

This section reviews literature on land use changes in the project region over the past twenty or so years. It was originally released as a working document entitled “Drivers of Land Use Change Adjacent to the Mesoamerican Reef: A Preliminary Review, by Emil Cherrington, Coastal Zone Management Institute, Belize City, in August 2005.

The individual Annotated Bibliographies compiled for the FAO’s 2000 Forest Resource Assessment for México, Belize, Guatemala and Honduras provide a great deal of additional insight into country-level environmental landscape changes in the respective countries (FAO 1999, FAO 2000a, FAO 2000b, FAO 2000c).

### 2.1.1 <u>Mexico</u>

The states of Campeche, Quintana Roo and the Yucatan fall in the MAR project area. . While national-level statistics are readily available on land cover change, GIS analysis is required to quantify changes within the project area. Considerable work on the drivers of land use change has been carried out for part of this area by the Southern Yucatan Peninsular Region (SYRP) project, a joint initiative between Mexico’s ECOSUR and the USA’s Harvard Forest (Harvard University) and Clark University.

Land use change can be summarized over the past thirty years as the result of an expansion of agricultural activities and rapid increase in population. Change seems to have reduced in light of the Mexican government’s promotion of the regional Mundo Maya archaeo-ecotourism initiative, which has also seen the designation of a number of protected areas in the project region since the late 1980s. It is acknowledged that even ecotourism will continue to affect the local environment.

#### 2.1.1.1 Historical Land Use Change

Following a forestry (selective logging)-dominated period for the first half of the twentieth century which went bust by the late 1960s due to international market conditions, the Mexican government sought to use its southern frontier “as a release valve for land stress elsewhere in Mexico.” Peasant farmers were drawn to the area due to readily accessible land in the form of communally-owned *ejidos*, “the primary form of land tenure in Mexico,” created by Article 27 of the 1917 Constitution (Merrill 1996).

Infrastructural development, such as the completion of Highway 186 in 1970, which connected the capitals of Campeche and Quintana Roo to the rest of the nation, also encouraged land use change. Emphasizing agriculture, Mexican governments of the 1970s and early 1980s sought to “[reshape the] forest frontier into a rice and cattle producing area.” Seasonal wetlands known as *bajos* were converted to large-scale rice paddies, but poor practices led to failure of this venture. The land has since been used for pastureland. Other agricultural activities include cattle ranching, fruit orchards, and the cultivation of chilli peppers, corn and beans.

Trade liberalization in the 1990s accompanied land reforms in which farmers received formal title to *ejidos*, allowing them to sell and lease plots (if this is agreed to by their communities). Subsidies and price controls were eliminated, as was further distribution of land.

Mexican participation in the regional Mundo Maya initiative is currently being promoted by the government, which is seeking to capitalize on the region's rich history. A number of protected areas have hence been designated since the late 1980s. According to WRI (2004), coastal development is a major issue due to resort developments, particularly on the Caribbean coast of Mexico.

#### 2.1.1.2 Explicit / Implicit Drivers

As indicated above, in the recent past, government agricultural policies in the form of subsidies, price controls and ready distribution of land encouraged deforestation in southern Mexico. These have been discontinued with trade liberalization and a new emphasis on tourism. However, even with nature-based tourism, in the archaeologically-rich inland and in coastal areas, a demand is placed on land resources.

It remains to be seen how poverty and population growth also affect land use change in southern Mexico, although discontinued distribution of lands may lead communities to encroach on protected areas. The effort at making *ejidos* transferable by sale and lease is aimed at improving the economic situation of peasant farmers by proving them with access to credit. The elimination of subsidies for export crops should not impact demand in local markets for food, especially given steady population growth.

Regional influences, such as Plan Puebla-Panama, are explored in section 2.1.5.

### 2.1.2 <u>Belize</u>

Land use change over the past twenty plus years of Belize's history can be summarized as the continuous expansion of agriculture (including aquaculture), and infrastructural expansion driven by population growth (including immigration) and tourism. These changes have occurred after Belize's attainment of independence from Great Britain in 1981. Despite a rapidly changing natural environment, deforestation was not acknowledged as an issue until resource assessments of the mid- to late-1990s which indicated that deforestation was occurring at rates of roughly 24 280 ha a year in the early 1990s (FAO 2000a). Whereas in the 1980s, Belize boasted 97% forest cover, the most recent (2004) assessment indicates that forest cover is closer to 63%, down from 72% in the beginning of the 1990s (DiFiore 2002, Fairweather & Gray 1994, Meerman 2005).

#### 2.1.2.1 Historical Land Use Change

For most of the past three hundred and fifty years of Belize's history, forestry was the mainstay of the territory's economy. Colonial masters intentionally suppressed agriculture to maintain forest resources, even as already-independent neighbouring republics had begun their phase of agricultural development. The 20$^{th}$ Century saw a gradual decline of forestry due to depressed prices on the world market, and the rise of a national economy founded on the export of agricultural and marine products. Passage of the Land Reform Ordinance in 1962 further shifted emphasis to agriculture, and between 1971 and 1982, 212 465 ha of land were transferred farmers. Plummeting prices for Belize's agricultural exports starting in the late 1970s, even further spurred agricultural expansion and made once-independent subsistence farmers even more dependent on international market forces.

The mid-1960s also saw the gradual establishment of a tourist industry based largely on the territory's offshore attractions though the industry, did not really take off until the post-Independent 1980s, following the creation of a Ministry of Tourism & the Environment whose efforts centred on marketing the nation as a Caribbean tourist destination (McMinn & Cater 1998). By the late 1990s, tourism began to displace agriculture as the major engine of economic growth, averaging 20.2% of GDP per year between 1997 and 2001 (GOB 2002). Although tourism relies on Belize's natural assets, the industry has exerted its own impact on the national landscape, particularly in coastal areas, where the most rapid changes are believed to be occurring.

#### 2.1.2.2 Explicit / Implicit Land Use Policies

The Belizean Government continues to be the largest landowner in Belize, and almost 37% of the country's land is vested in protected areas. Only a few of these are privately-owned. The government encourages small and large-scale enterprises in tourism or agriculture, in the face of ever-mounting foreign debt and continuing trade deficits. The implicit government policy has been support for the agricultural, aquacultural, and tourism sectors (over say forestry) because of the revenues and contribution to GDP generated.

The main export crops include citrus, bananas, and sugarcane, while locally-consumed crops include beans, rice and corn. With regard to the export crops, sugarcane is cultivated mostly in the north of Belize, while citrus and bananas are cultivated in the centre and south of the country. In the 1970s, for instance, revenue from sugar exports accounted for roughly 70% of export revenue (Merrill 1992). While there was no formal agriculture policy until 2003, agriculture was and still is widely promoted, though there are questions as to the impact of trade liberalization. Traditionally there have been price guarantees for Belizean crops in the American and European markets, even though such support is now waning.

Boles (2005) cites poverty as a significant driver of land use change, indicating that it has driven deforestation in southern Belize via slash and burn *milpa* agriculture. Some speculate that integration of Belize into the Caribbean Single Market & Economy (CSME) initiative may mean increased immigration from the Caribbean and hence greater demand for land.

Belize has one of the most extensive protected areas systems in the world, and almost one protected area has been added to the national list each year. Nevertheless, there have been de-gazettements of protected areas and sections thereof in recent years. The ongoing National Protected Areas Policy & System Plan (NPAPSP) project seeks to define a national policy on protected areas, and to rationalize their future existence.

The lack of an overarching, explicit land use policy and plan has resulted and continues to result in haphazard development. The National Lands Act encourages prospective landowners to 'develop' the land, whereby development is defined as modification of the land's original cover. There is a continued outlook in some quarters that natural habitat as 'useless' land to be 'developed,' irrespective of its biophysical potential. Due to the continued importance of coastal areas to tourism, a continuous, largely unregulated development in coastal areas (on the coastal mainland and on offshore islands) led to the establishment both of a national Coastal Zone Management Authority and, more recently, guidelines for development in coastal areas. Some institutional weakening of the Coastal Zone Management Authority has, however, occurred since its initial sponsorship through the UNDP-GEF and EU ran out in mid-2004.

A project in the pipeline through the UN Convention to Combat Desertification, includes the preparation of a national land use plan to guide future development efforts. An ongoing land titling initiative is occurring through the Land Management Programme, which is conducting cadastral surveys in the northern half of Belize. The LMP is intended to stimulate economic growth through secure land tenure. It remains to be seen if the end result will be further emphasis on productive enterprises such as agriculture.

In light of the above analysis, it seems that population growth, migration, coastal development, and agricultural / aquacultural expansion will be the main factors driving land use change in Belize in the near future.

### 2.1.3 Guatemala

While eight of Guatemala's southern Pacific states[1] fall outside in the MAR project area, most of the information available covers the whole country. The National Institute of Forestry (INAB) reports that in the 1980s, deforestation occurred at a rate of roughly 60 000 ha per year, while in the 1990s, the rate was roughly 90 000 ha per year (FAO 1999). This change seems to have driven jointly by agricultural expansion and human population dynamics, including migration to the largely forested eastern highlands of the Petén in northern Guatemala (FAO 1999). FAO (1999) further states that forest policy had changed three times over the twenty-year period, and that there has been competition between the forest and agricultural sectors, though since the 1990s, forestry has played a larger role in the economy.

#### 2.1.3.1 Historic Land Use Change

Large areas of land were converted to agriculture from the early 20$^{th}$ century onwards. Around the middle of that century, Guatemalan governments promoted agriculture as the major avenue of economic growth. Government policy was that the wide expanses of forest were essentially "useless" and should be converted to "productive" uses. In reality, some of the areas where such land conversion occurred, such as the Petén, are infertile. Land was openly distributed to peasant farmers, and promotion of agricultural activities took the form of subsidies, price guarantees and laws encouraging development via land conversion.

Commercial, export-oriented agriculture has been practiced mostly in southern Guatemalan states (most of which fall outside of the project area), while shifting cultivation, cattle ranching (and illegal logging) have predominated in the Petén (FAO 1999). Shriar (2002) cites the Petén as being 70-80% forested in 1970, but only 50% forested by the late 1990s.

The late 1980s through the mid-1990s saw the establishment of various protected areas such as the Maya Biosphere Reserve in the Petén, and institutional changes empowering the national Commission on Protected Areas (CONAP) and the INAB. The role of forests in the national economy has likewise changed, with the introduction of market incentives to prevent deforestation, including concessions, and exploration of carbon sequestration as options for revenue generation.

FAO (1999) recognizes the increasing role of managed forests in the Guatemalan economy, but notes that there is a national debate as to whether agriculture has stabilized or will continue to expand, and on the effectiveness of protected areas in maintaining forest resources. CONAP has delegated management duties of various parks to NGOs.

#### 2.1.3.2 Explicit / Implicit Drivers

Shriar (2002) points to a growing population in areas such as the Petén, while FAO (1999) discusses the significance of "migration, colonization and dependency" on change. FAO

[1] These are Escuintla, Huehuetenango, Jutiapa, Quezaltenango, Retalhuleu, San Marcos, Santa Rosa, and Suchitepequez. According to FAO (2001), these areas produce sugarcane, cotton and cattle for export.

(1999) also points to the emergence of forestry as a major player in the Guatemalan economy as being able to drive sustainable use of forests, particularly because of economic incentives coming from the government. Other factors mentioned by both Shriar (2002) and FAO (1999) are the availability of land (even despite protected area designations), and the incidence of rural poverty, which limits communities' options economically.

### 2.1.4 Honduras[1]

While the other nations of the project area are acknowledged to be underdeveloped, Honduras is one of the few Highly Indebted Poor Countries in Latin America (Jansen *et al*. 2005). The nation has a more diverse topography than the rest of the region, with a large mountainous area and largely infertile soil (Merrill 1993). As with the other nations, agriculture is a major contributor to GDP. The World Bank figures cites the nation's population growth at 2.6% per annum (World Bank 2004c).

#### 2.1.4.1 Historical Land Use Change

Martinez *et al*. (1999) indicate that almost half of the forests that existed in 1965 had been converted to other uses by 1992. FAO (2000b) and Merrill (1993) also indicate that large areas of forest land were converted to agriculture in the latter half of the twentieth century, continuing into the late 1980s. Farmers focused on the production of livestock, and the cultivation of coffee, bananas, sugar, and basic grains. Despite the poor soil of the nation's mountainous landscape, agriculture has mainly expanded, rather than intensified, and resulted in the erosion of an estimated 2.3 million ha (FAO 2000b). In the 1990s, following trade liberalization, commercial agriculture declined.

Other factors contributing to continuous land conversion have been population growth, and the incidence of natural disasters. Hurricane Mitch in 1998 had substantial impacts on both natural forests and human-dominated landscapes (FAO 2000b).

#### 2.1.4.2 Explicit / Implicit Drivers

The major cited drivers of deforestation have included expansion of agriculture & cattle-ranching, population growth & colonization, land tenure, energy production needs, competition between forestry and agricultural policies, forest fires, crop disease and natural disasters such as hurricanes (FAO 2000b).

According to Jansen *et al*. (2005: 18), trade and market liberalization in the 1990s saw the discontinuation of "land distribution and rural credit provision," agricultural extension services, consumer subsidies and guaranteed prices. In theory, this should have discouraged the expansion of export-based agriculture. The authors suggest that increased emphasis should be placed on intensification of existing agriculture as a means of poverty alleviation. They also recommend putting measures in place to limit population growth.

Bonta (2005: 95) states that "by 2000, Honduras alone possessed over 100 protected areas…including 37…'cloud forests' that had been set aside by presidential decree in 1987". He suggests that many Honduran protected areas are protected merely on paper.

### 2.1.5 Regional Synthesis

Certain cross-cutting themes seem to emerge from the four countries, including:

[1] Only the southern departments of Choluteca and Valle are excluded from the project region.

(i) A strong emphasis on agricultural activities in the last few decades, at the expense of forest land. In the case of both Belize and Honduras, it appears that agriculture is expanding rather than intensifying

A former emphasis on forest management (excluding Honduras), faltering in the mid-20th Century due to the international market

(ii) An expansion of road networks and settlements driven by population dynamics of both growth and migration

#### 2.1.5.1 Future Land Use Change

A number of factors operating at national and regional scales can be expected to influence future land use changes. For one, each of the countries of the region are the signatories to some form of trade liberalization agreement, whether it be the *Free Trade Agreement of the Americas*, the *Central America Free Trade Agreement* or the *Caribbean Single Market and Economy*. The conventional wisdom is that these will discourage agricultural expansion by removing subsidies and price guarantees

Other sources indicate that such liberalization will instead encourage agricultural expansion, because countries will have to export more products to maintain previous levels of revenue. Plan Puebla-Panamá can be expected to open up previously inaccessible areas to development. The regional fisheries & aquaculture policy advocated by the PREPAC project may in turn lead to increased aquacultural activities in coastal areas.

Population growth and migrations will themselves exert pressures on national land resources. Such migrations may be within individual countries, or between nations in the region, such as expected to impact Belize through the CSME initiative. Tourism is expected to continue to grow, with a proportionate increase in demand for land in coastal areas and offshore islands. The influence of climate change on land suitability will also become increasingly important in the future.

While the list of possible future causes of land use change can only go on, with regard to spatially explicit causes, infrastructural development and expansion of both settlements and roads, and expansion (rather than intensification) of agriculture and aquaculture seem like the most plausible factors.

## 2.2 Statistical analysis of explanatory factors for land use patterns

### 2.2.1 Methodology

One set of parameters for the CLUE-S land use change model is derived from regression equations that describe the relationship between each individual land use type and a relatively small but diverse number of “explanatory factors” or “location factors”. The regressions attempt to quantify the relationships between the location of all land cover types (dependent variables) and a set of explanatory factors (independent variables).

These regression equations are used to compute the relative suitability of a particular location for each of the possible land use types during a simulated future scenario. The regression coefficients are then input as model parameters. The regression analysis is one of the most critical and comprehensive tasks during the preparation of the CLUE-S model.

The regression analyses were completed using the statistical program SPSS v 11.5. A binomial (binary) logistic regression was used, as is appropriate when the dependent variable is a dichotomy (i.e. 0/1 values for each land cover class). Unlike OLS (ordinary least squares) regression, logistic regression does not assume linearity of the relationship between the independent variables and the dependent, does not require normally distributed variables, does not assume homoscedasticity[1], and in general has less stringent requirements. It does, however, require that observations are independent and that the logit (effect) of the independent variable is linearly related to the dependent.

The spatial relationships between land use and the selected set of variables were quantified in a two-step procedure using binary logistic multiple regression analysis. Independence between variables is a prerequisite for this method. The use of a stepwise regression procedure solves multi-collinearity problems. In step one, significantly contributing variables were selected with a stepwise forward regression, using the 0.05 significance criterion. In step two, this set of variables was used to construct multiple regression equations.

The regression analysis was performed separately for every land use type and stratified by dividing the study region into the four countries (or parts thereof).

The CLUE-S user's manual (Verburg 2004) and the associated exercise 4, "*How to do the statistical analysis*" (Verburg *et al*. 2004) explain how to conduct these analyses in SPSS. The guidelines provided in these documents provided the basis for the analysis, though additional online information proved useful.[2]

### 2.2.2 Evaluating statistical significance and goodness of fit

The output of a logistic regression in SPSS includes various statistics on the significance of the individual regression coefficient and the overall fit of the regression equation. These are found in the "Variables in the Equation" section of the output. The final regression model is the last step model for which adding another variable would not improve the model significantly.

#### 2.2.2.1 Regression coefficients

The standard regression coefficients (standardized betas) are used to indicate the relative importance of individual variables in a given equation. Note that you cannot compare the various coefficients for the partial factor across rows. That is, the absolute value of a regression coefficient is meaningless if it is not considered within the context of the total number of significant factors and their respective importance.

#### 2.2.2.2 Wald test

The Wald test is used to test the statistical significance of individual logistic regression coefficients ($\beta$ coefficients) for each independent variable, i.e., to test the null hypothesis that a particular logit (effect) is zero. A Wald test calculates a $Z$ statistic, which is B / SE. Values greater than zero indicate that their effect is <u>not</u> significant, and these independent variables may well be dropped from the model.

Initially, all explanatory factors were included in the regression. When the results indicated that a factor(s) was not statistically significant, the insignificant factor(s) was specifically removed (i.e., not selected as an independent variable) and the regression analysis was repeated. This process was iterated until all Wald values were zero or near-zero.

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[1] Homoscedasticity = constancy of the variance of a measure over the levels of the factor under study.

[2] Other useful sources included http://www2.chass.ncsu.edu/garson/PA765/logistic.htm and http://www.ats.ucla.edu/stat/spss/topics/logistic_regression.htm

#### 2.2.2.3 R-squared

The adjusted coefficient of determination ($R^2$), reported in the SPSS regression output, serves as a measure for the amount of variation in the dependent variable that is explained uniquely or jointly by the independents. However, note that it is a pseudo-$R^2$ that is not equivalent to the $R^2$ found in Ordinary Least Squares (OLS) regression. Hence, this $R^2$ statistic should be interpreted with great caution.

#### 2.2.2.4 Relative Operating Characteristic (ROC)

The ROC characteristic is a measure of the goodness of fit of a logistic regression model, similar to the $R^2$ statistic in Ordinary Least Squares regression. A completely random model gives a ROC value of 0.5; a perfect fit results in a ROC of 1.0. The ROC was calculated only for Belize and Guatemala as these datasets are relatively small. Attempts to calculate the ROC for Mexico and Honduras resulted in the computer being locked for hours on end. The ROC values should also be interpreted with care. For example, the equation for savanna in Guatemala has an ROC of 1.0, which seems excellent, but is meaningless because the area of Savanna is extremely small, so the regression equation and ROC are not significant.

### 2.2.3 Regression results

The statistically significant regression coefficients along with the total number of significant location factors (NF) and the ROC statistics are listed in Table 2-1 to 2-4. The default number of decimal values in the SPSS output was increased from 3 to 4 because some coefficients – in particular for elevation and annual precipitation, which are relatively large numbers--- are significant only at the third or fourth decimal.

There are no results for Water, because the regression analysis was not conducted for this land cover type. Also, note that the results for mangroves and savanna in Guatemala are not significant because the area of these land cover types is very small (respectively 0.8 and 0.3 $km^2$). These data should be ignored, but are included here because the CLUE-S model requires regression coefficients for all land use type present.

*Table 2-1: Summary of the logic regression analysis for **Belize**. For each dynamic land use, the regression coefficients for all statistically significant explanatory location factors are listed, with the four most significant ones in bold. Note that the absolute value of a regression coefficient is no indicator of its level of significance, so even relatively small values may be in the top four.*

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Unknown | B.L. Forest. | Pine forest | Agr/Pasture | Scrub | Savanna | Wetland | Mangroves | Urban | Water |
| | | | | | | | | | | |
| Constant | 22.3069 | -1.4571 | -5.8352 | -2.5870 | -5.1061 | -4.0898 | +1.3174 | -5.2436 | -5.4260 | -3.1271 |
| | | | | | | | | | | |
| 0. POPDEN | **-0.1271 (2)** | +0.0078 | -0.0400 | **-0.0782 (2)** | -0.0210 | +0.0241 | -0.0262 | - | +0.0060 | -0.0470 |
| 1. SDEPTH | - | +0.0112 | +0.0422 | +0.0309 | +0.0189 | +0.0477 | -0.0124 | +0.0046 | - | -0.0167 |
| 2. SDRAIN | -13.0878 | +3.0685 | **-24.843 (4)** | +2.6108 | +0.0003 | **-21.904 (2)** | -0.4416 | -8.0568 | -1.9926 | - |
| 3. RAINYR | **-0.0138 (1)** | **-0.0004 (4)** | +0.0010 | +0.0005 | - | +0.0011 | **-0.0008 (3)** | **+0.0015 (3)** | **+0.0024 (3)** | **+0.0017 (2)** |
| 4. DRYMON | -0.9545 | -0.1538 | - | +0.1446 | **-0.3929 (3)** | +0.0993 | - | **+0.6580 (4)** | +0.1273 | - |
| 5. ELEVAT | **-0.2195 (3)** | -0.0002 | **+0.0081 (1)** | -0.0003 | **-0.0017 (4)** | **-0.0186 (3)** | **-0.1676 (1)** | **-0.1927 (1)** | - | **-0.0258 (4)** |
| 6. SLPDGS | +0.4280 | **+0.0811 (3)** | +0.0140 | - | **0.0829 (2)** | **-0.7204 (4)** | +0.4240 | +0.0975 | -0.0594 | +0.2321 |
| 7. ACSMKT | - | **+0.3888 (1)** | **-0.9785 (2)** | **-0.8834 (1)** | **-0.2993 (1)** | **-0.4508 (1)** | **+0.2888 (2)** | **+0.3880 (2)** | **-3.7940 (1)** | **-2.0572 (1)** |
| 8. ACSRDS | | | | | | | | | | |
| 9. TOURIS | **-5.0293 (4)** | -0.4248 | - | -1.4025 | - | -1.1697 | -0.5085 | +0.7488 | **+2.3536 (2)** | **+2.0064 (3)** |
| 10. WDPAS1 | - | **+1.1660 (2)** | +1.1161 | **-2.1446 (3)** | +0.1790 | +0.2115 | **+0.8526 (4)** | - | **-1.5865 (4)** | +0.9016 |
| 11. WDPAS2 | - | +0.6111 | **+1.5436 (3)** | **-1.9867 (4)** | +0.3019 | +0.9286 | -0.7365 | +0.1544 | - | -0.6708 |
| | | | | | | | | | | |
| Final N.F. (significant number of location factors) | 7 | 11 | 9 | 10 | 9 | 11 | 10 | 9 | 8 | 9 |
| ROC (relative operating characteristic) | 0.986 | 0.790 | 0.914 | 0.856 | 0.746 | 0.877 | 0.944 | 0.949 | 0.930 | |

*Table 2-2: Summary of the logic regression analysis for **Mexico**. For each dynamic land use, the regression coefficients for all statistically significant explanatory location factors are listed, with the four most significant ones in bold. Note that the absolute value of a regression coefficient is no indicator of its level of significance, so even relatively small values may be in the top four.*

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Unknown | B.L. Forest. | Pine forest | Agr/Pasture | Scrub | Savanna | Wetland | Mangroves | Urban | Water |
| | | | | | | | | | | |
| Constant | +6.8517 | +0.7725 | | +3.3490 | -4.3477 | -1.4840 | -0.3299 | +2.4059 | -0.5279 | +3.9652 |
| | | | | | | | | | | |
| 0. POPDEN | -0.0087 | -0.0037 | | -0.0044 | +0.0038 | -0.0080 | +0.0004 | -0.0006 | **+0.0032 (2)** | - |
| 1. SDEPTH | +0.0931 | **-0.0363 (1)** | | **+0.0368 (4)** | +0.0277 | - | -0.0360 | **+0.0465 (2)** | -0.0183 | -0.0135 |
| 2. SDRAIN | **+8.1756 (2)** | +0.7826 | | +1.1185 | +0.7621 | -1.5481 | **-3.3492 (3)** | **+2.3327 (4)** | - | -3.2865 |
| 3. RAINYR | **-0.0096 (3)** | +0.0006 | | **-0.0049 (2)** | +0.0008 | **-0.0025 (4)** | +0.0007 | -0.0026 | - | -0.0028 |
| 4. DRYMON | **-1.0723 (4)** | **-0.2020 (4)** | NOT | +0.0315 | **+0.4965 (2)** | **-0.3356 (3)** | **-0.3577 (4)** | **-0.5768 (3)** | **-0.1976 (4)** | -0.1971 |
| 5. ELEVAT | **-0.2035 (1)** | **+0.0032 (3)** | PRESENT | +0.0004 | **+0.0082 (3)** | **-0.0061 (2)** | **-0.1152 (1)** | **-0.2902 (1)** | **+0.0134 (3)** | -0.1682 |
| 6. SLPDGS | -0.3045 | +0.0376 | | -0.1887 | -0.1187 | **+0.3921 (1)** | +0.3671 | +0.0974 | -0.4270 | +0.9935 |
| 7. ACSMKT | -0.1832 | **+0.1108 (2)** | | **-0.8789 (1)** | **-0.5194 (1)** | -0.0998 | **+0.1687 (2)** | +0.0558 | **-3.8397 (1)** | -0.8043 |
| 8. ACSRDS | | | | | | | | | | |
| 9. TOURIS | -0.3411 | -0.1851 | | -0.8338 | -4.4556 | - | -1.0558 | +0.3901 | - | +0.3677 |
| 10. WDPAS1 | -2.5142 | -1.9277 | | -3.9602 | - | - | - | +1.5087 | - | +1.5022 |
| 11. WDPAS2 | +1.4217 | -0.3500 | | **-1.2475 (3)** | **-1.1183 (4)** | - | +0.4964 | - | - | +1.1391 |
| | | | | | | | | | | |
| Final N.F. (significant number of location factors) | 11 | 11 | | 11 | 10 | 7 | 10 | 10 | 6 | 10 |
| ROC (relative operating characteristic) | 0.960 | 0.643 | | 0.772 | 0.755 | 0.696 | | | | |

*Table 2-3: Summary of the logic regression analysis for **Guatemala**. For each dynamic land use, the regression coefficients for all statistically significant explanatory location factors are listed, with the four most significant ones in bold. Note that the absolute value of a regression coefficient is no indicator of its level of significance, so even relatively small values may be in the top four.*

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Unknown | B.L. Forest. | Pine forest | Agr/Pasture | Scrub | Savanna[1] | Wetland | Mangroves[1] | Urban | Water |
| | | | | | | | | | | |
| Constant | 47.3927 | -1.0271 | -12.2485 | -0.9537 | -5.4976 | -18.2304 | -11.4624 | -53.4470 | -17.7335 | +9.9883 |
| | | | | | | | | | | |
| 0. POPDEN | **+0.0550 (2)** | +0.0004 | **-0.0016 (3)** | -0.0004 | -0.0019 | - | **+0.0063 (3)** | **-0.5870 (3)** | **+0.0013 (1)** | -0.0565 |
| 1. SDEPTH | - | -0.0037 | **+0.0998 (4)** | **+0.0213 (4)** | +0.0287 | - | +0.0388 | - | +0.1074 | -0.0300 |
| 2. SDRAIN | - | **+1.3851 (4)** | -1.3376 | -0.2118 | -1.5277 | +5.5433 (2) | **-7.7154 (4)** | - | +1.3544 | - |
| 3. RAINYR | **-0.0325 (3)** | -0.0004 | **-0.0016 (2)** | -0.0001 | +0.0006 | - | - | - | **+0.0033 (3)** | -0.0011 |
| 4. DRYMON | **+0.7634 (4)** | -0.0506 | -0.2201 | -0.1077 | **+0.3530 (2)** | - | - | - | +0.3273 | -0.8731 |
| 5. ELEVAT | **-0.1978 (1)** | - | **+0.0025 (1)** | -0.0002 | **-0.0009 (1)** | +0.0030 (1) | **-0.0183 (1)** | - | **-0.0016 (4)** | -0.0349 |
| 6. SLPDGS | - | -0.0016 | -0.0079 | -0.0172 | **-0.0497 (4)** | - | - | - | -0.3538 | -0.9330 |
| 7. ACSMKT | - | **+0.3799 (1)** | -0.0819 | **-0.3457 (1)** | -0.0578 | - | **+0.5710 (2)** | **-1.6120 (2)** | **-6.5289 (2)** | -1.6897 |
| 8. ACSRDS | | | | | | | | | | |
| 9. TOURIS | - | - | - | - | - | - | - | - | - | - |
| 10. WDPAS1 | - | **+1.9105 (2)** | - | **-1.3588 (3)** | -2.2227 | - | +2.0176 | **+6.6210 (1)** | - | +0.4520 |
| 11. WDPAS2 | - | **+1.3967 (3)** | +0.1446 | **-1.1538 (2)** | **-1.1085 (3)** | - | +2.1844 | - | - | - |
| | | | | | | | | | | |
| Final N.F. (significant number of location factors) | 4 | 9 | 9 | 10 | 10 | 2 | 7 | 3 | 8 | 8 |
| ROC (relative operating characteristic) | 1.000 | 0.787 | 0.906 | 0.748 | 0.755 | 0.972 | 0.963 | 1.000 | 0.993 | 0.994 |

[1] Results for savanna and mangroves are not significant and unreliable because the area of these land cover types in Guatemala is nil (respectively 0.3 and 0.8 $km^2$).

*Table 2-4: Summary of the logic regression analysis for* ***<u>Honduras</u>****. For each dynamic land use, the regression coefficients for all statistically significant explanatory location factors are listed, with the four most significant ones in bold. Note that the absolute value of a regression coefficient is no indicator of its level of significance, so even relatively small values may be in the top four.*

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Unknown | B.L. Forest. | Pine forest | Agr/Pasture | Scrub | Savanna | Wetland | Mangroves | Urban | Water |
| | | | | | | | | | | |
| Constant | -10.2362 | -2.4795 | +1.5916 | +1.4693 | +15.7990 | -14.6541 | +5.2971 | -6.0420 | -5.8989 | -14.8752 |
| | | | | | | | | | | |
| 0. POPDEN | -0.0007 | - | **-0.0095 (4)** | - | -0.0074 | **-0.1154 (2)** | - | -0.0150 | **+0.0026 (1)** | -0.0059 |
| 1. SDEPTH | +0.0511 | +0.0177 | -0.0059 | -0.0089 | - | +0.0573 | - | - | -0.0165 | -0.0295 |
| 2. SDRAIN | **+1.8542 (4)** | -0.5031 | +1.5214 | -0.7989 | -1.6502 | +2.3869 | -1.0514 | - | **-2.9412 (4)** | +0.6983 |
| 3. RAINYR | +0.0009 | **-0.0010 (4)** | **-0.0026 (1)** | **+0.0007 (3)** | **-0.0105 (1)** | **+0.0039 (3)** | **-0.0031 (2)** | **+0.0020 (4)** | +0.0016 | **+0.0066 (1)** |
| 4. DRYMON | -0.1531 | **-0.7078 (2)** | +0.0444 | **+0.2402 (2)** | **-1.2983 (3)** | -0.7053 | **-0.8714 (3)** | -0.8990 | -0.2122 | **+1.5561 (3)** |
| 5. ELEVAT | **-0.0192 (2)** | **+0.0017 (3)** | **+0.0010 (2)** | **-0.0011 (1)** | -0.0009 | +0.0027 | **-0.0332 (1)** | **-0.1165 (2/3)** | **+0.0025 (3)** | **-0.0064 (4)** |
| 6. SLPDGS | -2.6805 | +0.0476 | +0.0048 | - | **-0.2143 (4)** | **-0.5584 (4)** | -0.1944 | - | - | -0.1983 |
| 7. ACSMKT | **-0.1011 (1)** | **+0.2286 (1)** | -0.0208 | -0.2079 | -0.4109 | **-0.2150 (1)** | **+0.0625 (4)** | **-0.2285 (1)** | **-9.8104 (2)** | **-0.2251 (2)** |
| 8. ACSRDS | | | | | | | | | | |
| 9. TOURIS | - | - | - | -1.4446 | - | - | - | - | +1.0999 | - |
| 10. WDPAS1 | **+1.1004 (3)** | +1.5334 | **-1.5463 (3)** | **-0.6011 (4)** | **+2.8179 (2)** | -6.3652 | -1.4120 | **+1.6109 (2/3)** | - | +0.5007 |
| 11. WDPAS2 | - | - | - | - | - | - | - | - | - | - |
| | | | | | | | | | | |
| Final N.F. (significant number of location factors) | 9 | 8 | 9 | 8 | 8 | 9 | 7 | 6 | 8 | 9 |
| ROC (relative operating characteristic) | | | | | | | | | | |

# 3 GEO-4 scenarios and the ICRAN MAR project

**Acknowledgements**
With thanks to the Latin American scenarios working group for GEO-4, Barry Hughes, Bas Eickhout, Joep Luijten, Lauretta Burke, Emil Cherrington, Jan Meerman, Gladys Hernandez, Igor Lysenko and the GEO-4 Outlook team.

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## 3.1 Scenario summaries

Four scenarios for the ‘Latin America and the Caribbean’ UNEP region have been drafted in preparation for the publication of Global Environment Outlook 4 (GEO-4) in 2007. These narratives were developed by the LAC scenarios working group for GEO-4. The scenarios envisage differing social, political and economic trajectories, emphasising outcomes for the environment and human well-being. Three of the four draft scenarios have been selected for exploration of possible futures for land cover change within the ICRAN MAR project; the fourth scenario (Security First) is not presented here.

The GEO scenarios consider the period from 2007 through to 2050 for the whole of Latin America and the Caribbean, and encompass the overall interaction between human development and the environment. The ICRAN MAR project considers the period up to 2025, for the watersheds draining directly onto the reef and focuses on the impact of land cover change on coral reefs. This chapter summarises and adapts the GEO scenarios with a focus on this topic and timescale. The scenarios published in GEO 4 and in the forthcoming GEO-LAC will therefore differ in many respects from those presented here.

It is assumed that climate change and variability is not susceptible to further human influence up to 2025 – the change will occur has already been set in train. Changes in climate are therefore identical throughout the scenarios; what varies is the resilience and response of societies within each of the scenarios. For example, coral bleaching events can be expected to increase in frequency in every scenario; but the approach to and coordination in tackling the issue varies.

A comparison of modelled population and land cover changes up to 2025 for the scenarios follows the narrative description; the methods are described in Sections 3.2 and 3.3.

### 3.1.1 About the GEO-4 scenarios

UNEP is working on the fourth *Global Environment Outlook* (GEO-4), for release in 2007, 10 years after the first GEO, and 20 years after the Brundtland report (WCSD, 1987). The Global Environment Outlook process was initiated by UNEP for global environmental assessment and reporting process, in response to several Decisions of the UNEP Governing Council. The aim is to ensure that environmental problems and emerging issues of wide international significance receive appropriate, adequate and timely consideration by governments and other stakeholders. Projects are undertaken under the GEO programme at global, regional and local scales.

There are seven GEO regions, each divided into subregions for finer scale analysis and reporting. The Latin America and Caribbean (LAC or ALC) region is composed of the Caribbean, Meso-America and South America regions. The Meso-America subregion is the one relevant to the ICRAN MAR project, being composed of Belize, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua and Panama. Many GEO processes have been undertaken in the LAC region. The most relevant for the ICRAN MAR project are *GEO LAC 2000*[1], *GEO LAC 2003*[2], *Caribbean Environmental Outlook (1999, 2005)*[3] (includes Belize), *GEO Centroamerica 2004*[4], *GEO Biodiversidad (Centroamerica) 2003*[5], *GEO Guatemala 2003*[6], *GEO Honduras 2005*[7] and *GEO México 2004*[8].

GEO-3 presented a set of divergent global scenarios running from 2002 to 2032: Markets First, Policy First, Security First and Sustainability First (UNEP, 2002). These scenarios are being updated and extended to 2050 for GEO-4, with the global narratives being based on the work of seven regional working groups. Each regional scenario focuses on regional priorities defined by contributors to the GEO process. The LAC group met first as part of the global scenarios meeting in Bangkok, September 2005, and then in a follow-up meeting in Trinidad & Tobago, in February 2006. Each meeting included representatives from throughout the LAC region. In addition, feedback has been sought from a broader group including the regional team working on the state and trends section of GEO-4.

The narratives will be represented in the GEO-4 report alongside a set of quantitative outcomes. A process of reconciliation of the assumptions made in the different regional scenarios and by the modelling team is currently underway, with the first order draft of GEO-4 being circulated for review in May 2006.

It is anticipated that the adaptation of the GEO scenarios for the ICRAN MAR project will render the project outcomes more immediately accessible to policy makers who have already encountered the GEO work through UNEP's outreach efforts. It also allows the ICRAN MAR project to benefit from the substantial amount of work undertaken through GEO, including the modelling of regional scale land-cover change within an integrated modelling framework. The MAR project has discarded the Security First scenario, which results in a level of land cover change in between those of Markets and Policy First.

In the following sections, the global overview of each scenario is presented as described in GEO-3, and is followed by a regional summary based on the draft for GEO-4.

### 3.1.2 Markets First

#### 3.1.2.1 GEO-3 scenario overview

"*Most of the world adopts the values and expectations prevailing in today's industrialized countries. The wealth of nations and the optimal play of market forces dominate social and political agendas. Trust is placed in further globalization and liberalization to enhance corporate wealth, create new enterprises and livelihoods, and so help people and communities to afford to insure against — or pay to fix — social and environmental problems. Ethical investors, together with citizen and consumer groups, try to exercise growing corrective influence but are undermined by economic imperatives. The powers of state*

[1] http://www.unep.org/geo/regreports.htm

[2] http://www.unep.org/geo/regreports.htm

[3] http://www.unep.org/geo/regreports.htm

[4] draft pdf obtained

[5] pdf obtained

[6] http://www.pnuma.org/dewalac_ingles/guatemala03_i.htm

[7] http://www.serna.gob.hn/documentos/GEO_Honduras_2005.pdf

[8] http://www.ine.gob.mx/ueajei/publicaciones/consultaPublicacion.html?id_pub=448

*officials, planners and lawmakers to regulate society, economy and the environment continue to be overwhelmed by expanding demands.*" (UNEP, 2002).

### 3.1.2.2 MAR region summary (based on GEO-4 draft)

*Economy and governance*

- Public policy is geared towards supporting **commercial interests** and promoting the open exchange of goods and services. Social and environmental policies receive little attention or financial support; it is assumed that economic growth is in itself a sufficient route to progress.
- **Remittances** (funds sent home by migrant workers) are more important than foreign investment or aid; this is especially valuable for Mexico's economy.
- New **industrial parks** are built to entice national and foreign investment.
- **Tourist visits** to the MAR region increase until around 2025. With limited regulation, the impact of tourism on coastal ecosystems also increases. Visits then start to drop off as a result of deteriorating habitats and increasing pollution.

*Population and standard of living*

- **Populations increase**, but the growth rate slows with falling birth rates.
- For all MAR countries, the highest rates of **urbanisation** are seen under this scenario, with 80% of the regional population living in urban areas by 2025. Most development is unplanned, and built on the coast or around the industrial parks.
- Social services are reduced, and **inequity** in resource distribution increases.
- **Emigration** increases, with people from all countries of Central America moving northwards. This is especially relevant for Mexico, which after 2010 sees a lower rate of national population growth within this scenario than in any other. Migration also occurs within the country, with agriculturalists moving from the dry central region to the south, including the Yucatan penisula.

*Environmental impacts*

- Although sustainable development is much discussed, this scenario sees the greatest rate of **agricultural expansion**. Rates of habitat loss, fragmentation and soil erosion increase. Comparing the MAR countries, the rate of agricultural expansion is greatest in Mexico, Belize and then Guatemala. However, Honduras sees the highest rates of decrease in natural habitats, because the area remaining is already substantially reduced[1].
- Agrochemical **pollution** increases, despite the influence of emissions standards.
- The terrestrial **protected area** network expands slightly by 2025, to encompass 10% of all biomes. For 20% of the new sites, natural ecosystems are successfully protected from change over the scenario period. 60% are partially protected from change, and 20% fail to be protected (see Section 3-4).
- **Water** quality decreases and abstraction for tourism and agriculture increases, as a result of limited interest in promoting good watershed management practices.
- Both agricultural and natural ecosystems are vulnerable to an increasing frequency of **climate** extremes. Fire frequency increases, especially in the dry forests of Honduras and Guatemala.

[1] 56% of Honduras was already dedicated to agriculture by 2000, as opposed to 31% in Guatemala, in 19% in Belize and only 6% in Mexico.

### 3.1.3 <u>Policy First</u>

#### 3.1.3.1 GEO-3 scenario overview

"*Decisive initiatives are taken by governments in an attempt to reach specific social and environmental goals. A coordinated pro-environment and anti-poverty drive balances the momentum for economic development at any cost. Environmental and social costs and gains are factored into policy measures, regulatory frameworks and planning processes. All these are reinforced by fiscal levers or incentives such as carbon taxes and tax breaks. International 'soft law' treaties and binding instruments affecting environment and development are integrated into unified blueprints and their status in law is upgraded, though fresh provision is made for open consultation processes to allow for regional and local variants.* " (UNEP 2002).

#### 3.1.3.2 MAR region summary (based on GEO-4 draft)

*Economy and governance*

- Whilst many **policies** are more reactive than strategic, governments take a close interest in social and environmental problems.
- Exports of **primary goods** continue to form a crucial part of the region's economy, and the **tourism** sector grows significantly with public support.
- By 2025, this is the scenario with the highest **GDP** per capita growth rates for Guatemala, Belize and Honduras. For Mexico, Markets First has a slightly higher growth rate, partly as a result of increased remittances from North America.

*Population and standard of living*

- Equity increases, with progress towards the Millennium Development Goals on **education, income and health**. Emigration decreases as quality of life improves.
- Over the MAR region, **population growth** continues, but the rate of increase slows more rapidly than in Markets First, especially in Honduras and Guatemala.
- **Urbanisation** continues, but is subject to stronger planning constraints.

*Environmental impacts*

- Land use becomes better regulated, especially around riverine corridors. Implementation is patchy, but the rate of deforestation decreases. Over the MAR region, **deforestation** continues to result in erosion and land degradation, but at a lesser rate than in the Markets First scenario. In Mexico, forest cover decreases only until 2010, when an ambitious national forestry plan reverses the trend. Mexican forest area surpasses 2000 levels by 2025.
- By 2015, cooperation on the management of **transboundary watersheds** develops in the MAR region. Water quality increases as a result.
- Certification schemes for timber, agriculture and fisheries are encouraged.
- The terrestrial **protected area** network expands by 2025 to encompass 10% of all biomes and all single-site endemic species by 2025. For 65% of the new sites, natural ecosystems are completely protected from change over the period. 25% are partially protected from change (allowing sustainable use), and 10% fail to be protected (see Section 3-4). The marine protected area network also grows, with a focus on enhancing resilience to coral bleaching[1].

[1] through reserve network design to optimise larval dispersal opportunities and to include more resilient reef types (Schuttenberg 2001)

- Research is undertaken into **adaptation** measures to cope with the changing climate. By 2025, more diverse agricultural systems are being encouraged with the aim of resilience to climate change impacts.
- Policies are adopted to assign economic values to coastal ecosystems such as **mangroves** that provide protection from sea surges. However, coastal developments continue to expand, and coastal degradation continues.

### 3.1.4 Sustainability First

#### 3.1.4.1 GEO-3 scenario overview

"*A new environment and development paradigm emerges in response to the challenge of sustainability, supported by new, more equitable values and institutions. A more visionary state of affairs prevails, where radical shifts in the way people interact with one another and with the world around them stimulate and support sustainable policy measures and accountable corporate behaviour. There is much fuller collaboration between governments, citizens and other stakeholder groups in decision-making on issues of close common concern. A consensus is reached on what needs to be done to satisfy basic needs and realize personal goals without beggaring others or spoiling the outlook for posterity.* " (UNEP 2002).

#### 3.1.4.2 MAR region summary (based on GEO-4 draft)

*Economy and governance*

- **Economic cooperation** between the MAR countries increases.
- Governments make a strong commitment to **sustainable development**. Efficiency in the use of energy, land and material resources is promoted. There are efforts to adopt an ecosystem approach to land use planning, with particular attention to watershed protection. Awareness campaigns are directed both at industry and the general public, and help to change consumption patterns.
- The **tourist industry** continues to grow, but smaller packages become more popular, so that there are fewer large developments.
- For Belize, Guatemala and Honduras, **GDP per capita** growth rates are greater than those for Markets First, but are slightly smaller than for Policy First. Most other quality of life indicators are strongest under this scenario.

*Population and standard of living*

- Considerable resources are directed to **poverty alleviation** as the scenario progresses. Many of the Millennium Development Goals are achieved by 2015, and further progress is made by 2025.
- For Guatemala and Honduras in particular, this is the scenario with the lowest rate of **population increase**. The rate of population growth in this scenario for Mexico is therefore higher than in Markets First, partly because fewer people feel the need to migrate to find work. Overall, population growth rates decrease.
- There is less growth in **urban area** within this scenario than any other; most urban development is concentrated in medium and small cities.

*Environmental impacts*

- A shared environmental agenda arises in the region. National regulation and incentives develop further to control pollution and generate local payments for local environmental services such as water.
- At national to local scale, Agenda 21 gains strength, promoting involvement of community and business groups in areas such as integrated land management. The rate of loss and fragmentation of key habitats decreases.
- The move towards organic agriculture and the use of biological controls is unexpectedly assisted by rising oil prices, which increase the cost of agrochemical use. Extension services for these more sustainable practices develop. Food yields improve. The combined impact of increased efficiency of natural resource use and ecosystem restoration means that by 2025, agricultural area begins to decrease slightly in all MAR countries.
- Several large Clean Development Mechanism projects are implemented, with forest landscape restoration initiatives being particularly successful in Honduras.
- The terrestrial protected area system expands to represent all key regional ecosystems and species, including more transboundary reserves. It includes at least 10% of all biomes and all single-site endemic species by 2025. For 30% of the new sites, natural ecosystems are completely protected from change over the period. 65% are partially protected from change (allowing sustainable use), and 5% fail to be protected despite the best intentions (see Section 3-4). The marine protected area network also grows, with no-catch zones being established by local agreement to conserve fisheries.

## 3.2 Population and land cover change: comparisons between scenarios

This section summarises the population and land cover changes across the scenarios. Land cover change was modelled using a combination of three models (for methods, see next section). Figure 3-1 summarises the questions addressed using the different models. For Mexico, the annual rate of agricultural expansion within Markets First was multiplied by 1.5, to represent internal migration by farmers from the dry central parts of the country.

The rate of land cover change under the different scenarios was estimated for the whole of the four countries based on results from IFs and IMAGE. The changes in land cover were then applied to the watershed area, assuming the rate of land cover change within the MAR model region would match that within the remainder of the countries. CLUE-S was used to allocate land cover within the region.

Differences between the scenarios can more easily be seen by comparing the changes in human population or land cover (Figures 3-2, 3-3, 3-4 and 3-4) than by comparing the total population and area values (Figures 3-2, 3-5 and 3-6). Greater detail for land cover change is available in the Section 3.3.

The population of all four countries continues to grow under all scenarios (Figures 3-2 and 3-3). The population figures shown here represent the whole countries, not just the MAR region. The highest growth rates are consistently found in Guatemala and Honduras, but there is high variation between scenarios. All except Mexico experience the smallest increase under Sustainability First; for Mexico, Markets First is smallest. Variation in growth rate between scenarios from 2005 to 2025 is smaller for Mexico than for other countries, with Markets First at 17% and the other three scenarios from 21 to 22%. For Belize, rates vary from 24% to 39%, for Guatemala from 44% to 68%, and for Honduras from 37% to 58%.

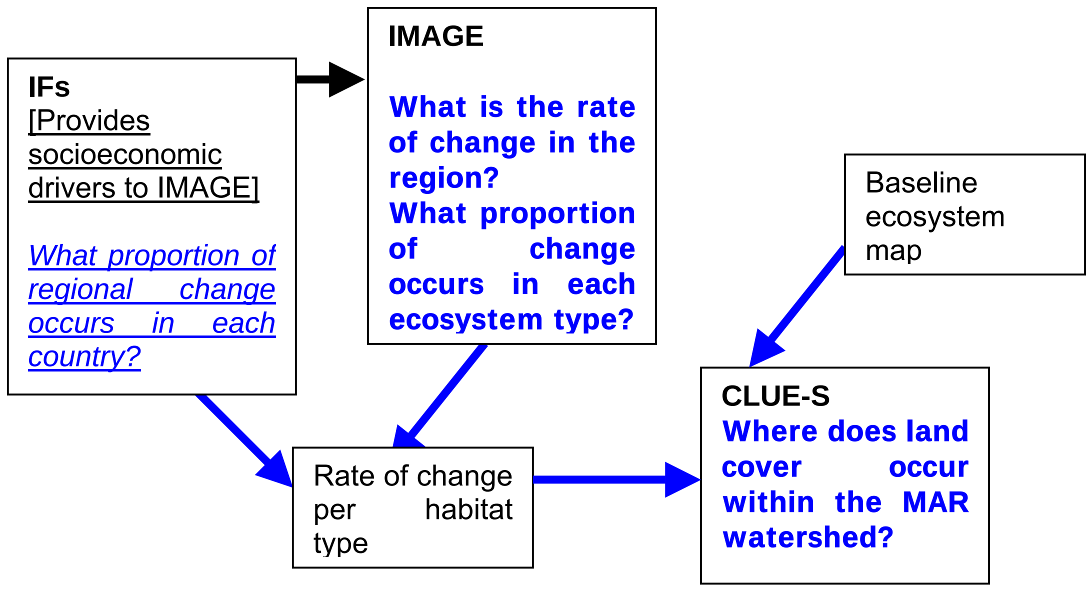


*Figure 3-1: Role of three models used to simulate land cover change*

The greatest increases in urban and agricultural land are seen under Markets First, followed by Policy First. Where there is an increase in wildland under Sustainability or Policy First, it is usually scrubland, which may regenerate to forest in time. For Mexico, forest area increases under Policy First.

To illustrate the variation between scenarios and countries in detail, change in forest cover can be examined. When considering total change in all forest classes, all countries lose most forest in Markets First (Table 3-1). However, there are differences between the response of the different countries to the different scenarios. Belize, Guatemala and Honduras all lose least forest in Sustainability First (in the case of Honduras, there is an increase in forest area), whilst Mexico still loses a substantial amount of forest to agriculture in that scenario. Whilst there is a gradual decrease in area devoted to agriculture (including pastureland), the major increase by 2025 is in the area of scrubland, rather than of forest (Figure 3-5). This is especially true in Mexico.

Whilst these scenarios provide a range of outcomes, more radical changes are also be possible. For GEO Honduras, the Polestar model was used to quantify the scenarios. It simulated a decrease in forest area of ~20% by 2020 for the Markets-First equivalent, and an increase of 15% under the Sustainability-First equivalent.

*Table 3-1: Forest cover change by scenario*

| Land unit | Percentage change, 2005 to 2025 | | |
|---|---|---|---|
| | **Markets First** | **Policy First** | **Sustainability First** |
| IMAGE Central America | -12.5 | -5.1 | +1.6 |
| Belize | -6.2 | -2.2 | -0.2 |
| Guatemala | -9.2 | -3.9 | -1.3 |
| Honduras | -14.1 | -7.0 | +0.8 |
| Mexico | -3.5 | +1.7 | -2.1 |

Within any country, the MAR modelling framework allocates an equal percentage change to broad-leaved forest, pine forest and mangroves between 2005 and 2025. However, the percentage change in the area of each forest type over the whole of the four countries between 2005 and 2025 differs (Figures 3-9 through 3-12) because there is variation between countries in the baseline forest area belonging to the three categories (Figure 3-8) and in the percentage change allocated to that country.

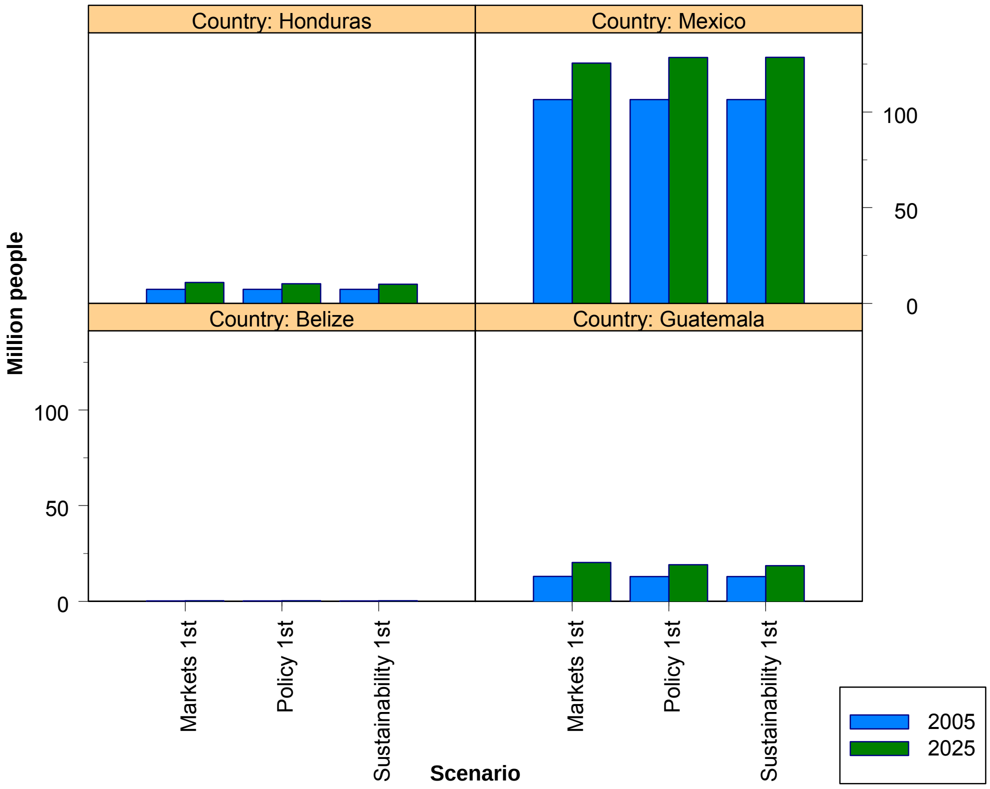


*Figure 3-2: National human population at 2005 and 2025 by scenarios (IFs)*[1]

[1]Belize population is modelled as 0.26 million at 2005, and at 2025 varies little, from 0.33 million (Policy First, Sustainabilty First) to 0.34 million (Markets First).

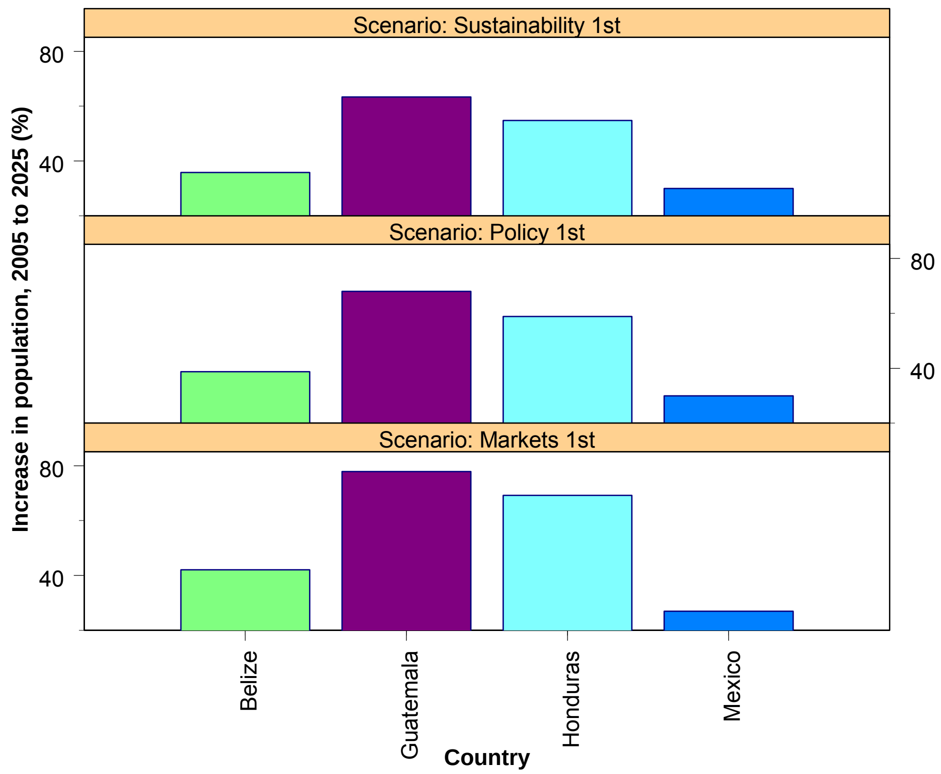


*Figure 3-3: Percentage change in national populations, 2000 to 2025, by scenario (IFs)*

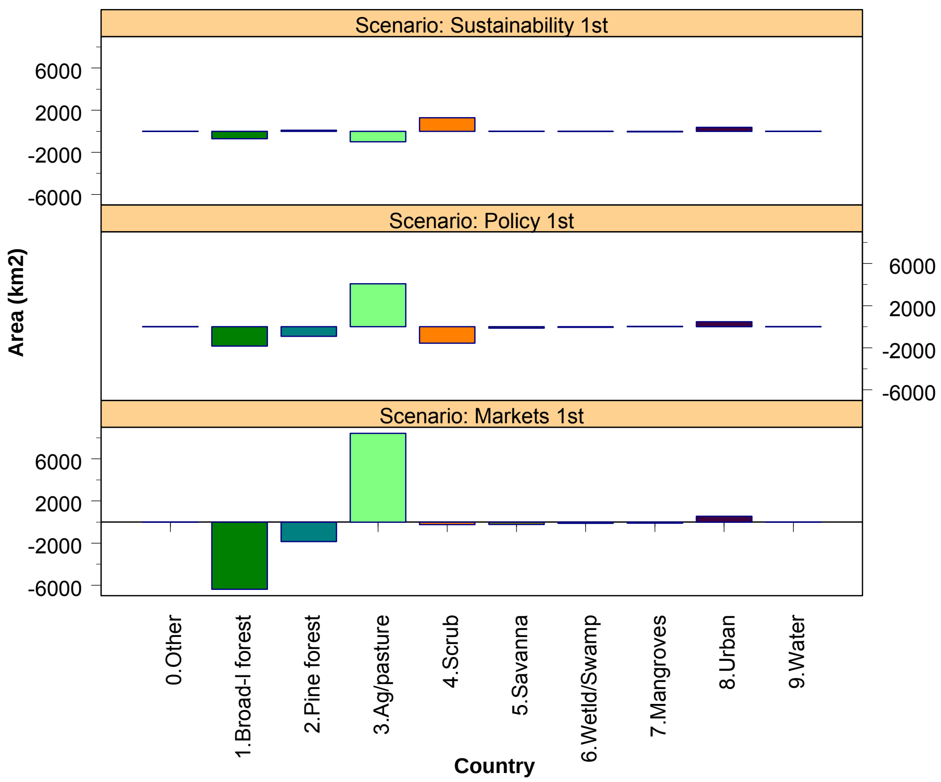


*Figure 3-4: Change in land cover, 2005 to 2025, all countries combined*

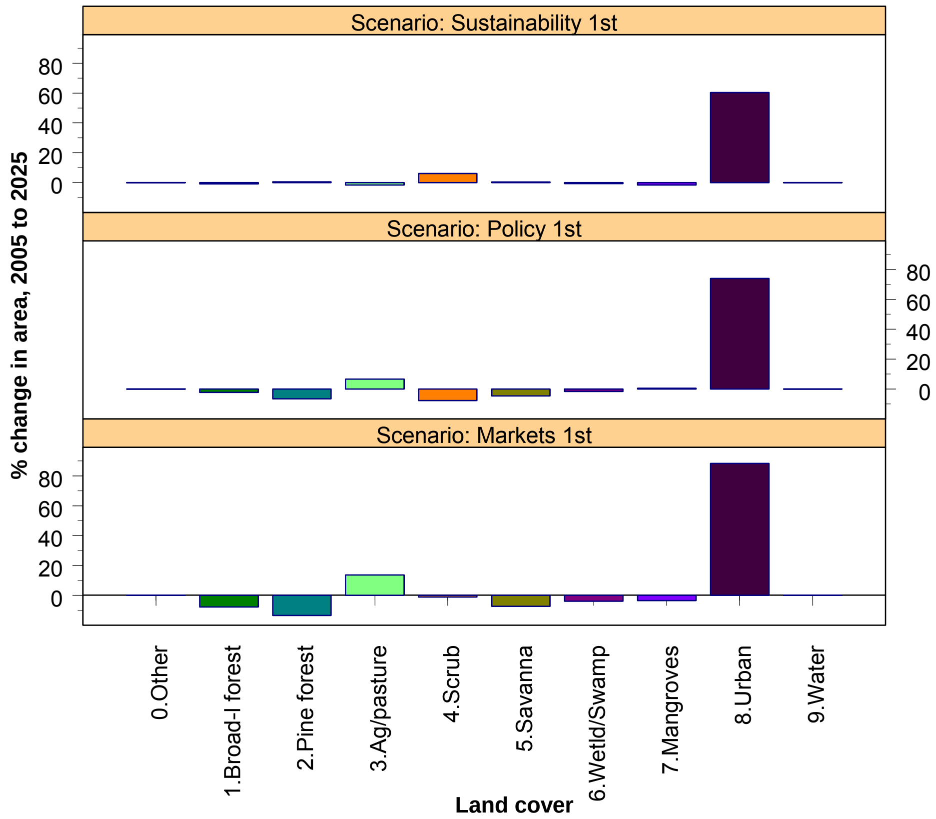


*Figure 3-5: Percentage change in land cover, 2005 to 2025, all countries combined*

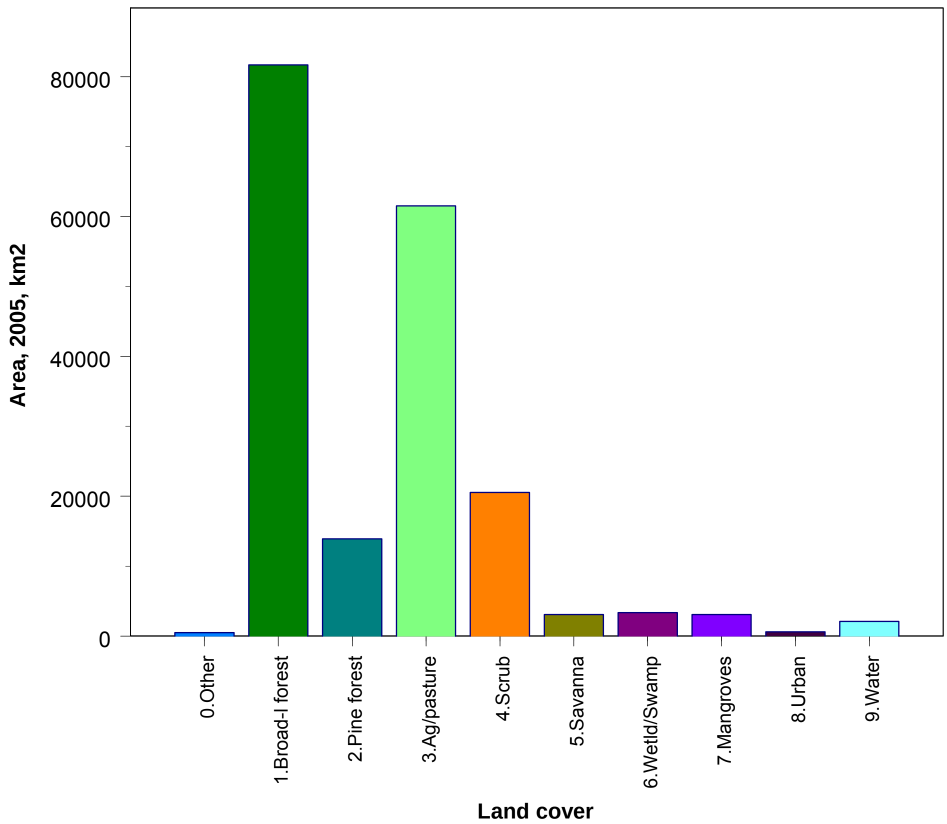


*Figure 3-6: Land cover for watershed area at 2005; all countries combined*

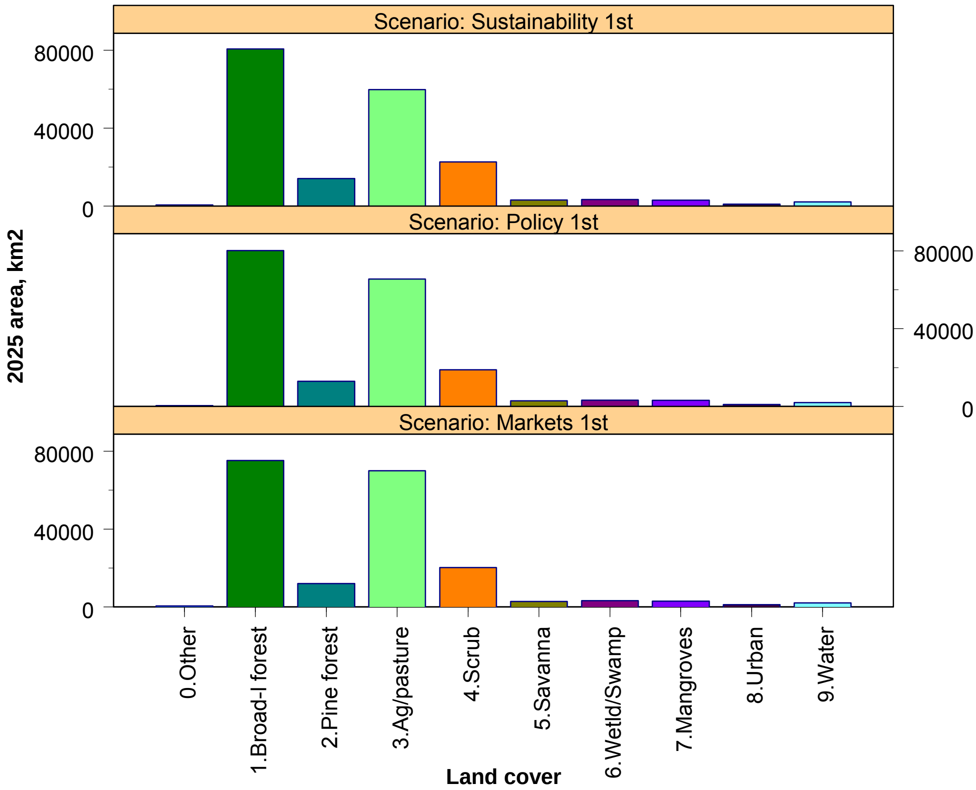


*Figure 3-7: Land cover for watershed area at 2025 by scenarios; all countries combined*

## 3.3 Land cover quantification: the IFs and IMAGE models

### 3.3.1 Model background

Two of the models used in support of GEO are relevant to the MAR project. IMAGE-2[1] is a gridded integrated assessment model, operating at the global scale. It is able to simulate issues like the impact of global climate change on crop production. International Futures (IFs)[2] is a 'macro-agent' based model, also operating at the global scale, but at the resolution of countries rather than on a spatial grid. It represents major agent classes (households, governments, firms), simulating relationships in a variety of global structures (demographic, economic, social, and environmental) (Hughes 2004). It is available online for use in scenario exploration and teaching. IFs provides the driver variables for the GEO-4 scenario. IMAGE projects land use based on these drivers and other interrelated factors, using a half-degree grid, but its outputs are intended to be interpreted on a regional scale.

Within the ICRAN MAR project, the Conversion of Land Use and its Effects (CLUE-S) model has been selected for land cover change modelling on a 250-m grid. The GEO models are used to obtain percentage change in land cover types (rather than area of change) through time, to drive the CLUE-S model.

Each model has been configured independently, so uses its own land cover classification. The land cover classes have been mapped onto one another to give a minimum set as shown in Table 3-2. The major assumptions are that (i) despite inconsistencies between land cover definitions, the ratio of change in land cover between countries and the Meso-America

[1] http://www.mnp.nl/image/

[2] http://ifsmodel.org/; http://www.ifs.du.edu/

region within the IFs model is still a good proxy for the ratio within the IMAGE model; (ii) the relative change between land cover types within the IMAGE model is a reasonable indicator of the change between equivalent types within the CLUE-S model. The ‘other’ class within CLUE-S and the ‘other’ class within IFs represent rather different concepts, and do not map onto one another. The ‘other’ class within CLUE-S represents only 0.25% of the land area for the four countries at the baseline year, and is not allowed to change in area. In IFs, the ‘other’ class represents 18% and is subject to change. Here, the IFs class is used to assist in calculating change in the scrub, savanna, wetland and swamp categories within CLUE-S.

The baseline year for Belize is 2004; for Mexico, Guatemala and Honduras it is 2000 (Figure 3-8). These are the years for which the latest Ecosystem Map land cover data was available (Meerman & Sabido 2001, Vreugdenhill *et al*. 2002).

IMAGE simulates a historical 8.7% loss over the whole of Central America from 1990 to 2005. Looking into the future, IMAGE simulates a 12.5% loss in forest cover from 2005 to 2025 under Markets First, a 5.1% loss under Policy First and a 1.6% loss under Sustainability First.

In IFs, forest area is initiated using FAO data, with simulated changes being dependent upon the rate of conversion to cropland and grazing area. This rate is driven by agricultural supply and demand, based upon factors such as human population and land development costs. Urban area expands into all other land cover classes equally. The IMAGE model, conversely, uses a terrestrial vegetation model factoring in impacts of climate and soils. As IMAGE does not model urban area changes, IFs values have been used for change to urban land.

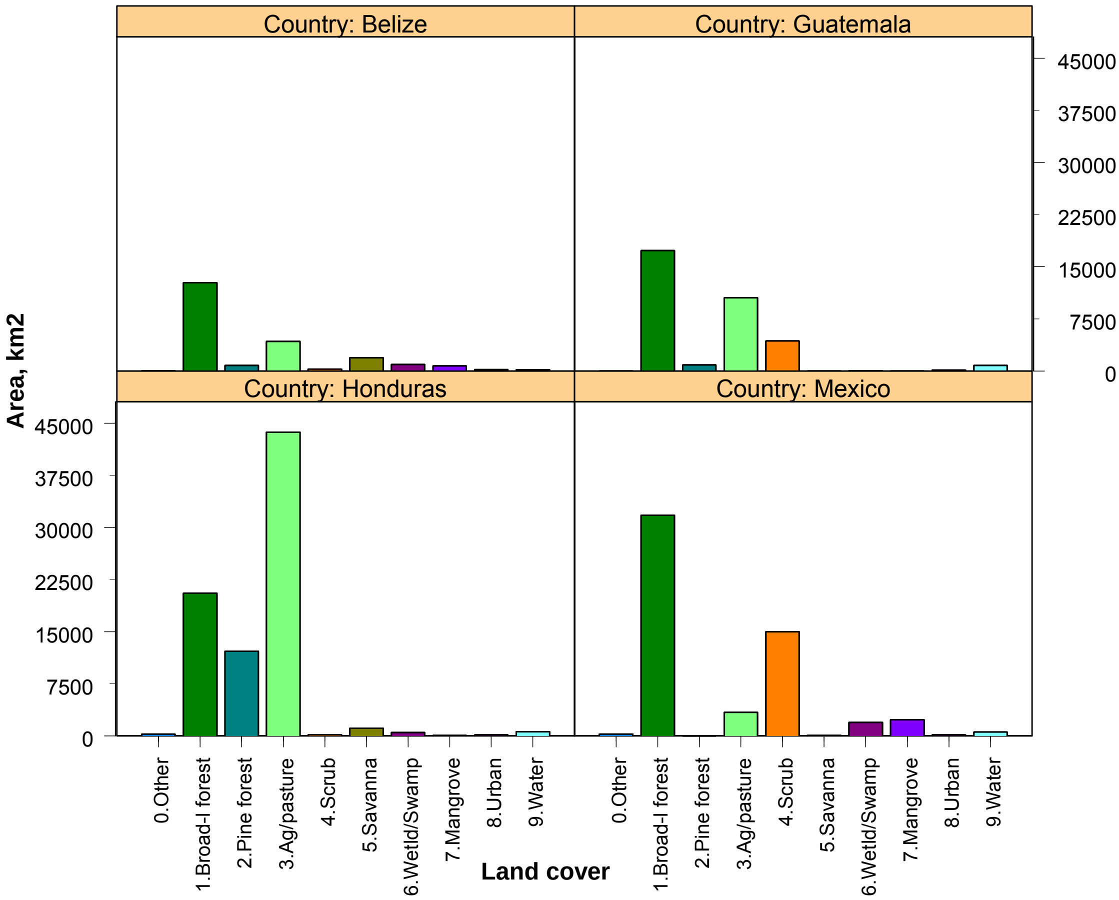


*Figure 3-8: Land cover at baseline year (2004 for Belize, 2000 for Guatemala, Honduras and Mexico)*

### 3.3.2 Bringing the models together: methods

The land cover values for the future scenarios as applied to CLUE-S are derived by allocating the percentage change as seen in IMAGE, distributed between countries according to the proportionate national changes in IFs. The land cover types differ between the three models, and are mapped onto one another as shown in Table 3-2. The resulting values are used to drive the CLUE-S land allocation routine as described in detail below.

*Table 3-2: Mapping of land cover types between IFs, IMAGE and CLUE-S*

| Land cover type (CLUE-S[1]) | Land cover type (IFs) | Land cover types (IMAGE) | Assumptions for CLUE-S application |
|---|---|---|---|
| 0. Other/Unknown (NO CHANGE)) | N/a | N/a | CLUE-S requires no change to this class |
| 1. Broad-leaved forest<br>2. Pine forest<br>7. Mangroves | Forest | Carbon plantations<br>Regrowth forest (abandoned)<br>Regrowth forest (timber)<br>Warm mixed forest<br>Tropical woodland<br>Tropical forest<br>[On a global scale, this category would include other forest types not present in the Meso-America region] | Equal probability of change of CLUE-S types |
| 3. Agriculture/ pasture | Crop | Food crops<br>Biofuel crops | IFs types are subtypes of CLUE-S type |
| | Grazing | Grass and fodder | |
| 4. Scrub | Other | Scrubland | |
| 5. Savanna<br>6. Wetland/swamp | Other | IMAGE savanna, desert, grassland/steppe [on basis that it will include wet grasslands] | Equal probability of change of CLUE-S types |
| 8. Urban | Urban | Excluded from IMAGE by reducing land area per cell accordingly; not modelled in future. | IFs increase in urban area is applied directly, with the expansion reducing the 'other' category. |
| 9. Water (NO CHANGE) | N/a | N/a | CLUE-S requires no change to this class |

[1] The 10 land cover classes used by the CLUE-S model are not dictated by CLUE-S. Instead, this is a reduced classification of the land cover classes of the source 'Ecosystem Map' land cover dataset, which was developed and agreed upon by the watershed partners.

For any given year, scenario and IFs land cover type:

f = area for country in IFs (mill ha)
F = area for region in IFs (mill ha) = Σf
m = area for country equivalent to that in IMAGE (mill ha) [derived in this exercise]
M = sum of area for appropriate categories from Table X for region in IMAGE (mill ha) = Σm
c = area for country in CLUE-S ($km^2$) [derived from map data for year 1, and for later years in this exercise]
C = area of country

i) Estimation of area in IMAGE for country in year n

Foe urban land (see Table 3-2)
$m_{yn\ (urban)} = f_{yn}$

where $f_{yn\ (urban)} = f_{yn-1\ (urban)}$, smoothing was carried out to ensure percentage change in cover was not zero in alternate years (this was an issue for the very small amounts of urban land cover in Belize).

For grazing, forest, crop land categories from IFs
$m_{yn} = M_{yn}\ (f_{yn}/F_{yn})$

For scrub and savanna / wetland categories from CLUE-S and IMAGE, taking national proportions from the Other category in IFs:
$m_{yn} = M_{yn}\ (f_{yn}/F_{yn})$

ii) Percentage change assigned to CLUE-S for year n
$= 100\ (m_{yn} - m_{yn-1})/\ m_{yn-1}$

iii) Land cover assigned to equivalent CLUE-S categories for year n. Area per class is then normalised to country area, based on the fraction represented by that land cover class in that year for that country. The area belonging to 'other' and 'water' CLUE-S categories do not change between years.
$d_{yn} = c_{yn-1} + c_{yn-1}\ ((m_{yn} - m_{yn-1})/\ m_{yn-1})$
$c_{yn} = d_{yn} + ((C - \Sigma d_{yn\ all\ classes}) * d_{yn}) / C)$

Figures 3-9 through 3-12 show the calculated change in land demand for each land use type under all three scenarios. The land demand each year for each land use types is given in Appendix 5.

## 3.4 Future changes in protected areas

A protected area scenario dataset was created based on the scenario assumptions. These maps represent one hypothetical expansion of the network, rather than a recommended set of designations. No distinction is made between managed and unmanaged forests within CLUE-S, but a distinction can be made between the different protection categories. Existing and new protected areas are allocated to the following categories within the scenarios:

- Sustainable-use (probability of conversion is reduced by designation; driven by the logistic regression)
- No-use (no change after designation to natural ecosystems contained within the area)
- Failed (no protection from land cover change)

The protected areas are implemented within CLUE-S as follows:

1) all no-use areas are designated at the start of the scenario period. No land use change occurs within the natural ecosystem cells inside these areas over the period. This category is applied to IUCN categories I–IV and uncategorised protected areas.

2) New sustainable-use areas may be designated at any time. These areas are applied within the model as a dynamic factor grid, which influences the probability of land cover change, rather than via rule-based restrictions. This is therefore a ‘partially protected’ rather than a strict ‘sustainable use’ designation. Applied to categories V-VI.

In summary, areas are assigned to the scenarios as follows:

*Markets First* – expansion of terrestrial network to 10% of all biomes/countries by 2025; new sites allocated as 20% no-change, 60% sustainable-use, 20% failed

*Policy First* – expansion of terrestrial network to 10% of all biomes/countries + all single-site endemic species by 2025 and 20% of all biomes/countries by 2050; new sites allocated as 65% no-change, 25% sustainable-use, 10% failed

*Sustainability First* – expansion of terrestrial network to 10% of all biomes/countries + all single-site endemic species by 2025 and 20% of all biomes/countries by 2050; new sites allocated as 30% no-change, 65% sustainable-use, 5% failed

Failure indicates that there is no barrier to land use change in this protected area.

In Policy First and Sustainability First, the new protected areas are first allocated to priority areas for biodiversity to attain at least 10 percent of each biome/country combination. Additional areas are then allocated to cover single-site endemic species that have not captured, based upon the Alliance for Zero Extinction point dataset. These additional areas are circles of equivalent size to the area required for that species (or for the mean area where this is not specified), thus giving an artificial appearance to the scenario data. The coverage of some biomes is therefore expanded to greater than 10 per cent by 2025 within these two scenarios. A number of protected areas were assigned outside the MAR region of Guatemala, Honduras and Mexico.

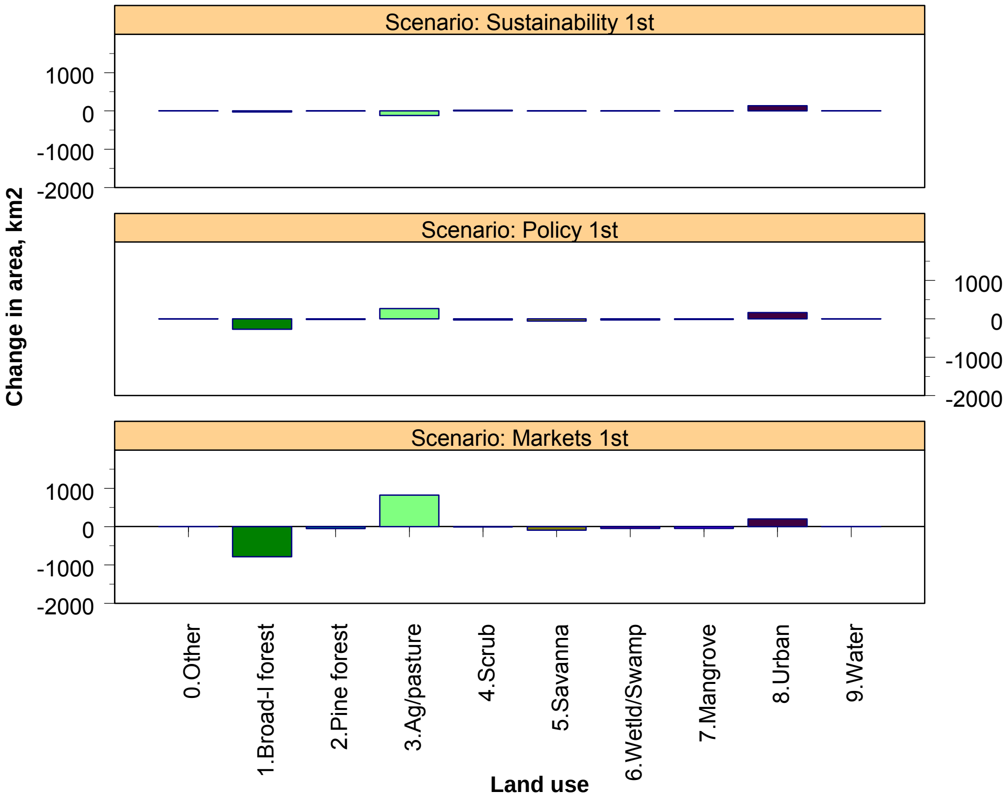


*Figure 3-9: Change in land cover for Belize, 2005 to 2025, scenarios*

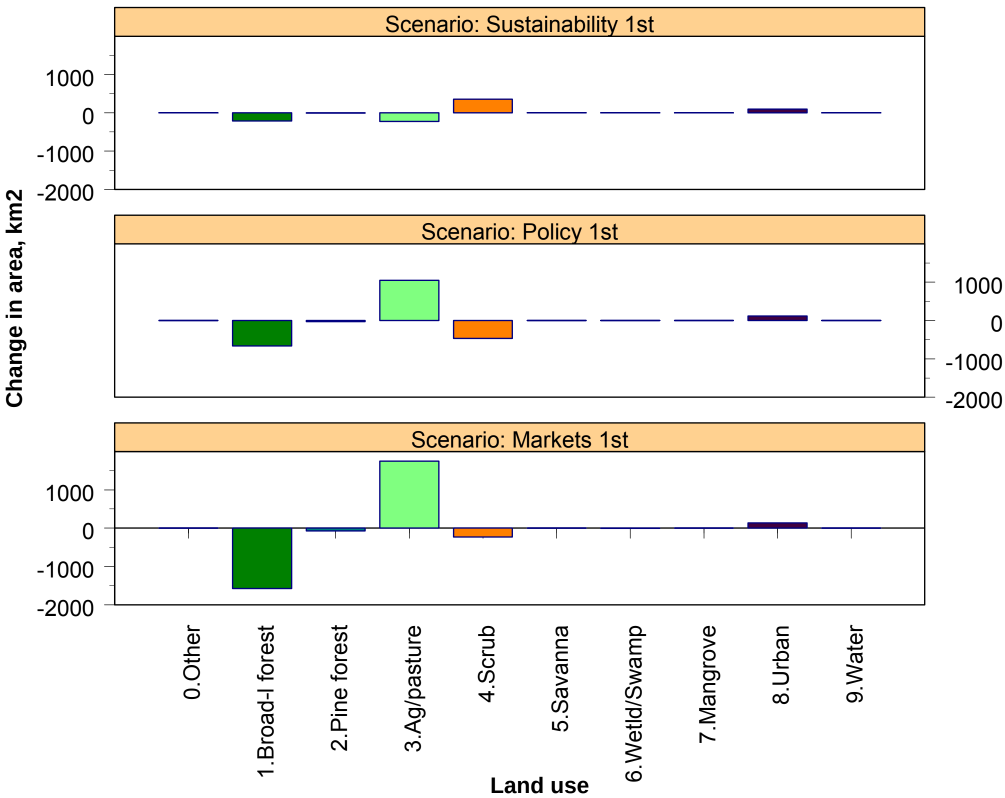


*Figure 3-10: Change in land cover for Guatemala, 2005 to 2025, scenarios*

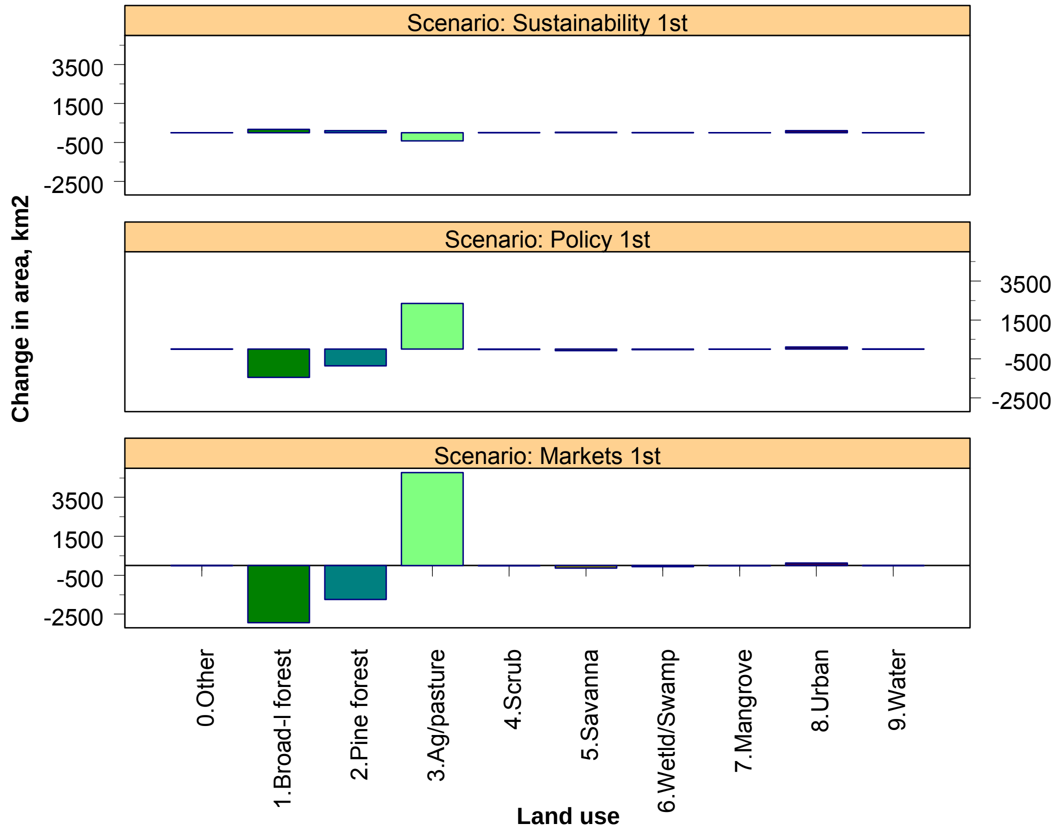


*Figure 3-11: Change in land cover for Honduras, 2005 to 2025, scenarios*

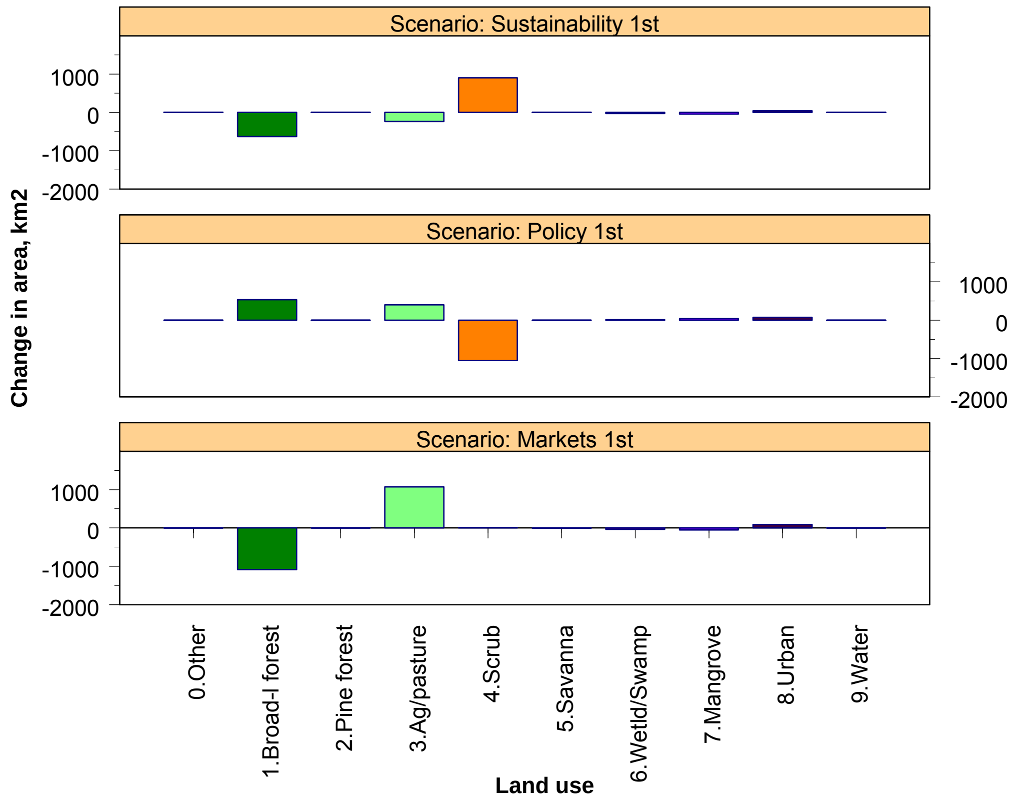


*Figure 3-12: Change in land cover for Mexico, 2005 to 2025, scenarios*

# 4 Modelling land use changes for scenarios using CLUE-S

## 4.1 Important aspects of model development

### 4.1.1 Land use data

In working with CLUE-S, it became clear that the Ecosystem Map land cover data use were not ideal for use by this model. The model had difficulty with the enormously skewed land use distributions and with the large homogenous areas, particularly in Honduras, which is in part a consequence of the relative large minimum mapping units that were used in the vector Ecosystem Map dataset (10 ha for Belize; 150 ha for the other countries). It is likely that the model would have had less trouble with a remotely sensed classification rather than raster data converted from vector data. It is therefore strongly recommended to use different, more detailed remotely sensed data if the study is to be undertaken or refined in the future.

### 4.1.2 Probability Surfaces

The single most important aspect of the model development process is to inspect and verify the probability surfaces that CLUE-S uses to allocate land. These surfaces are constructed from the regression parameters and they directly reflect the goodness of fit of the regression equations. They are extremely helpful in assessing whether the way the model is going to allocate land makes sense. If this is not the case, the regression equations should be inspected for any possible typographical errors or, in case they are not statistically significant, replaced by a better equation. Unfortunately, the Relative Operating Statistic (ROC, introduced in Section 2.2.) could be calculated only for Belize, so we do not know the goodness of fit for the equations for the other countries. Therefore, the manual inspection of probability surfaces is essential. Adjustments in the model were made where necessary.

Not surprisingly, the probability surfaces for the Belize looked most plausible, whereas those for Honduras were worst, with Guatemala and Mexico in between. The simulation of Honduras posed a particular problem. The probability surfaces for all but Broadleaved Forest, Pine Forest, and Agriculture\Pasture looked quite unlikely or clearly incorrect. The cause is twofold. First, the three dominant land use types occupy over 95% of the total area, the remaining seven types occupy < 5% of the area. The regression results are not significant for those seven types. As a consequence, the model was not able to reach a solution, i.e., it was unable to properly allocate the demanded land-use based on the probability surfaces.

Two workarounds were applied:

- If the difference in the calculated demand for a land use types hardly changed throughout the simulation period (2000/2004 to 2025), then the land demand was kept constant and the changes that should have occurred were added to another (most comparable) land use type to ensure that the total area remained the same. The regression equations were not changed, because by keeping the land demands equal the equations were essentially bypassed and not relevant.
- The regression equations for urban land in Mexico, Guatemala and Honduras were replaced by equations that made more sense. A generic regression equation based on population density, distance to markets and the presence of tourism hotspots was adopted. This is explained in more detail in Section 4.3.4.

### 4.1.3 Neighbourhood settings

The user manual and available parameters suggest that CLUE-S can allocate land use in a user-specified (e.g, a 3x3 or 4x4) neighbourhood. Specifying such neighbourhoods (in **`NEIGHMAT.TXT`**) and giving a weight of 1 to the neighbourhood suggests that the probability surface are constructed in a way that reflects the neighbourhood settings, and that new land use can only be allocated inside the that neighbourhood. This would be useful if you require new grid cells of, for example, forest or urban, to be adjacent to existing cells. However, Peter Verburg confirms that land allocation cannot be influenced in this way.

## 4.2 Input data preparation

### 4.2.1 Files used by CLUE-S

*Table 4-1: Input files used by CLUE-S. The "created" column indicates which software is used to create the files and the "mandatory" column indicates whether the file is a minimum input data requirement. Files created using CLUE-S are plain text files and may also be edited in a text editor.*

| Filename | Description | Created | Mandatory |
|---|---|---|---|
| **MAIN.1** | **Main parameters file**. Listed on exactly 19 lines. Some parameters settings will dictate whether the optional files must be specified or not. | CLUE-S | yes |
| **ALLOC1.REG** | **Regression parameters**. Length of file depends on number of land use types and location factors. | CLUE-S | yes |
| **ALLOC2.REG** | **Neighbourhood results**. These are additional regression parameters based on the enrichment factor equation. **NOT USED** | CLUE-S | no |
| **ALLOW.TXT** | **Change matrix**. The number of rows and columns equal the land cover types, here 10x10. | CLUE-S | yes |
| **NEIGHMAT.TXT** | **Neighbourhood settings**. Defines the shape and size (in the form of a small weight matrix) of the analysis neighbourhood for every land use type. | CLUE-S | yes |
| **REGI*.*** | **Area restriction file**. A grid that defines where land use changes can and cannot occur. The * is a wildcard here; it does not indicate the simulate year. All active cells must have the value 0, restricted cells a value of –9998, and all others cells –9999 (NoData). | ArcView | no |
| **DEMAND.IN*** | **Land use requirements**. Calculated at the aggregate level and organized by rows (simulated years starting at 0) and columns (for every land use types). The * denotes a unique number, not simulated year. | Excel | yes |
| **COV_ALL.0** | **Initial land use**. A grid of all land use types at the start (year 0). Grid values must match the land use codes listed in the main parameters file. | ArcView | yes |
| **SC1GR#.FIL** | **Static location factor grid**, where # is the number of the location factor; or | ArcView | yes |
| **SC1GR#.FIL (SAME AS ABOVE)** | **Land change restrictions grid**. Grid that indicates whether a land use conversion can occur. The # does not denote a location factor. Instead it is a unique values that is also specified in the alloc1.reg. | ArcView | no |
| **SC1GR#.*** | **Dynamic location factor grid**, where # is the number of a location factor. The * is the simulated year starting at 0, not a wildcard. Note that also the file src1gr#.fill is | ArcView | no |

| | | | |
|---|---|---|---|
| | needed and it is identical to src1gr#.0. | | |
| `LOCSPEC#.FIL` | **Location specific preference addition**. Grid used to increase the probability at specific locations. Must be specified for every land use type. **NOT USED.** | ArcView | no |

### 4.2.2 Land use requirements for different scenarios

#### 4.2.2.1 Requirements calculated using IMAGE model

Land use requirements were calculated by Lera Miles using outputs from the International Futures and IMAGE and GEO-4 models, as part of the scenario development process (Section 3.3).[1] Tables 4-2 through 4-5 give the percentage area of each land use type at the present time along with future demands. The precise demand values for every land use type in every simulated year are given in Appendix 5.

*Table 4-2: **Belize**: Distribution of present land use and land demand for the scenarios. Blue coloured land use types were kept fixed at present values and not allowed to change over time.*

| | Present | Markets | Policy | Security | Sustain. |
|---|---|---|---|---|---|
| 0. Other/Unknown | 0.06% | 0.06% | 0.06% | 0.06% | 0.06% |
| 1. Broad-leaved forest | 58.02% | 54.33% | 56.69% | 55.16% | 57.78% |
| 2. Pine forest | 3.53% | 3.31% | 3.45% | 3.36% | 3.52% |
| 3. Agriculture/pasture | 19.37% | 23.20% | 20.64% | 22.70% | 18.85% |
| 4. Scrub | 1.26% | 1.23% | 1.13% | 1.10% | 1.37% |
| 5. Savanna | 8.63% | 8.23% | 8.35% | 8.11% | 8.65% |
| 6. Wetland/Swamp | 4.26% | 4.07% | 4.12% | 4.01% | 4.27% |
| 7. Mangroves | 3.29% | 3.08% | 3.22% | 3.13% | 3.28% |
| 8. Urban | 0.87% | 1.79% | 1.64% | 1.68% | 1.51% |
| 9. Water | 0.70% | 0.70% | 0.70% | 0.70% | 0.70% |

*Table 4-3: **Mexico**: Distribution of present land use and land demand for the scenarios. Blue coloured land use types were kept fixed at present values and not allowed to change over time. Note that there is no pine forest in Mexico; this required some adjustments to the model.*

| | Present | Markets | Policy | Security | Sustain. |
|---|---|---|---|---|---|
| 0. Other/Unknown | 0.45% | 0.45% | 0.45% | 0.45% | 0.45% |
| 1. Broad-leaved forest | 57.33% | 54.35% | 57.52% | 56.78% | 54.43% |
| 2. Pine forest | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| 3. Agriculture/pasture | 6.13% | 8.00% | 6.78% | 7.65% | 5.39% |
| 4. Scrub | 27.06% | 28.18% | 26.05% | 25.96% | 30.84% |
| 5. Savanna | 0.11% | 0.11% | 0.11% | 0.11% | 0.11% |
| 6. Wetland/Swamp | 3.47% | 3.45% | 3.48% | 3.48% | 3.46% |
| 7. Mangroves | 4.18% | 4.02% | 4.20% | 4.14% | 3.97% |
| 8. Urban | 0.26% | 0.43% | 0.41% | 0.42% | 0.34% |
| 9. Water | 1.00% | 1.00% | 1.00% | 1.00% | 1.00% |

[1] CLUE-S does not dictate a particular method for calculating the land use requirements. The use of IMAGE and International Futures was possible only because we had access to these models. Simpler methods are possible and recommended. For example, land use requirements could be calculated using appropriate economic demand models or, very simply, by setting hypothetical land use requirements for the scenarios end year and interpolating the land requirements between start year and end year using a linear or exponential growth model.

*Table 4-4: **Guatemala**: Distribution of present land use and land demand for the scenarios. Blue coloured land use types were kept fixed at present values and not allowed to change over time. The area savanna is very small but not exactly zero (the distinction is significant).*

| | Present | Markets | Policy | Security | Sustain. |
|---|---|---|---|---|---|
| 0. Other/Unknown | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% |
| 1. Broad-leaved forest | 51.11% | 45.76% | 48.61% | 46.63% | 49.74% |
| 2. Pine forest | 2.48% | 2.22% | 2.36% | 2.26% | 2.41% |
| 3. Agriculture/pasture | 31.00% | 36.27% | 34.15% | 36.64% | 29.81% |
| 4. Scrub | 12.66% | 12.56% | 11.76% | 11.31% | 14.97% |
| 5. Savanna | 0.001% | 0.001% | 0.001% | 0.001% | 0.001% |
| 6. Wetland/Swamp | 0.04% | 0.04% | 0.04% | 0.04% | 0.04% |
| 7. Mangroves | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| 8. Urban | 0.35% | 0.79% | 0.71% | 0.76% | 0.66% |
| 9. Water | 2.34% | 2.34% | 2.34% | 2.34% | 2.34% |

*Table 4-5: **Honduras**: Distribution of present land use and land demand for the scenarios. Blue=forced fixed at initial area, not allowed to changed over time.*

| | Present | Markets | Policy | Security | Sustain. |
|---|---|---|---|---|---|
| 0. Other/Unknown | 0.29% | 0.29% | 0.29% | 0.29% | 0.29% |
| 1. Broad-leaved forest | 25.94% | 22.47% | 24.42% | 22.90% | 26.64% |
| 2. Pine forest | 15.39% | 13.34% | 14.49% | 13.59% | 15.81% |
| 3. Agriculture/pasture | 55.17% | 60.74% | 57.59% | 60.13% | 53.74% |
| 4. Scrub | 0.19% | 0.18% | 0.17% | 0.16% | 0.23% |
| 5. Savanna | 1.41% | 1.27% | 1.32% | 1.24% | 1.50% |
| 6. Wetland/Swamp | 0.60% | 0.54% | 0.56% | 0.52% | 0.63% |
| 7. Mangroves | 0.10% | 0.09% | 0.10% | 0.09% | 0.11% |
| 8. Urban | 0.16% | 0.35% | 0.32% | 0.32% | 0.32% |
| 9. Water | 0.74% | 0.74% | 0.74% | 0.74% | 0.74% |

#### 4.2.2.2 Adjustments in land demands for CLUE-S model

The initial plan was to use the calculated demands in Appendix 5 as the land demand files for CLUE-S. From the initial model runs, it became clear that the model could not always reach a solution. This was caused by some land use types that occupy only a small fraction of the total area and hardly change over time. The annual changes may be close to within the convergence criteria of the model. Examples include scrub and mangroves in Honduras (Table 4-5). This adds complexity to the model without yielding any benefits - the input data made it difficult for the model to reach a solution.

Some adjustments were made to the land demands that provided a workaround for this issue. The adjustment was to keep the area of certain land use types constant, and adding the hectares that should have changed to those of the most similar land use type (so that total area remains constant). Note that the demand for *Other* and *Water* is always kept constant. Table 4-6 indicates which land use change demands were kept constant. For example, for Mexico, Savanna was fixed and the change in Savanna that *should have occurred* was allocated to Scrub (that is what the +#5 means). Wetland was also kept constant, with the change that *should have occurred* being added to mangroves.

Table 4-6 shows that generally, along with Water and Other, the land use types that occupy < 0.5% of the total area were kept constant. Wetland in Mexico occupies a larger fraction (3.47%), but was kept constant as it hardly changes across all scenarios (Table 4-3).

Note that Urban land was considered too important to keep constant, even though the area can be quite small. Instead, problems with the allocation of Urban land were tackled by modifying the regression equations.

*Table 4-6: Present land use distribution with red coloured values for those types for which the demand was kept constant over time because the demand changes were smaller than the iteration tolerance of CLUE-S, or so small that the model was prevented from reaching a solution. The required change in land was added to another land use type, as indicated within parenthesis.*

| | Belize | Mexico | Guatemala | Honduras |
|---|---|---|---|---|
| 0. Other/Unknown | *0.06%* | *0.45%* | *0.02%* | *0.29%* |
| 1. Broad-leaved forest | 58.02% | 57.33% | 51.11% | 25.94% |
| 2. Pine forest | 3.53% | *0.00%* | 2.48% | 15.39% |
| 3. Agriculture/pasture | 19.37% | 6.13% | 31.00% | (+#6,7) 55.17% |
| 4. Scrub | 1.26% | (+#5) 27.06% | (+#5,6,7) 12.66% | *0.19%* |
| 5. Savanna | 8.63% | *0.11%* | *0.00%* | (+#4) 1.41% |
| 6. Wetland/Swamp | 4.26% | *3.47%* | *0.04%* | *0.60%* |
| 7. Mangroves | 3.29% | (+#6) 4.18% | *0.00%* | *0.10%* |
| 8. Urban | 0.87% | 0.26% | 0.35% | 0.16% |
| 9. Water | *0.70%* | *1.00%* | *2.34%* | *0.74%* |

### 4.2.3 Main model parameters

The main parameter file has 19 lines with numbers. For further details, please see the User's Manual. Below are the main parameters used for Belize. Only lines 5, 6, 8 and 9 are different for the four countries. These parameters can be read from the header of the ascii grid files.

*Table 4-7a: Main model parameters as used for the simulations.*

| Line | Parameters | Description |
|---|---|---|
| | | |
| 1 | 10 | Number of land use types |
| 2 | 1 | Number of regions |
| 3 | *country-dependent* | Max number of independent variables in equation |
| 4 | 12 | Total number of driving factors |
| 5 | *country-dependent* | Number of rows |
| 6 | *country-dependent* | Number of columns |
| 7 | 6.25 | Cell area in ha (250 m grid) |
| 8 | *country-dependent* | Xll coordinate of grids |
| 9 | *country-dependent* | Yll coordinate of grids |
| 10 | 0 1 2 3 4 5 6 7 8 9 | Number coding land use types |
| 11 | 1 .8 .8 .1 .4 .4 .8 .8 .9 1 | Codes for conversion elasticities |
| 12 | *country-dependent* | Iteration variables for land use types |
| 13 | 2000[1] 2025 | Start and end year of simulation |
| 14 | 1 11 | Number and codes of dynamic explanatory factors |
| 15 | 1 | Output file choice |
| 16 | 0 | Region specific regression choice |
| 17 | 1 15 | Initialization of land use history |
| 18 | 0 | Neighbourhood calculation choice |
| 19 | 0 | Location specific preference addition. |

[1] The start year for Belize was 2004.

*Table 4-7b: Country specific variables*

| | Belize | Mexico | Guatemala | Honduras |
|---|---|---|---|---|
| Line 3. nvariables | 11 | 11 | 10 | 9 |
| Line 5. nrows | 1151 | 1674 | 1503 | 1005 |
| Line 6. ncols | 604 | 1262 | 1310 | 2131 |
| Line 8. xllcorner | 261500 | 213250 | 41250 | 260250 |
| Line 9. yllcorner | 1757500 | 1971250 | 1596500 | 1521000 |
| Line 12. Iteration[1] | 0.3 1.5 | 0.5 3.0 | 0.5 3.0 | 0.4 3 |

Some variables proved more challenging:

- Line 10: Number coding of land use types. In principle very straightforward, but note that the numbering must be without any gaps. Mexico has no pine forest (land use type 2) within the MAR, yet this land use must be included.
- Line 11: Conversion elasticities. Too many values of, or close to, 1 will stabilize the system and may prevent the model from reaching a solution. The elasticities had to be relaxed.
- Line 12: Iteration variables. Settings that are too relaxed could result in land use allocations different from the expected one (as specified in the land use requirements file), whilst settings that are too strict could significantly increase the simulation time -- because more iterations are needed each time set—or cause the model to fail to reach the desired iteration[2]. The default settings (0.3 and 3.0) were a good starting point and only some minor adjustments had to be made.
- Line 18: Neighbourhood function. Was not used because there was insufficient information available about the potential influence within the neighbourhood. See section 4.1.3 for further information about neighbourhood settings.
- Line 19: Location-specific preference addition. A potentially powerful feature, which was not used because insufficient spatial data was available to support it.

### 4.2.4 Regression parameters

The regression equation parameters (Tables 2-2 through 2-4) were reformatted to **ALLOC1.REG** files for each country. Although this is, in principle, a straightforward task, initial model runs indicated that for all countries but Belize, the model was unable to reach a solution. The land use allocation module was not able to significantly change the land allocation even after thousand of iterations.

[1] These iteration variables are the smallest settings with which the model was able to reach a solution. The variables are slightly different among countries, which is a reflection of the different country sizes, land distribution, and in particular smallest and largest (percentage wise) land allocation.

[2] The model execution stops if no solution has been reached after 20 000 iterations for any simulated year.

Numerous tests runs with adjusted model parameters were run to identify the cause[1]. It was concluded that the problems were the combined effect of the following aspects of the model and the MAR data:

- Regression results for land use types with a small percentage of the area, such as Urban, were inaccurate because the sample size that the regression is based on is too small. One solution is to substitute a "common sense" equation.
- The land use distribution of all four countries is extremely skewed, with the most dominant land use type occupying over 50% of the area and the least dominant one less than 1%, and Mexico, Guatemala and Honduras have one or more land use type occupying less than 0.1% of the area (Table 4-6). The results of the regression analysis are naturally insignificant for the least dominant land use types and the probability maps that CLUE-S calculates for those land use types not significant either and in fact very incorrect. They have predominantly zero values.
- The CLUE-S allocation module seems restricted in that it may be unable to make simultaneous adjustments in allocated areas across a wide range[2]. For example, the model had problems making an adjustment of < 10 ha in one land use type and 5 000 ha in another land use type during the same iteration. Consequently, the model is unable to arrive at very small demand figures and the maximum allowed deviation of those land use types is almost always exceeded, causing the model to iterate until the maximum of 20 000 iterations is met.

  The underlying problem may by relatively small iteration variables. These variables (the numbers between the "*" columns in the **`LOG.FIL`**) have only three decimal places, and if the operating values are only significant at the third decimal, it is very difficult for the model to make small adjustments. For example, if an iteration variable is 0.002 then a change to 0.003 represents a 50% adjustment in the area.

As a workaround the following changes were attempted:

- First, if initial model runs show that iteration variables are significant only at the third decimal place, the relative elasticities are reduced (this will increase the value of the iteration variable because $TPROP_{I,U} = P_{I,U} + ELAS_u + ITER_u$)
- Second, the regression equations for land use types occupying less then 0.5% of the area were deemed inaccurate and insignificant, despite an apparently high ROC value. The regression coefficients were removed from the **`ALLOC1.REG`** files and replaced by a constant (probability) of 0.5. Whilst not a proper parameter setting, this change is insignificant because few grid cells are affected, and it allows the model to find a solution at last.
- Land use demands that change very little between the initial year and 2025 –for example, the area of Mangroves in Mexico, which are always around 0.09 – 0.11% of the total area (Table 4-6), were adjusted to remain constant (at the initial value), similar to the Water and Other/Unknown categories. The difference in area was allocated to the most similar land use type so that the total area remained the same.

[1] Temporary adjustments in model parameters that were made include: (1) use of much larger iteration variables, in both absolute and relative mode, thus allowing the model to reach a solution quicker and reducing the number of iterations needed; (2) use of a change matrix composed only of 1s, thus providing the greatest flexibility by allowing any land use type; (3) replacement of the least accurate regression equations by a constant equation of 0.5.

[2] This is not documented anywhere based on own experience using the model.

- For all countries, the regression coefficients for Urban were considered inaccurate and were replaced by a subjectively chosen function with a dependency on population density, access to markets, and tourist hotspots ($-1 + 0.0005*LF_0 - 0.2*LF_7 + 0.5*LF_9$). The parameters used in this function were slightly adjusted after inspection of the probability surfaces and test simulation runs.
- For Honduras, the following regression constants were changed:
    - For Savanna, the regression constant was changed from –14.65 to –13.0. This did not expand the area with a non-zero probability, but it did increase the probability of areas that already had a non-zero probability. It was expected that this would made a conversion to Savanna more likely as its probability would now exceed that of (most importantly) Broadleaved Forest, and other types.
    - For Other (#0), Scrub (#4), Wetland/Swamp (#6), Mangroves (#7) and Water (#9), the regression equation was replaced by a constant of 1 (the value is unimportant). These land use types were kept constant during the simulation.
    - A new regression equation for Urban was selected: $0.5 + 0.005*LU_0 - 0.3*LU_7$. This produced a much-improved probability surface that is dependent on population density and accessibility to markets.

The neighbourhood function will ensure that no pixellated areas can exist.

### 4.2.5 Conversion elasticities

This parameter relates to the reversibility of the land use change. Land use types with a high capital investment (e.g., urban; permanent crops such as banana plantations) will not easily be converted in other uses as long as there is sufficient demand. Other land use types easily shift location when the location becomes more suitable for different land use types. Arable land often makes place for urban development, while expansion of agricultural land occurs at the forest frontier.

For each land use type, a value needs to be specified that represents the relative elasticity to change, ranging from 0 (easy conversion) to 1 (irreversible change).

> 0: Means that all changes for that land use type are allowed, independent from the current land use of a location. This means that a certain land use type can be removed at one place and allocated at another place at the same time: for example, in shifting cultivation.
>
> 1: means that grid cells with one land use type cannot be added and removed at the same time. This is relevant for land use types that are difficult to convert, i.e., urban settlements and primary forests. This stabilizes the system, for example, preventing simultaneous deforestation and reforestation in different areas.
>
> >0…<1: Means that changes are allowed, however, the higher the value the higher the preference that will be given to locations that are already under this land use type.

After initial trial and error runs, it was clear that the key was to use elasticities that are as high as possible, but that do not stabilise the system too much and would prevent the model from reaching a solution. Values of 1 stabilize the system and from the initial model runs it appeared that these values are too stringent, i.e., they can prevent CLUE-S from reaching a solution even after thousands of iterations. Changing a value of 1.0 to 0.95 makes the model significantly more flexible. Likewise, with values of 0 for more flexible land use types such as agriculture, the model changes land use too much throughout the area. Higher values such as 0.2 for agriculture and 0.5 for scrub gave model results that appeared more plausible, i.e., a less complete overhaul of the land use pattern. The suggested settings (Table 4-8) are based on expert knowledge of actual past land use patterns and observed model behaviour.

*Table 4-8: Default conversion elasticities for the land use types.*

| Land use type | elasticity |
|---|---|
| 0. Other/Unknown | 0.9 |
| 1. Broad-leaved forest | 0.95 |
| 2. Pine forest | 0.95 |
| 3. Agriculture/pasture | 0.0 |
| 4. Scrub | 0.2 |
| 5. Savanna | 0.5 |
| 6. Wetland/Swamp | 0.8 |
| 7. Mangroves | 0.8 |
| 8. Urban | 0.9 |
| 9. Water | 1.0 |

### 4.2.6 Conversion matrix

Table 4-9 indicates the default conversion settings, and Tables 4-10 through 4-13 the actual values used for each country. Note that the conversion to and from Other/Unknown (#0) and Water (#9) are not allowed. The 'demand' for these land use types is unlikely to change, and the CLUE-S model operates better if conversions are prohibited. Per-country adjustments were made for those land use types that were artificially kept constant. For example, for Mexico, the rows and columns associated with Pine Forest (non existent) Savanna and Wetland/Swamp were constant 0s as well.

Care had to be taken that there is always at least 1 "from" land use types for every "to" land use type (besides the "to" land use type itself), and vice versa; otherwise the model may be unable to reach a solution because no conversion can be carried out. Most importantly, in `ALLOW.TXT` the values in all rows and columns of all land use types kept constant had to be set to 0, except for the value on the same row and column. This adjustment in `ALLOW.TXT` is critical to prevent the model from starting calculations with these cells.[1]

*Table 4-9: default conversion matrix. Note that some adjustments had to be made for all countries to allow for sufficient change options, as indicated in blue in the next four tables.*

| Current ↓ Future → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| **0. Other/Unknown** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **1. Broad-leaved forest** | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 |
| **2. Pine forest** | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 |
| **3. Agriculture/pasture** | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 |
| **4. Scrub** | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 |
| **5. Savanna** | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 |
| **6. Wetland/Swamp** | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| **7. Mangroves** | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 |
| **8. Urban** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **9. Water** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

[1] This was found out by trial and error, and is not a documented model feature.

*Table 4-10: Modified conversion matrix for* ***Belize*** *conversion. The medium grey coloured rows and/or columns are associated with land use types that were kept constant and did not change.*

| Current ↓ Future → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0. Other/Unknown | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1. Broad-leaved forest | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 |
| 2. Pine forest | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3. Agriculture/pasture | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 |
| 4. Scrub | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 |
| 5. Savanna | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 |
| 6. Wetland/Swamp | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| 7. Mangroves | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 |
| 8. Urban | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 9. Water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

*Table 4-11: modified conversion matrix for* ***Mexico****. The medium grey coloured rows and/or columns are associated with land use types that were kept constant and did not change.*

| Current ↓ Future → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0. Other/Unknown | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1. Broad-leaved forest | 0 | 1 | 0 | 105 | 105 | 0 | 0 | 0 | 105 | 0 |
| 2. Pine forest | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Agriculture/pasture | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| 4. Scrub | 0 | 1 | 0 | 1 | 1 | 0 | 0 | ***1*** | 1 | 0 |
| 5. Savanna | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 6. Wetland/Swamp | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 7. Mangroves | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 |
| 8. Urban | 0 | 0 | 0 | 0 | ***1*** | 0 | 0 | 0 | 1 | 0 |
| 9. Water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

*Table 4-12:* modified conversion matrix *for* ***Honduras****. The medium grey coloured rows and/or columns are associated with land use types that were kept constant and did not change.*

| Current ↓ Future → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0. Other/Unknown | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1. Broad-leaved forest | 0 | 1 | 0 | 105 | 0 | 105 | 0 | 0 | 1 | 0 |
| 2. Pine forest | 0 | 0 | 1 | ***105*** | 0 | 105 | 0 | 0 | 1 | 0 |
| 3. Agriculture/pasture | 0 | ***1***[1] | ***1*** | 1 | 0 | 1 | **0** | 0 | 1 | 0 |
| 4. Scrub | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 5. Savanna | 0 | ***0*** | ***0*** | 1 | 0 | 1 | 0 | 0 | ***0*** | 0 |
| 6. Wetland/Swamp | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | *0* | 0 |
| 7. Mangroves | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 8. Urban | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 9. Water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

[1] Conversion from agriculture to broad-leaved and pine forest had to be allowed so that the model could reach a solution, whereas conversion from savanna to either forest type was not allowed to prevent large shifts in the location of savanna.

*Table 4-13:* modified conversion matrix *for* ***Guatemala****. The medium grey coloured rows and/or columns are associated with land use types that were kept constant and did not change.*

| **Current ↓ Future →** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|---|
| **0. Other/Unknown** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **1. Broad-leaved forest** | 0 | 1 | 0 | 105 | 105 | 0 | 0 | 0 | 105 | 0 |
| **2. Pine forest** | 0 | 0 | 1 | 0 | 105 | 0 | 0 | 0 | ***0***[1] | 0 |
| **3. Agriculture/pasture** | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| **4. Scrub** | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | ***0*** | 0 |
| **5. Savanna** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **6. Wetland/Swamp** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **7. Mangroves** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **8. Urban** | 0 | 0 | 0 | 0 | ***1*** | 0 | 0 | 0 | 1 | 0 |
| **9. Water** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

### 4.2.7 Dynamic location factor grids: Protected Areas

From all location factors listed in Table 1-6, only the last two - fully protected areas and partially protected areas - were used as dynamic location factor grids that are different in every simulated year. While population density is often a dynamic location factor in CLUE-S applications, the lack of spatially-explicit population scenarios made this impossible.

Two shapefiles (**`EXISTING_PA.SHP`** and **`SCENARIO124.SHP`**) that were used for creating all necessary dynamic location grids. The fields *USE_CLASS, SC1-USE, SC2-USE, SC3-USE* and *SC4-USE* indicated whether the polygon was fully protected ("NO_USE"), partially protected area ("SUST-USE"), or not designated under that scenario ("EXCLUDED"). For the third scenario about 20% of the areas were identified as "FAILED". There is no difference from the land use model's point of view between an protected area labelled FAILED or EXCLUDED - in both cases the area is not considered protected, because under that future scenario its protection failed, or it was not protected in the first place.

An Avenue script was developed for creating all location factor grids in a fully automatic way and saved in ASCII grid format (Appendix 2). This script uses a specially created shapefile **`SCEN_COMBINED_4RASTER.SHP`** that has 9 additional fields: *YEARINCL, S1PAS1, S1PA2, S2PAS1, S2PA2, S3PAS1, S3PA2, S4PAS1,* and *S4PA2.*

### 4.2.8 Dealing with absence of pine forest in Mexico

There is no pine forest on the map for the MAR region of Mexico. This is the only total absence of any land use type in the four countries. It required special attention and some adjustments in model parameters to avoid a runtime error (overflow error).

One solution might be to adjust the numbering of the land use types to fill the gap, i.e., numbers 0-1,3-9 (2 is the missing pine forest) would have to be changed to 0-8. As this process is cumbersome and error-prone, the following tweaks were made instead:

- Added dummy regression coefficients for land use type 2 in file **`ALLOC1.REG`** because this file must contain regression coefficients for all land use types. A dummy equation with a constant of 0 and a regression coefficient of 0 for the first factor grid was used.

[1] Conversion from pine forest and scrub to urban was prohibited to force change from broad-leaved forest to urban and generate more plausible urban expansion

- In **`COV1.ALL`**, changed the value of four grid cells from 1 (broadleaved forest) to 2 (pine forest), thus introducing artificial pine forests. Four cells in the bottom-left corner of the grid were chosen solely because these cells are easy to identify. These cells were returned to broadleaved forest in the simulated land use grid **`COV22.ALL`**. Note that the change was made for 4 cells instead of 1 cell, so that the corresponding area has no significant decimal value, and CLUE-S will not make a rounding error when the demand figures are read in (the demand values in **`LOG.FIL`** suggest that they are rounded to 1 decimal place, although that may a formatting matter).
- In the demand file **`DEMAND1.FIL`**, replaced the 0 hectare value in the third column with 25. That is the area of the additional cell in ha. The values in the second column (broadleaved forest) are reduced by 25 hectares.
- In **`ALLOW.TXT`**, changed all values in the third row and third column to 0 except the value at position [3,3]. Thus, pine forest cannot change to anything else.

## 4.3 Simulation results

### 4.3.1 Simulated changes in land use and in forest cover

Figures 4-1 to 4-5 show the present and simulated land use patterns for 2025. These land cover raster data were shared with WRI on 20th July 2006 for use in the N-SPECT hydrological simulations. Figures 4-6 to 4-8 show the areas of change only, making the new areas of each land use class easier to identify.

A minor anomaly in the simulated land use pattern near San Pedro Sula, Honduras can be seen, with some areas of forest “sandwiched” in between new urban land. The cause of this was identified (probability surfaces and regressions) but could not easily be resolved. It is merely a reflection of the probabilistic nature of the model and that the exact allocation by the model of land use at a local level cannot easily be influenced.

### 4.3.2 Average and maximum deviation of solution

The iterative allocation module never achieves an allocation that fully matches the demand. This is controlled by the iteration variables on line 12 of the main parameter file. A relative iteration mode with an average deviation of 0.5% and a maximum individual deviation (for any individual land use type) of 3.0% was used. Table 4-15 below gives the actual deviations that were achieved, which are always equal to or lower than the maximum values.

*Table 4-15: mean and maximum deviation between demand and allocated land use, in percentage of absolute area, for land use in the final simulated year, 2025 ). These statistics are calculated for every simulated year but presented here only for the final year). The maximums (2nd and 3rd columns) are specified in the main parameter file and are slight adjustments from the default settings in CLUE-S, respectively, 0.35% and 3.0%. In almost all cases the highest deviation applies to land use that occupies the least area and is not kept constant, which almost always is Urban*

| | Maximums | | 1. Market First | | 2. Policy First | | 4. Sustain. First | |
|---|---|---|---|---|---|---|---|---|
| | *Mean* | *Max* | Mean | Max | Mean | Max | Mean | Max |
| Belize | *0.3%* | *1.5%* | 0.29% | 1.00% | 0.30% | 1.08% | 0.27% | 0.80% |
| Mexico | *0.5%* | *3.0%* | 0.31% | 2.96% | 0.31% | 2.99% | 0.34% | 2.99% |
| Guatemala | *0.5%* | *3.0%* | 0.48% | 1.85% | 0.47% | 1.82% | 0.48% | 2.27% |
| Honduras | *0.4%* | *3.0%* | 0.39% | 1.58% | 0.40% | 2.03% | 0.40% | 2.87% |

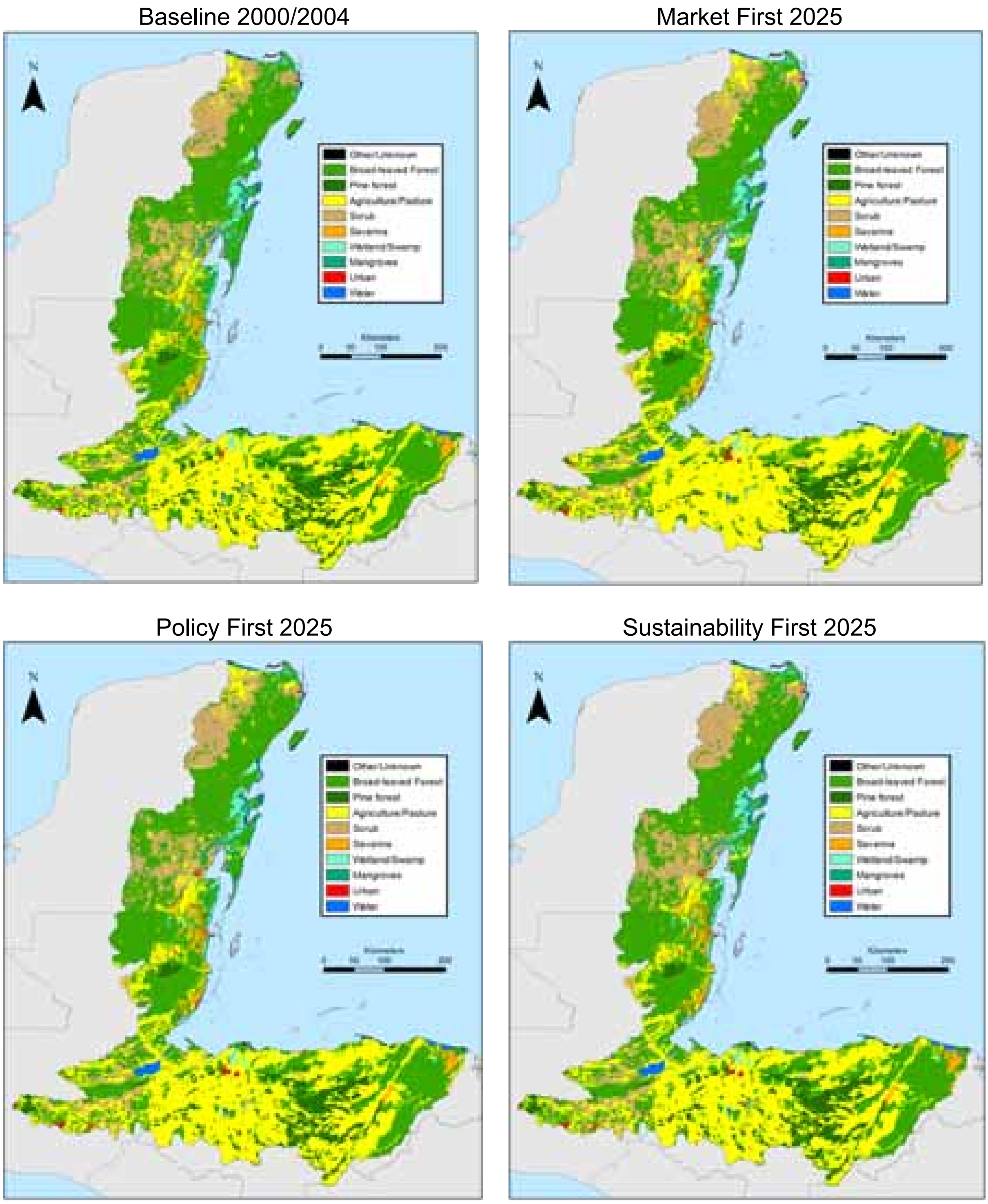


*Figure 4-1: Present land cover and simulated land cover for the three scenarios in 2025.*

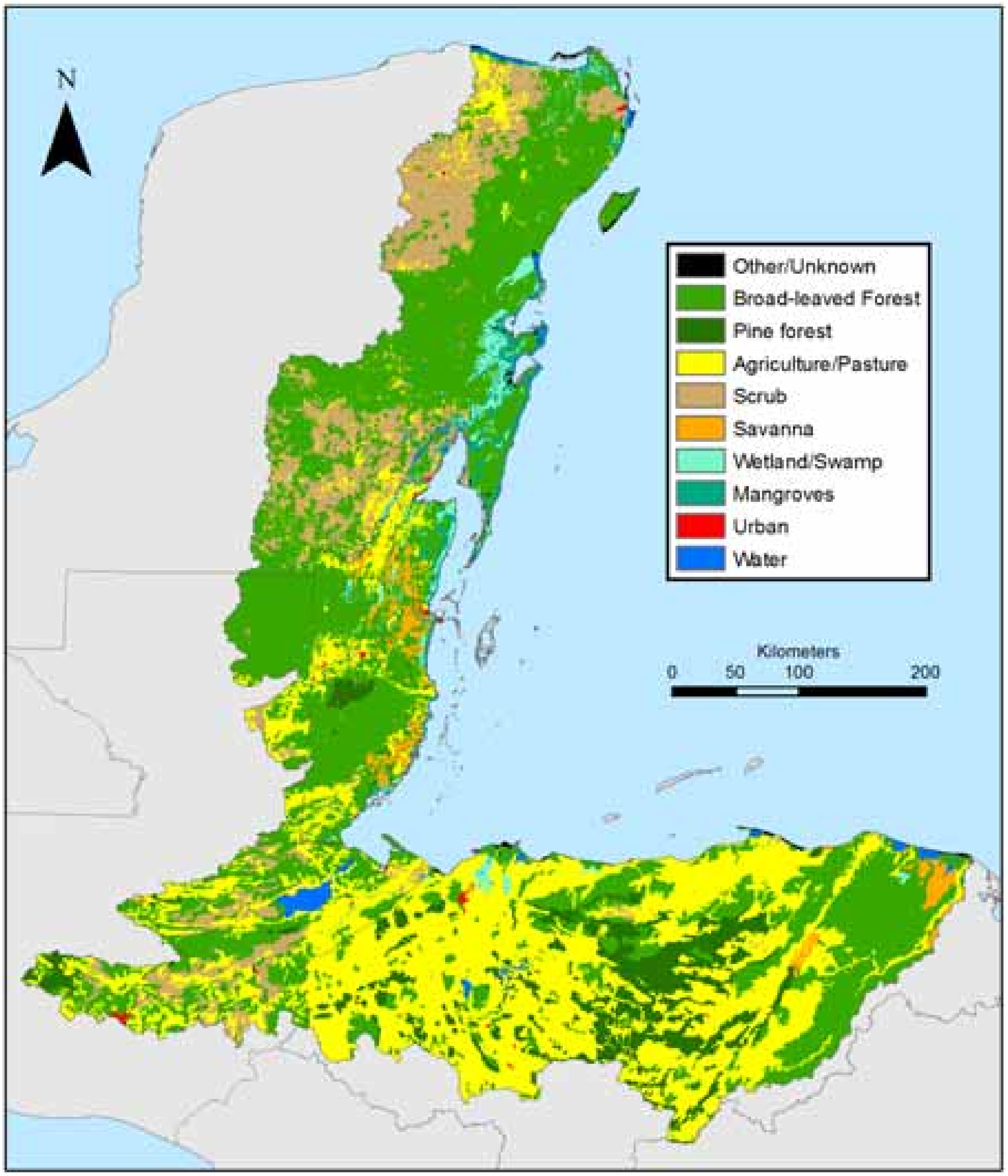

*Figure 4-2: Baseline (2000/2004) land use*

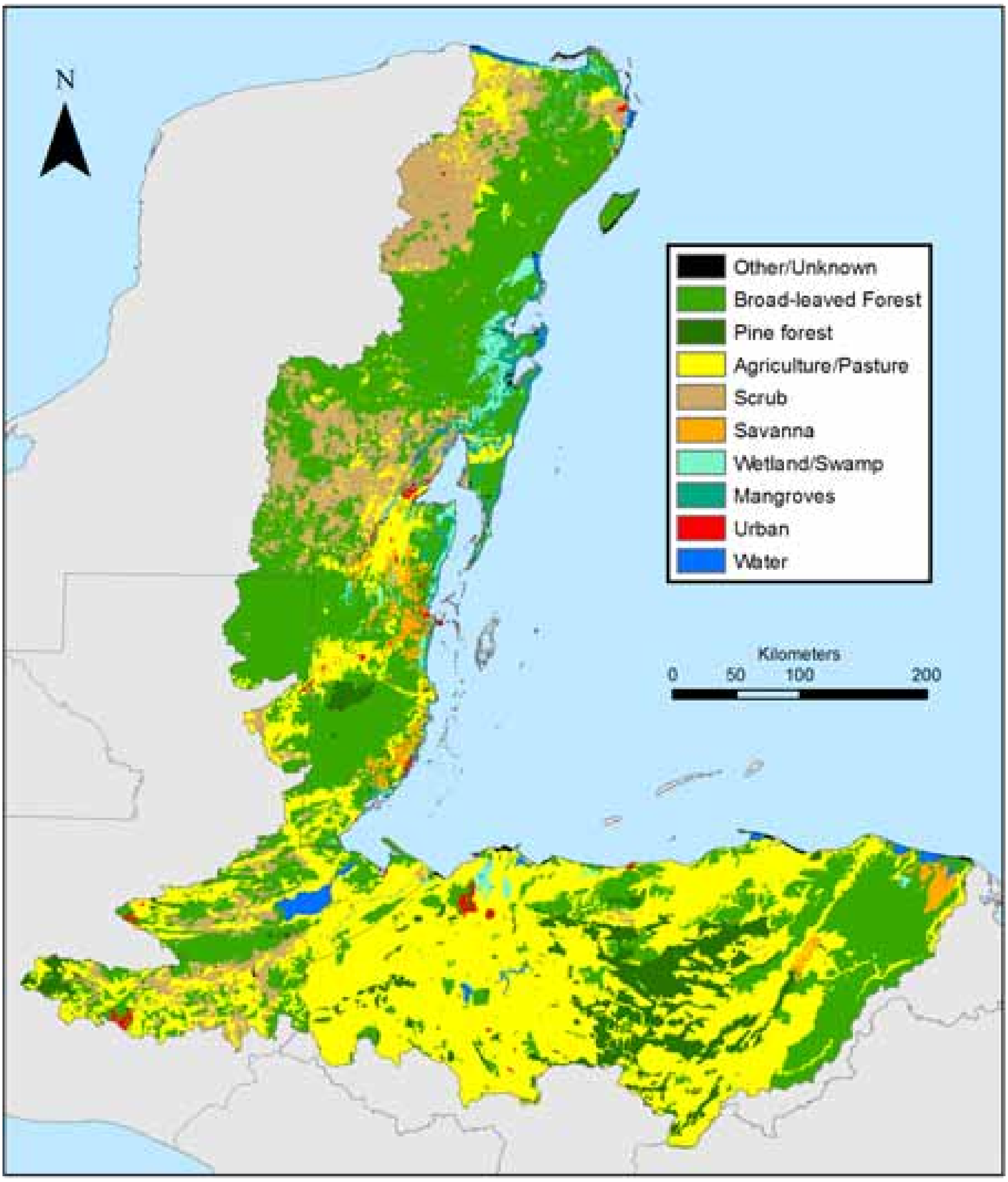


*Figure 4-3: Simulated land cover for scenario 1, Markets First, in 2025*

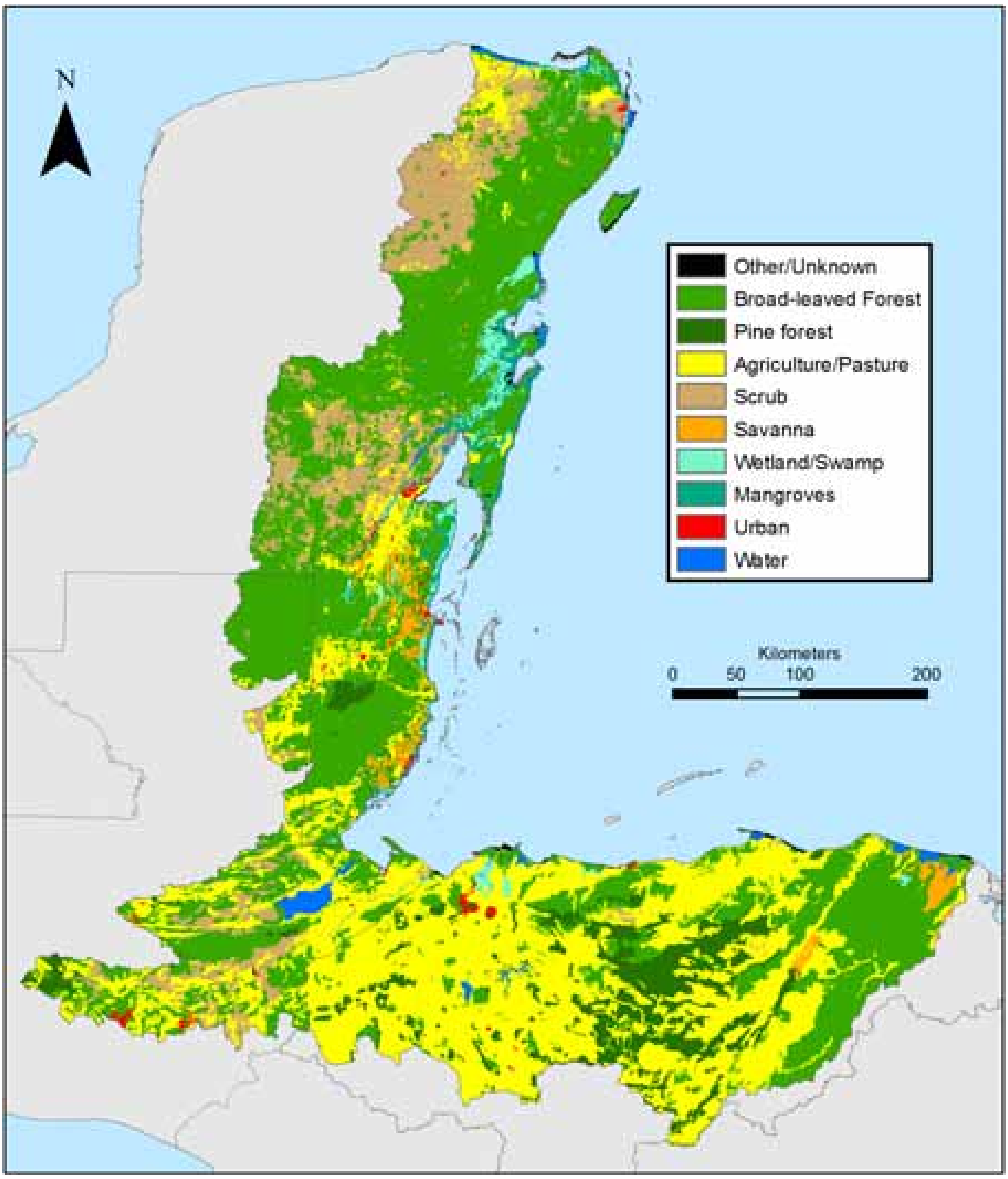

*Figure 4-4: Simulated land cover for scenario 2, Policy First, in 2025*

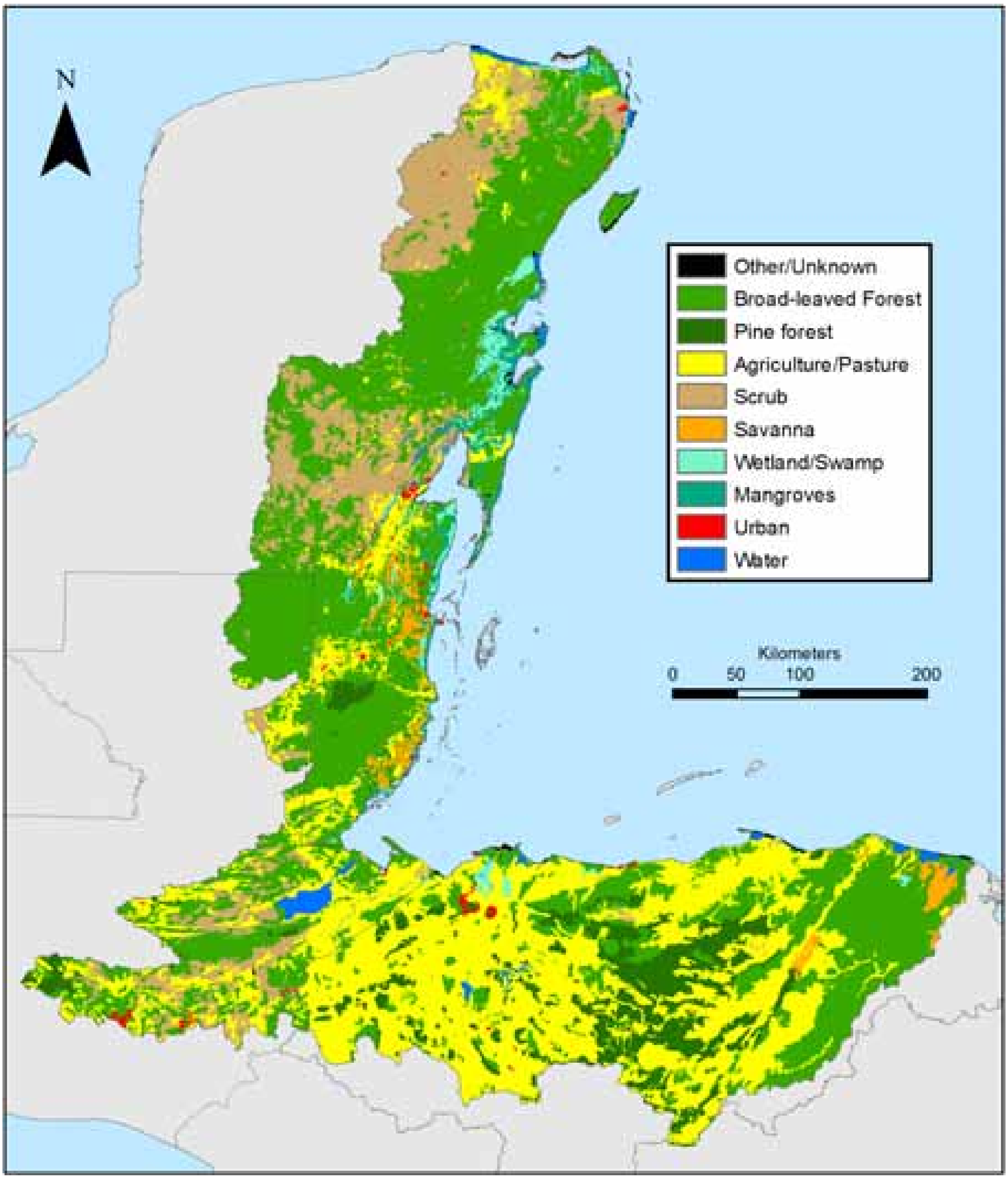


*Figure 4-5: Simulated land cover for scenario 4, Sustainability First, in 2025*

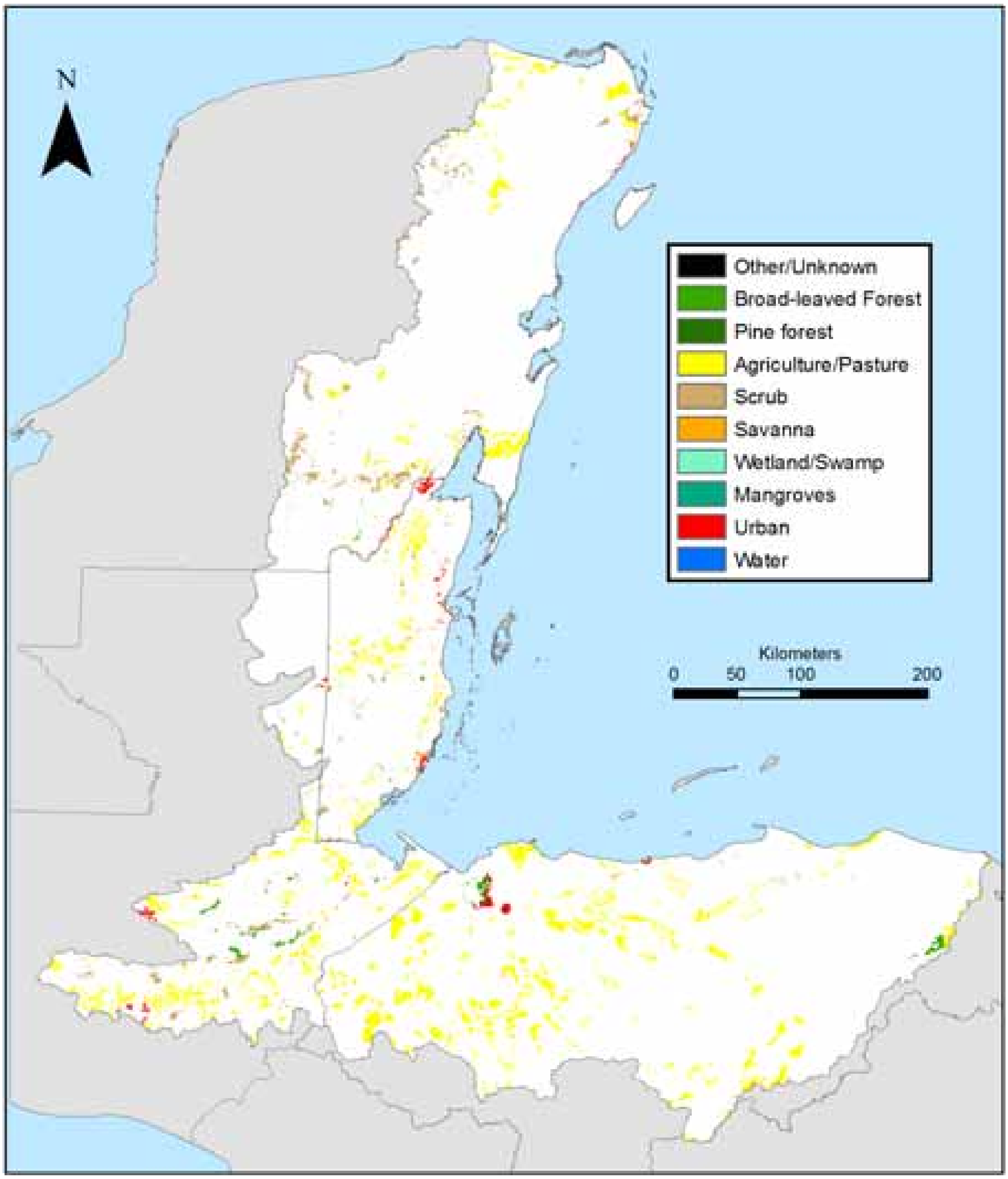


*Figure 4-6: Simulated areas of change with 2025 land cover for scenario 1, Markets First*

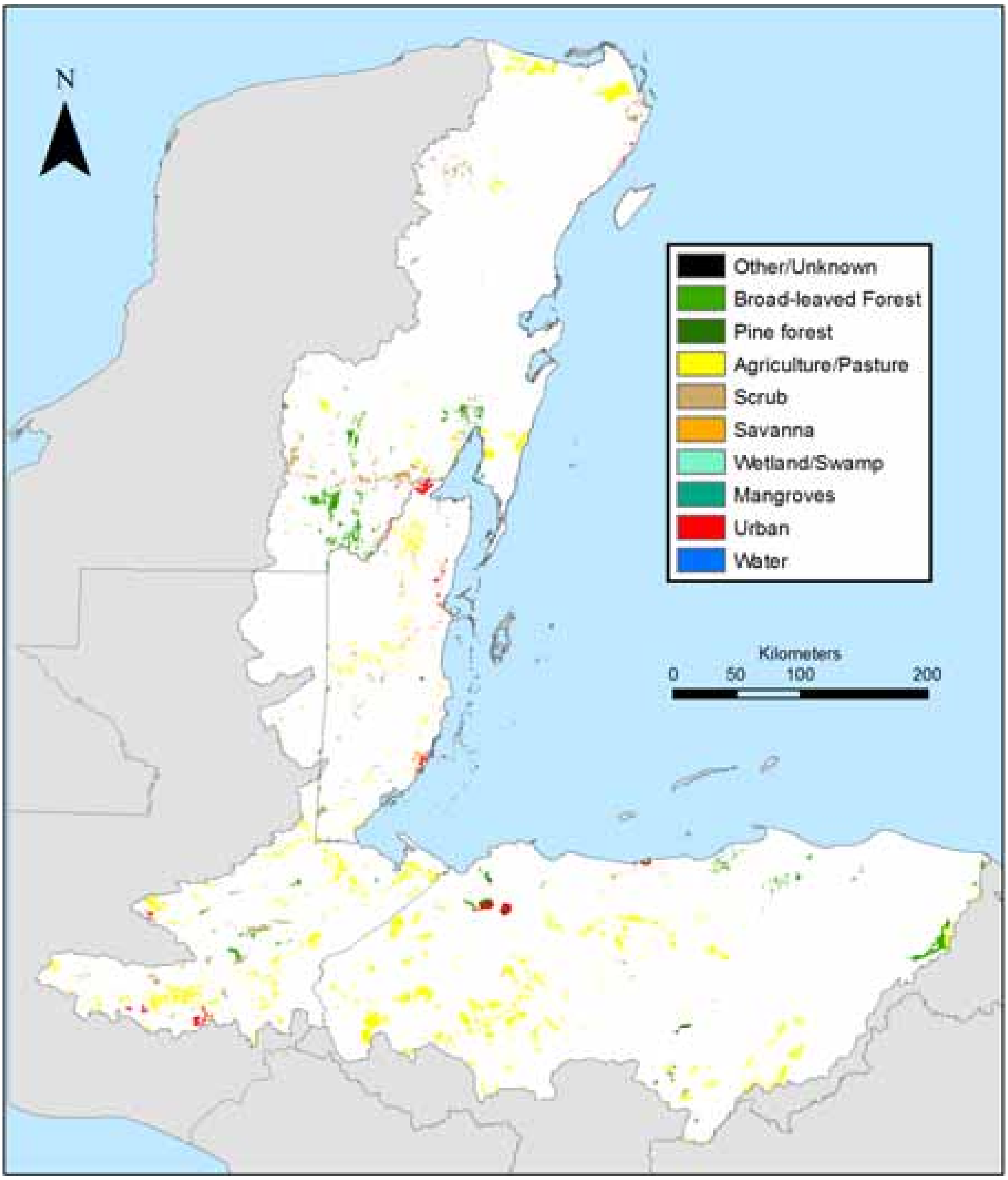


*Figure 4-7: Simulated area of change with 2025 land cover for scenario 2, Policy First*

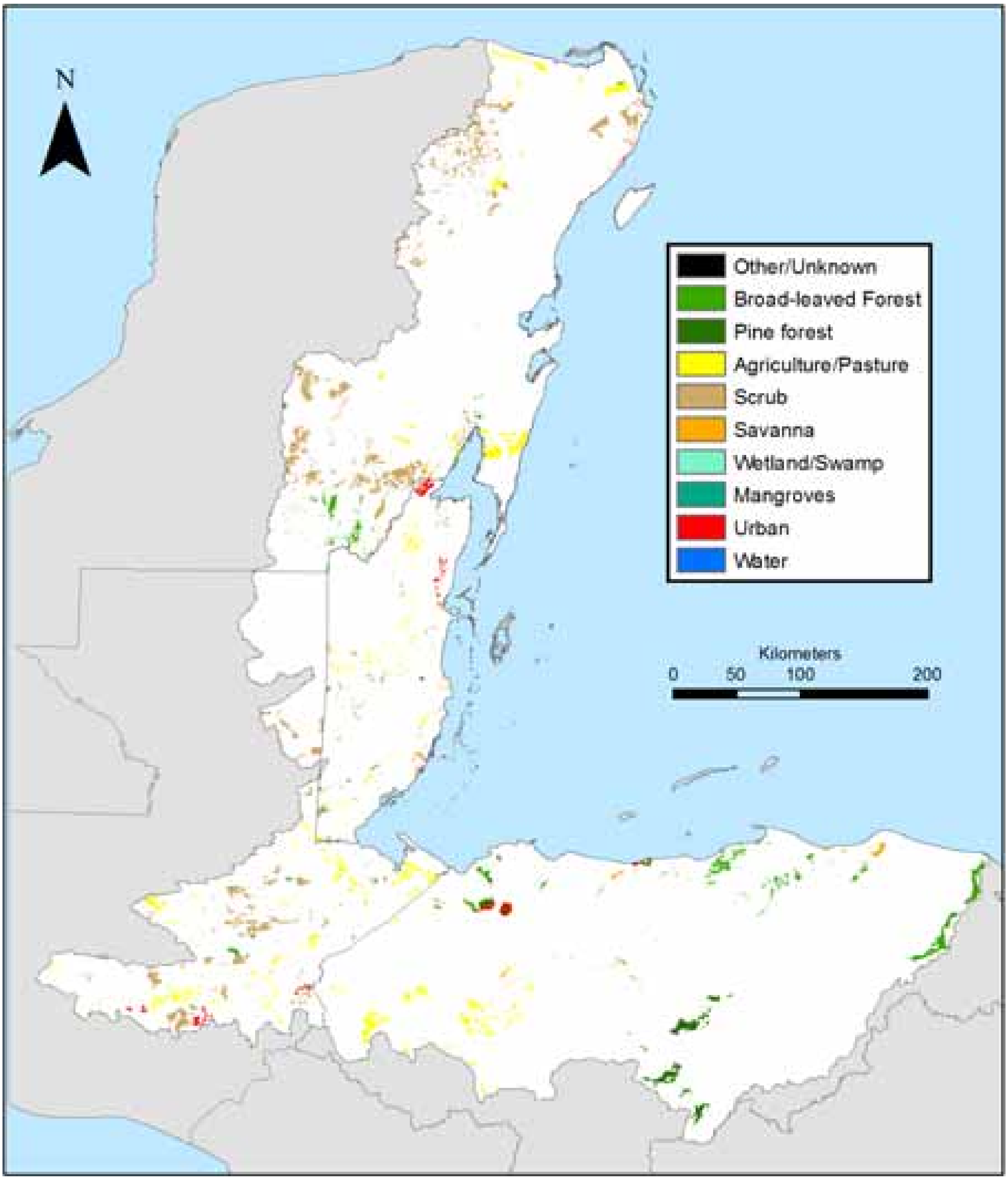


*Figure 4-8: Simulated areas of change with 2025 land cover for scenario 4, Sustainability First*

# 5 Workshop, conclusions and recommendations

## 5.1 Technical Workshop

A *Workshop on Watershed Management, Land Cover Change Analysis, and Modeling of Land-based Sources of Pollution and Sediment Discharge to the MAR* was held 15-18 August 2006 at Galen University, Belize. The workshop consisted of a policy session (1 ½ day) and a technical session (2 ½ days). Two presentations about the scenario development and the land use change modelling were given during the policy session, alongside presentations on the background of the land-use-change threats to the Mesoamerican Reef, and the policy implications of the MAR project.

The last day of the workshop was dedicated to training in land use change modelling using the CLUE-S model. The training programme, exercises and further supporting information --all bundled in a 30 page training package—can be found in Appendix 6.

Proceedings from the workshop have been compiled separately, and summarise feedback received from workshop participants.

## 5.2 Conclusions and Recommendations

The following conclusions and recommendations are compiled based upon Joep Luijten's experience with the application of CLUE-S to the MAR region, and on feedback received during the workshop.

### 5.2.1 Application of CLUE-S model to the MAR region

- The CLUE-S methodology has been successfully used to simulated land use changes in the MAR region over the next 25 years. A separate model was developed for each country. This was the correct approach, as it allows more accurate models that better capture the relevant (and different) explanatory factors in each of the countries.
- Simulated land use changes in different directions under the three scenarios, with substantial conversion from forest to agricultural land under the Markets First and Policy First scenarios. Under the Sustainability First scenario, changes towards other land use types could be observed too; most notably changes towards scrub and new forest areas.
- Whilst CLUE-S is a relatively easy model to use, the overall land use change modelling component of the project is quite complex. CLUE-S is not a model that can be quickly applied and run; preparation and implementation requires substantial time (months) and many data conversions. A significant portion of the hours required was spent on data collection and/or creation and quality assurance, data preparation for use in SPSS (regression analysis) and CLUE-S, and the regression analysis. Once the model was properly calibrated, the final simulation runs were a relatively straightforward task.
- CLUE-S does not dictate any particular method for calculating the land use requirements. The use of IMAGE and International Futures was possible only because we had access to these models. Simpler methods are possible and recommended, especially where specific regional policies are to be applied. For example, land use requirements could be calculated using appropriate economic demand models or simply by setting hypothetical land use requirements for the final scenario year and interpolating the land requirements between the start year and end year using a linear or exponential growth model.

- The regression analysis was a somewhat weak part of the study in that many relationships were not very significant and had to be manually tweaked or replaced by either a more logical regression equation (e.g., Urban), as detailed in Section 4.2.4. This is a direct consequence of the characteristics of the land use data that were used. The Ecosystem Map data were relatively coarse and polygon-based. It is believed that the regression analysis and the way CLUE-S allocates land based on the probability surfaces would give better results (and need fewer adjustments in model parameters and/or workarounds for the model not being able to reach a solution) if an original remote sensed raster dataset is used. Workshop participants knew of several recently released new land cover datasets, in particular for Guatemala.
- Another potential approach for improving the regression analysis is to use a "balanced sample" dataset instead of the full dataset for the region. A balanced sample is a dataset for a region that clearly exhibits the relevant relationships between a particular land use type and one or more location factors. Only full datasets were used for the MAR study.
- CLUE-S can be used if land use data from only a single year are available because the model is parameterized: in principle, based on the results of the regression analysis of the present land use pattern and a set of potential explanatory factors. However, it is always better if land use data for two or even three years are available, and these additional data can be used to improve the models. Having data for two years, $y_1$ and $y_2$, allows one to parameterize the models based on an regression analysis of the data for $y_1$, then run the model from $y_1$ to $y_2$, compare the simulated land use pattern with the actual land use pattern at $y_2$, and adjust (calibrate) the improve the model fit. If a third year $y_3$ is available, then a simulation run from $y_2$ to $y_3$ can be undertaken for model verification.

### 5.2.2 Workshop and training

- This overall work was covered during a 1-hour presentation during the policy part of the workshop and a 1-day training day in CLUE-S. The response to the questionnaires indicated that, in general, the participants found working with CLUE-S very useful.
- The CLUE-S training was quite intense. Any future training should dedicate at least 2 or 3 days to CLUE-S, as that will allow participants to spend more time on three important aspects of the study: (i) in-depth understanding and hands-on working with the actual data for Belize, Mexico, Guatemala and Honduras; (ii) how to use their own datasets; and (iii) the regression analysis of location factors and methods for incorporating additional or different location factors into the model. Any follow-up training should include these aspects, as some attendees requested this in the questionnaires.

# 6 References

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# 7 Appendices

## Appendix 1. Avenue script for NoData filling and filtering

The following Avenue script was created to fill NoData holes and to apply a majority filter to rasters, as mentioned in Section 1.1.1. This script removes any minor imperfections in the raster grids and adds a small buffer of value cells at the edge so that every raster being used for the statistical analysis has exactly the same number of value cells. The script can handle both mean filter and majority filters, and up to 10 iterations at once.

```
' SWBM.Grid.FillNodataGaps

' July 14, 2004. Joep Luijten
' This script was written fill the common Nodata cells in SRTM elevation
' data. The NoData cells are typically areas with steep gradients, river
' valleys, etc. The fill is done iteratively. See ESRI article 22853.
' http://support.esri.com/index.cfm?fa=knowledgebase.techarticles.articleShow&d=22853
' The number of necessary iterations depends on how large the data gaps are.

' 4/1/06. Provide selection menu to choose focalstats type (MEAN ort MAJORITY) and
' output type (floating or integer). This enables to use this script also to fill
' gaps in classified data. The majority filter wasn't as straightforward, though.
'
' The use of the MajorityFilter() does correctly fill any NoData holes inside a grid
' providing that the second argument is set TRUE, however, it does not convert NoData
' cells to value cells at the edge. On the other hand, a FocalStats() of type
' GRID_STATYPE_MAJORITY does create value cells at the edge (1 cell wide per
' iteration). Hence, it was deemed necessary to implement a succession of both
' methods at each iteration step to achieve the desired result.

theView = av.GetActiveDoc
theTheme = theView.GetActiveThemes.Get(0)
rawDem = theTheme.GetGrid
titmsg = "Fill NoData gaps in GRID"

' Check to proceed
if (MsgBox.YesNo("Fill NoData gaps in GRID theme" ++ theTheme.GetName + "?",titmsg, FALSE) =
FALSE) then
 return nil
end

' Method
iMethodList = {"MEAN 3x3 filter, return floating grid",
      "MEAN 3x3 filter, return integer grid",
      "MAJORITY 3x3 filter, return integer grid"}
iMethod = Msgbox.ListAsString (iMethodList, "Select FocalStats method", titmsg)

if (iMethod = nil) then
 return nil
else
 iMethodIndex = iMethodList.FindByValue(iMethod)

 if (iMethodIndex = 0) then
  bMean = true
  bFloat = true
 elseif (iMethodIndex = 1) then
  bMean = true
  bFloat = false
 elseif (iMethodIndex = 2) then
  bMean = false
  bFloat = false
 end
end


' Prompt for number of iterations
errorMsg = "You must enter a number between 1 and 10"
while (true)
 Niter = MsgBox.Input("Number of iterations [1-10]:",titmsg,"3")
 if (nIter = NIL) then return nil end
 if (nIter.IsNumber.Not) then
  MsgBox.Warning(errorMsg,titmsg)
 else
  nIter = nIter.AsNumber
  if ((nIter < 1) or (NIter > 10)) then
   MsgBox.Warning(errorMsg,titmsg)
  else
   break
```

```
  end
 end
end


' Check for any values < 0 or >= 32768 (in SRTM data, 32768 is used for NoData).
gStats = rawDem.GetStatistics

setMin = false
if (gStats.Get(0) < 0) then
 setMin = Msgbox.YesNo("The grid contains negative values (as low as"++
  gStats.Get(0).AsString ++ "). These are unusual --though not impossible-- elevation"++
  "values that you may want to set to zero. Do you want to do this?",titmsg, TRUE)
end

setMax = false
if (gStats.Get(1) >= 32768) then
 setMax = Msgbox.YesNo("The grid contains very high values that are unlikely elevations."++
  "Note that SRTM data often contain values 32768 (NoData) and 95xxx (incorrect)."++
  "You are strongly recommended to set these values to NoData. Okay?",titmsg, TRUE)

 if (setMax) then
  mxMsg = "You must enter a number between 0 and 100000"
  while (true)
   mxCut = MsgBox.Input("Maximum cutoff value (excluded):",titmsg,"32768")
   if (mxCut = NIL) then return nil end
   if (mxCut.IsNumber.Not) then
    MsgBox.Warning(mxMsg,titmsg)
   else
    mxCut = mxCut.AsNumber
    if ((mxCut < 0) or (mxCut > 100000)) then
     MsgBox.Warning(mxMsg,titmsg)
    else
     break 'Value is OK
    end
   end
  end
 end
end

' Apply min and max values
if (setMin and setMax) then
 g0 = ((rawDem < 0.asgrid).Con(0.asgrid,(rawDem >= mxCut.asgrid).SetNull(rawDem)))
elseif (setMin and setMax.Not) then
 g0 = ((rawDem < 0.asgrid).Con(0.asgrid,rawDem))
elseif (setMin.Not and setMax) then
 g0 = ((rawDem >= mxCut.asgrid).SetNull(rawDem))
else
 g0 = rawDem
end

' Perform iterative fill. Two methods in succession for the majority filter.

theNbrHood = NbrHood.Make ' Default 3x3 rectangular neighborhood

if (nIter >= 1) then
 if (bmean = true) then
   g1 = (g0.IsNull).Con((g0.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g0)
 else
   g1tmp = ((g0.IsNull).Con(g0.MajorityFilter(TRUE, TRUE),g0))
   g1 = (g1tmp.IsNull).Con((g1tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g1tmp)
 end
 if (nIter = 1) then
  gFinal = g1
 end
end

if (nIter >= 2) then
 if (bmean = true) then
   g2 = (g1.IsNull).Con((g1.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g1)
 else
   g2tmp = ((g1.IsNull).Con(g1.MajorityFilter(TRUE, TRUE),g1))
   g2 = (g2tmp.IsNull).Con((g2tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g2tmp)
 end
 if (nIter = 2) then
  gFinal = g2
 end
end

if (nIter >= 3) then
 if (bmean = true) then
   g3 = (g2.IsNull).Con((g2.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g2)
 else
   g3tmp = ((g2.IsNull).Con(g2.MajorityFilter(TRUE, TRUE),g2))
   g3 = (g3tmp.IsNull).Con((g3tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g3tmp)
```

```
 end
 if (nIter = 3) then
  gFinal = g3
 end
end

if (nIter >= 4) then
 if (bmean = true) then
   g4 = (g3.IsNull).Con((g3.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g3)
 else
   g4tmp = ((g3.IsNull).Con(g3.MajorityFilter(TRUE, TRUE),g3))
   g4 = (g4tmp.IsNull).Con((g4tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g4tmp)
 end
 if (nIter = 4) then
  gFinal = g4
 end
end

if (nIter >= 5) then
 if (bmean = true) then
   g5 = (g4.IsNull).Con((g4.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g4)
 else
   g5tmp = ((g4.IsNull).Con(g4.MajorityFilter(TRUE, TRUE),g4))
   g5 = (g5tmp.IsNull).Con((g5tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g5tmp)
 end
 if (nIter = 5) then
  gFinal = g5
 end
end

if (nIter >= 6) then
 if (bmean = true) then
   g6 = (g5.IsNull).Con((g5.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g5)
 else
   g6tmp = ((g5.IsNull).Con(g5.MajorityFilter(TRUE, TRUE),g5))
   g6 = (g6tmp.IsNull).Con((g6tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g6tmp)
 end
 if (nIter = 6) then
  gFinal = g6
 end
end

if (nIter >= 7) then
 if (bmean = true) then
   g7 = (g6.IsNull).Con((g6.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g6)
 else
   g7tmp = ((g6.IsNull).Con(g6.MajorityFilter(TRUE, TRUE),g6))
   g7 = (g7tmp.IsNull).Con((g7tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g7tmp)
 end
 if (nIter = 7) then
  gFinal = g7
 end
end

if (nIter >= 8) then
 if (bmean = true) then
   g8 = (g7.IsNull).Con((g7.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g7)
 else
   g8tmp = ((g7.IsNull).Con(g7.MajorityFilter(TRUE, TRUE),g7))
   g8 = (g8tmp.IsNull).Con((g8tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g8tmp)
 end
 if (nIter = 8) then
  gFinal = g8
 end
end

if (nIter >= 9) then
 if (bmean = true) then
   g9 = (g8.IsNull).Con((g8.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g8)
 else
   g9tmp = ((g8.IsNull).Con(g8.MajorityFilter(TRUE, TRUE),g8))
   g9 = (g9tmp.IsNull).Con((g9tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g9tmp)
 end
 if (nIter = 9) then
  gFinal = g9
 end
end

if (nIter >= 10) then
 if (bmean = true) then
   g10 = (g9.IsNull).Con((g9.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g9)
 else
   g10tmp = ((g9.IsNull).Con(g9.MajorityFilter(TRUE, TRUE),g9))
   g10                                                                              =
(g10tmp.IsNull).Con((g10tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g10tmp)
```

```
 end
 if (nIter = 10) then
  gFinal = g10
 end
end

' Make final grid
if (bFloat = true) then
 gFinal2 = gFinal.Float
 sOper = "("+nIter.asstring++"pass)"
else
 gFinal2 = gFinal.Int
end

' Construct new title name
if (bMean = true) then
 sname = theTheme.GetName++"("+nIter.asstring++"pass MEAN filter)"
else
 sname = theTheme.GetName++"("+nIter.asstring++"pass MAJORITY filter)"
end

' Add filled grid theme to view
newGTheme = GTheme.Make(gFinal2)
newGTheme.SetName(sname)
theView.AddTheme(newGTheme)
theView.Invalidate
```

## Appendix 2. Avenue script for creating dynamic protected areas grids

The script below was used to create dynamic location grids for the protected area scenarios. The script requires a view that contains five themes: the protected areas shapefile (**SCEN_COMBINED_4RASTER.SHP**) and the four mask grids for the countries (**MASK_BZ_250, MASK_GT_250, MASK_MX_250, MASK_HN_250**). The protected areas shapefile must have eight additional fields *S1PA1*, *S2PA2*, *A1PA1*, *..*, *S4PA2*, each with 0 and 1 values, indicating whether the polygon is a full or partially protected area. The scripts generates the grid **SRC1G11.FIL** (static fully protected areas), **REGION_NO_USE_S1MKT.FIL** (also static fully protected areas a value of –9998 for those areas) and **SRC1G12.0, SRC1G12.1**, …, through to **SRC1G12.25** (dynamic partially protected areas).

```
' Create.Dynamic.ProtectedAreas.Grids

' Location factor numbers (as in CLUE-S regression files)
locFacNum_fullProt = 11
locFacNum_partProt = 12
baseOutFolder = "D:\Work_WCMC\CLUES\dyndata\"

' Get active view
theView = av.FindDoc("protected areas")
thePrj = TheView.Getprojection
if (theView.Is(View).Not) then
 msgbox.Info ("Active document must be a view","")
 return nil
end

' Select country to process
country = MsgBox.ListAsString({"BZ","MX","GT","HN"}, "Select country","")
if (country = NIL) then
 return nil
end

' select scenario to process
scenario = MsgBox.ListAsString(
 {"1 Market First","2 Policy First","3 Security First","4 Sustainability First"},
 "Select scenario","")
if (scenario = NIL) then
 return nil
else
 scenNo = scenario.Left(1).AsNumber
end

' Select protected areas shapefile (modified to with special fields added)
thmList = theView.GetThemes
if (thmList.Count > 0) then
  wdpaThm = MsgBox.ListAsString(thmList, "Select the Protected Areas shapefile." +
   "The attribute table must include fields S"+scenNo.asstring+
    "PA1 and S"+scenNo.AsString+"PA2.","")
  if (wdpaThm = NIL) then
   return nil
  else
   theFTab = wdpaThm.GetFTab
   fldList = theFtab.GetFields
  end
else
 return nil
end

' Output directory
outDir = Msgbox.Input("Output folder","",baseOutFolder + country)
if (outDir = NIL) then return NIL end
if (scenNo = 1) then
 subdir = "s1mkt"
elseif (scenNo = 2) then
 subdir = "s2pol"
elseif (scenNo = 3) then
 subdir = "s3sec"
elseif (scenNo = 4) then
 subdir = "s4sus"
end
outDir = outDir + "\" + subdir

' Get mask grid. If the hardcoded name not found the selection menu will be shown.
maskName = "mask_" + country + "_250"
maskThm= theView.FindTheme(maskName)
```

```
if (maskThm <> NIL) then
 maskGrid = maskThm.Getgrid
else
 if (thmList.Count > 0) then
  maskThm = MsgBox.ListAsString(thmList,
   "Select the mask grid for " + country,"")
  if (maskThm = NIL) then
   return nil
  else
   maskGrid = maskThm.Getgrid
  end
 else
  return nil
 end
end

' Set analysis extent same to mask grid
aRect = maskgrid.getExtent
aCell = maskgrid.getCellSize
Grid.SetAnalysisExtent (#GRID_ENVTYPE_VALUE, aRect)
Grid.SetAnalysisCellsize(#GRID_ENVTYPE_VALUE, aCell)

' Create grid with only zeros for country extent
zeroGrid = ((maskGrid.IsNull).setnull(0.asgrid))


' **** STATIC LOCATION FACTOR FOR FULLY PROTECTED AREAS ****

' Filename for static location factor grid
cluename = "Src1gr" + locFacNum_fullProt.asstring + ".fil"

' Query to select all WDPA to include
fld1 = "S" +scenNo.asString + "pa1"

expr = "(["+fld1+"] = 1)"
theBitmap = theFTab.GetSelection
theFtab.Query(expr, theBitmap, #VTAB_SELTYPE_NEW)
theFTab.UpdateSelection

' Convert shape to grid.
tmp1Grid = Grid.MakeFromFTab(theFTab,thePrj,nil,nil)
tmp2Grid = (tmp1Grid.IsNull).Con(0.AsGrid,tmp1Grid) 'Grid with 0s and 1s
finGrid = ((maskGrid.IsNull).setnull(tmp2grid)) 'Clip grid

' Save grid in ascii format
theFn = (outdir + "\" + cluename).AsFileName
if (File.Exists(theFn)) then File.Delete(theFn) end
fingrid.SaveAsAscii(theFn)

' Also make a correspnding area restriction file. Active cells must have value
' of 0, restricted cells -9998, all other cells (NoData) -9999.
resGrid = (finGrid = 1.asgrid).Con(-9998.asgrid,finGrid)
theFn = (outdir + "\region_no_use_" + subdir + ".fil").AsFileName
if (File.Exists(theFn)) then File.Delete(theFn) end
resGrid.SaveAsAscii(theFn)

resGrid = nil
fingrid = nil
tmp2grid = nil
tmp1grid = nil

' **** DYNAMIC LOCATION GRIDS FOR PARTIALLY PROTECTED AREAS ****

' Number of years for which to save dynamic grids
 if (country = "BZ") then
  nYears = 21 '2004 to 2025
 else
  nYears = 25 '2000 to 2025
 end

' Save 2 WDPA location factor grid for each year
for each i in 0..nYears

  ' New grid name
  cluename = "Src1gr" + locFacNum_partProt.asstring + "." + i.asstring

  ' Actual simulated year. First year will be 0 for grid naming convention.
  if (country = "bz") then
   year = 2004 + i
  else
   year = 2000 + i
  end

  ' Select field name
  fld1 = "S" +scenNo.asString + "pa2"
```

```
  fld2 = "Yearincl"

  ' Query to select all WDPA to include
  expr = "(["+fld1+"] = 1) and (["+fld2+"] <= "+year.asstring + ")"
  theBitmap = theFTab.GetSelection
  theFtab.Query(expr, theBitmap, #VTAB_SELTYPE_NEW)
  theFTab.UpdateSelection

  ' Convert shape to grid.
  tmp1Grid = Grid.MakeFromFTab(theFTab,thePrj,nil,nil)
  tmp2Grid = (tmp1Grid.IsNull).Con(0.AsGrid,tmp1Grid) 'Grid with 0s and 1s
  finGrid = ((maskGrid.IsNull).setnull(tmp2grid)) 'Clip grid

  ' Save grid in ascii format
  theFn = (outdir + "\" + cluename).AsFileName
  if (File.Exists(theFn)) then File.Delete(theFn) end
  fingrid.SaveAsAscii(theFn)

  fingrid = nil
  tmp2grid = nil
  tmp1grid = nil

  ' Add theme to view
  'grdThm = GTheme.Make(finGrid)
  'grdThm.SetName(cluename)
  'theView.addTheme(grdThm)

end

zerogrid = nil
```

## Appendix 3: Complete list of available spatial data

Below is a complete list of all land cover/land use datasets and other spatial data that were identified during the data collection phase. Many of these data have also been downloaded. The yellow shaded rows indicate the datasets selected for this project. Informal notes on data availability and access have been left in the table in case of relevance to readers.

### LAND USE / LAND COVER DATASETS

| Dataset Name / Theme | Extent / Country | Years | Resolution | Classes | Got data? | Status / Comments / Constraints |
|---|---|---|---|---|---|---|
| **GLOBAL/ REGIONAL** | | | | | | |
| GLC2000 | Global | 2000 (Nov 1999 to Dec 2000) | 1 km | 22 | Joep has 2000 | Based on SPOT VEGETATION data. Good regional accuracy as local experts involved. May lack global consistency of Modis, less important for this project. |
| MODIS Land Cover | Global | Oct 2000 to Oct 2001 | 1 km | | | Globally consistent automated classification. No training sites in project region. Will be updated every six months and or a land cover change product provided. Gill contacted Boston University and EROS Data Center re next update/ release schedule. |
| FRA 2000 | Global | 2000 – based on 1992- 1996 images | 1 km | | | Only forest / open forest / non-forest in legend. |
| FRA control site data | Global network of 117 Landsat scenes | 1980s, 1990s and around 2000 | 30 m (Landsat) | | | Used for calibration of the lower resolution data above. Three control sites are totally within the project area, three more are partially of interest. *Dataset release is being investigated.* |
| GeoCover | Global (split into regions) | 1990 (1989, 90 & 94) and<br>2000 (2000 & 2002) | 30 m | 13 | | Estimated costs are $650 per date layer. WRI experience suggests **agricultural land under classified**. Richard Borda (rborda@earthsat.com) emailed Gill on 7/5/05 that 2000 data for Central America are now available. http://www.geocover.com/gc_lc/data_products/<br>Composites (band 742) from http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp show substantial patchy cloud coverage (and cloud shadows) throughout the region, particularly in eastern Belize and Guatemala. Therefore, this data is unlikely be very useful. **Suggest not to use these data.** |

| | | | | | | |
|---|---|---|---|---|---|---|
| NASA SERVIR | Regional | 2000, 2003, 2004 and 2005 | 30 m (Landsat) | | | Could use 2000 Landsat and STRM data as a baseline? Technical problems with Landsat mean data for 2004/5 is not available – recent MODIS data substituted. Other regional data layers available through MesoStor at http://servir.nsstc.nasa.gov.<br>*Contacts* = daniel.irwin@nasa.gov and jtullis@cast.uark.edu<br>It seems that land cover data cannot be downloaded through MesoStor |
| Ecosystems map (CCAD)<br>**2003 revision** | Regional (Central America **excluding Mexico**) | Varies by country, 1993-99, both pre- and post-Mitch | Polygons, based on LandSat 5 data, 1:250 000 | Modified UNESCO classification, 22 classes with Spanish legend | Joep has a copy | Detailed ecosystem legend (a modified UNESCO classification) contains one class for Agricultural Systems, one for Plantations and one for Urban Areas. This is the 2003 revision (the first version was released in 2001), which is still based on the same 1993-99 Landsat TM imagery, however the revised version corrects known errors on the map, includes a completely revised version of Costa Rica, and includes some changes to the classification system that resulted from agreements between the countries at a workshop in Guatemala in late 2002. |
| | | | | | | |
| **MANGROVES** | | | | | | |
| UNEP-WCMC Mangroves | Pan Tropical but not MEXICO | Continuing Updates | Various | | Yes | Only shows Mangroves, but is supposedly (!!) frequently improved and updated. Comparison with the Ecomap showed that the data is the same for Honduras (2003 version) but very different for Belize (2004 version). Lack of confidence in accuracy of WCMC data so suggest to not use them |
| Ecomap 2003 Mangroves | | | | | Yes | Full coverage. Best option to use as source, except for Belize, for which more recent and more accurate data is available. |
| BZ Ecomap 2004 mangroves | Belize only | see below | | | Yes | Relatively minor updates compared to the 2003 Ecomap. Assumed better. Best option for Belize. |
| CZMAI / Emil Mangroves | Belize only | Emil says latest | | | Yes | File: bz_mainland_mangrove_2004_c92_2. The data is generally more detailed and contains lots of small polygons. Also, the data appears to be converted from a raster but the source raster is unknown. Very different from the Mangroves in the 2004 Ecomap. The latter contain numerous areas classified as mangroves that are not included in this (Emil's) dataset so we cannot just complement both data. |
| | | | | | | |
| **BELIZE** | | | | | | |
| Fairweather & Gray (1994) | Belize | 1989-90-92 | SPOT XS 30 m, 1:76k | 54 | | Detailed methodology available – see Land Use of Belize 1989-92.pdf |

| | | | | | | |
|---|---|---|---|---|---|---|
| Iremonger & Brokaw (1995) | Belize | 1993 | Landsat 1:250 000 | 52 | | Results of NARMAP project. Methodology available – provided to mabr@unep-wcmc.org in late June 2005. |
| Meerman & Sabido (2001) | Belize | 1993-96-98 | LandSat 1:250 000 | 83 | | Initial (2001) version of Ecosystem map. Now obsolete.<br>Meerman & Sabido 2001 - Vol 1.pdf |
| 2004 Ecosystem Map of Belize | Belize | Landsat TM 98-99-04 + many other sources | Landsat ETM 1:110 000 | Total of 96. Default legend has 18 classes. Multiple agric. | Joep has a copy | Originally from 1998-99 TM imagery, but improved upon through fieldwork, additional TM imagery (Jan 04), etc. Also includes the reefs and islands. See NPAPSP Gap Analysis (public).pdf and ecosys_bze_2004.pdf http://biological-diversity.info/Ecosystems.htm |
| | | | | | | |
| **HONDURAS** | | | | | | |
| CIAT Hurricane Mitch Atlas; CIAT indicators CD | Honduras (not full country coverage) | 1986 and 1994 | 30 m, TM based | | Joep has 1986 and 1994 | http://gisweb.ciat.cgiar.org/cross_scale/atlas-mitch.htm<br>Contains recommended land use, capacity and forestry.<br>CIAT does not have more recent data. |
| Iremonger Vegetation data | Honduras | | | | | Emil emailed Susan Iremonger for further information on data on 7th August 2005. I think this data is the Honduran part of the initial 2001 Ecosystem map. |
| 2003 Ecosystem map | | 2 x 2/93, 2x 3/94, 1x12.98 (west) images + aerialphotos | | | | SEE "GLOBAL/REGIONAL" SECTION FOR DETAILS.<br>Note that base TM imagery is the oldest used for the ecosystem map, though completed with aerial photos/verification./ |
| | | | | | | |
| **MEXICO** | | | | | | |
| INEGI "Serie II" National Forest Inventory | Mexico | 1993 | 125k / 30 m | | | http://www.selvamaya.org<br>Mexican forest inventory of 1994. An update of mexico's 1968-1986 land cover classification using 1993 Landsat TM images. Data made public in 2000 and re-processed by TNC for inclusion in Selva Maya CD |
| National Forest Inventory 2000 | Mexico | 2000 | | | | **http://indy2.igeograf.unam.mx/ua_morelia/_private/2002/mapping_of_Mexico.PDF.** |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2003 Ecomap<br>(not quite true) | | 1999, 2000 | 250 km | 18 | Joep has a copy | UNAM / INEGI / SEMARNAT. Conducted a complete land cover classification for Mexico Aerial photos also used, assessment of accuracy provided, covers whole country. Data set made available by CCAD as part of the 2003 revision of the Central American Ecosystem map. Note, however, that the original 2001 Ecomap didn't include Mexico.<br>Mas *et al*. (2004) |
| Clark / Harvard / ECOSUR | Mexico, S. Yucatan, Campeche State | | | | | Modelling program already undertaken in area adjoining Petén in Guatemala. http://www.clarku.edu/departments/geography/research/sypr.shtml http://earth.clarku.edu/lcluc/ |
| | | | | | | |
| **GUATEMALA** | | | | | | |
| Maya Vegetation Map (CI) | Northern part GT, BZ, and some MX | 1997-98 Landsat TM | 30 m | 12 classes, 1 of which agric. | Joep has a copy | Created by Conservation International from 1997-98 imagery, published in 2000. Daniel Juhn shared this data with Joep in 2001 |
| Forest and Forest changes 1986-2002 | Petén only | up to 2002 | | Forest, agric, water + forest changes every two years | Joep has a copy | A continuation of the work undertaken by the Univ of Maine in 1996-97, this datasets was created by CEMEC-CONAP and WCS, Flores, Guatemala, using SPOT and LANDSAT ET+ data from March 2002. **Very detailed and considered accurate** but covers only Petén. Victor Hugo Ramos shared this data to Joep in April 2003, when the data was just completed. |
| MAGA | Guatemala | Complete 2001. Source image years unknown | 250 km | 24 | | Acquired by MBRS intern, cannot be shared at present. Metadata in **BASE250.PRF** suggest that this is the same as the ecosystem map, although an overlay of the polygons shows that it is not. |

## OTHER DATASETS

| Dataset | Extent | Resolution / Source year | Received / Requested | Comments |
|---|---|---|---|---|
| **ROADS** | | | | |
| CCAD Roads | Regional – in separate file for each country | | Joep has a copy | Roads stop at edge of cities – not good for network analysis. Also seems to haver an offset of about 100-200 m (all CCAD data suffer from this). http://www.ccad.ws/documentos/mapas.html |
| Selva Maya roads | Regional | | | **VISA_COMUNICACION.SHP** (from Selva Maya CD) and **BZ-GT-MX_ROADS_SELVA_YR-UNKNOWN.SHP** (from Emil). Same data, but with a bad offset of > 1 km, so it was decided not to use these data. |
| MesoStor | Regional | 1990s ? | Joep has a copy | **(RED_VIAL_LINE)** In principle the same as the CCAD data but doesn't have a datum offset. Data have been reclassified in 5 classes: Highway-paved, Highway-unpaved (all year), Highway-unpaved (dry season only), Other road, and paths/tracks. Best available data, however, it remains a fairly low scale dataset. There are obvious discrepancies and missing roads when comparing with imagery (from Google Earth) |
| J. Meerman, E. Cherrington | Belize only | 2000-03 | Joep has a copy | **(BZ_ROADS_BTFS_2000-03)** Received from Emil; according to the Belize Spatial Data Inventory (Dec 05) this is an updated of the Land Information Centre's (LIC) roads dataset, using 2000-03 Landsat Imagery, by Meerman. A major visible change with the MesoStor/CCAD dataset is the inclusion of the major road from Belize City in northwest direction (as opposed to the one going in more northern direction from B.C.) |
| CZMAI | Southern Belize | 2005 | Joep has a copy | **(BZ_SOUTH-ROADS_CZMAI_2005)**. Revised roads created by Emil Cherrington. |
| CIAT roads | Honduras | | Joep has a copy | From topographic maps. |
| CCAD Airports | Regional | | Joep has a copy | |
| CCAD Ports | Regional | | Joep has a copy | |
| | | | | |
| **POPULATION / URBAN EXTENT** | | | | |
| CCAD Population Centres | Regional – in separate file for each country | | Joep has a copy | Contains data on district and town name, but no population data attached. |
| Latin America and Caribbean Pop. Database CIAT | Regional (LAC) | 1960 – 2000; 1 km grid | Joep has a copy. | From CIAT web site, http://gisweb.ciat.cgiar.org/population/. Contains vector population maps (pop. per admin unit) and raster surfaces created with an accessibility model. When compared to GPW v3 and overlaying on a Landsat image it becomes clear that this dataset is visibly less accurate than GPW. |
| GPW v3 | Global and by country | 1990 – 2015, in steps of 5 years. 1 km grid | Joep has a copy. | Latest version 3 and final GRUMP data available in Dec 05. Actual population density for 1990, 1995 and 2000, and estimated for 2005, 2010 and 2015, and pop density grid appears more accurate than CIAT's LAC. For the actual population, the "ag" grids were selected: adjusted population density to match UN totals. Datasets seem generally better |

| | | | | |
|---|---|---|---|---|
| | | | | than the LAC dataset, except for Belize. |
| Landscan 2004 | Global | | | Access requested but not yet received |
| GRUMP urban extent & settlements | Global | Around 2000 | Joep has a copy. | Not very accurate. It may be better to digitize the polygons again from Landsat imagery. The settlements points from El Salvador were used to compile a MAR settlements dataset as no alternative data available for that country. |
| IGN/CCAD settlements | Honduras | unknown | Joep has a copy | (**HN_SETTLEMENTS_IGN-CCAD.SHP**). The most detailed population point data for Honduras. Other dataset from INEGI and CCAD did not included population size. Received from Emil Cherrington |
| BTFS settlements | Belize | unknown | Joep has a copy | (**BZ_SETTLEMENTS_BTFS.SHP**). Settlements + population size from Belize Tropical Forest Studies, received from Emil. |
| Selva Maya settlements | MX, BZ and part of GT | Around 2000 | Joep has a copy | (**BZ-GT-MX_SETTLEMENTS_SELVA_C2000.SHP**) Settlements and population size from Selva Maya CD. |
| | | | | |
| **ELEVATION / SLOPE** | | | | |
| STRM DEM for elevation and slope. (CIAT) | Regional | Orginal 30 deg-sec (90 m), resampled to50 m. | | Created by Joep from CIAT's filled SRTM 90 data. Accurately projected to UTM 16/NAD 1927 using Joep's customized Raster Project tool. (downloaded from http://srtm.csi.cgiar.org/) |
| | | | | |
| **CLIMATE** | | | | |
| FAO Clim | Global | Some data from 1960 onwards | No | Data from a global network of climatic stations (2 in Belize, ~ 100 in Honduras) available on CD-ROM *(Copy was requested).*<br>http://www.fao.org/sd/2002/EN1203_en.htm |
| CIAT Worldclim | | 1km | Joep has a copy | http://biogeo.berkeley.edu/worldclim/worldclim.htm. Considered the best data to use. Has monthly mean temperatures and precipitation in several resolutions (30 sec, 2.5, 5 and 10 min). 1 km resolution is more than sufficient for land use modelling. |
| | | | | |
| **SOILS** | | | | |
| SOTER LAC (Latin America and the Caribbean) with parameter estimates | Latin America | 1:5 million | Joep has a copy | Can purchase from FAO ($44) but downloaded for free on 13/8/05 from ISRIC http://lime.isric.nl/index.cfm?contentid=162<br>A secondary dataset of soil parameters estimates was also obtained http://lime.isric.nl/index.cfm?contentid=%20452<br>These data can be linked to the SOTER GIS data |
| ISRIC WISEv3 | Global | December 2005; 0.5 degree grid | | http://www.isric.org/UK/About+Soils/Soil+data/Thematic+data/Soil+Geographic+Data/. WISE dataset contains grid of man of the sae soil properties as the SOTERLAC but also has grid of soil depth |

| | | | | |
|---|---|---|---|---|
| IIASA GAEZ 2000 | Global | 10 km grid | No | Global Agro-Ecological Zoning 2000. Website states that better databases may be available elsewhere (i.e., SOTERLAC) (http://www.iiasa.ac.at/Research/LUC/gaez.html) |
| INEGI | Mexico | 1:250 k – 1M ?? | | Included on their map server http://galileo.inegi.gob.mx/website/mexico/viewer.htm, http://mapserver.inegi.gob.mx/map/datos_basicos/uso_suelo/. See metadata http://mapserver.inegi.gob.mx/dsist/Internet%202003/pagina1m.html |
| Selva Maya | MX, BT, GT, but not Honduras | 1: 250 k | Yes | Much more spatial detailed than the FAO SOTER. Emil thinks the classification were originally different in each country but were harmonized to FAO classification as part of the Selva Maya work (http://www.selvamaya.org). **Lacks soil properties data so limited use.** |
| CONAP / FAO (faosoil.shp) | | 200-250 k? | | From the Grunberg CD. Metadata indicate that FAO was the data source but they say that they do not have such a detailed regional map on record. The data appears to be in at a scale of 200-250 km because it has comparable detail to the Selva Maya data. However, they are absolutely different from the Maya soil data and the soil classes at various picked locations are also different from the SOTERLAC. Rejected for this reason. |
| | | | | |
| **ACCESSIBILITY** | | | | |
| Accessibility to markets, roads | | | Joep created | Created using CIAT's Accessibility Wizard, using roads, cities data. |
| Accessibility to ports | | | | |
| | | | | |
| **RIVERS** | | | | |
| MesoStor / CCAD | Regional, split by country. | 1:250 000 | Joep has them | http://servir.nsstc.nasa.gov/MesoStor/index.html . Same data on CCAD website as on MesoStor. Contains rivers names. Mostly digitized from 1:50 k-100 k topographic maps. Brief comparison with DCW (1:1m scale) shows that CCAD data are more detailed, but many small 1st order streams included in DCW are missing from the CCAD dataset. For Honduras doesn't include as many secondary streams as CIAT"s "*rios oficiales*" data. Also, unlikely high stream density in central Belize—these are probably very small streams that we may not want to include. |
| WRI | Regional | | | More accurate datasets delineated from 90 m SRTM DEM. Locally burned in rivers will be identical to those from other (CCAD) datasets, though overall the DEM_delineated rivers should be more accurate than the older vector data. |
| CIAT | Honduras | 1:50 k | Joep has them | Official rivers (grouped by primary and secondary rivers) digitized from 1:50 k topographic maps. Includes more secondary rivers than the CCAD data. |
| CZMAI | Belize | | Joep has them | Major rivers in Belize. Includes significantly fewers rivers than in the CCAD rivers data, though this seems more plausible and fits better with the rivers data for the other countries. |

| | | | | |
|---|---|---|---|---|
| | | | | |
| **PROTECTED AREAS** | | | | |
| Mesostor / CCAD protected areas | Regional | May 2003 | Joep has a copy | *Mapa de Areas Naturales Protegidas de la región Mesoamericana*. The data download from the CCAD website (http://www.ccad.ws/documentos/mapas.html) are the same as those from MesoStor. For Honduras also the same as CIAT's data. |
| WDPA<br>(UNEP-WCMC) | Global, but only updated for MX, GT, HN and BZ | Updated Jan 2006 | Joep has a copy | The 18-05-2005 dataset showed significant differences compared to the CCAD dataset and well as CIAT's dataset for Honduras. Major omissions and inaccurate boundaries in Honduras. Dataset updated by WCMC in January 2006 and this version appears to be complete and match the CCAD/MeSostor data. ICUN categories used. |
| CIAT | Honduras | 2000 - 2001 | Joep has a copy | On Honduras / Mitch data CD that Joep received from Andy Nelson in 2001. Data could be older than 2001, however, polygon boundaries are the same as those of Mesostor / CCAD dataset. Lacks attribute data and names of area so not very useful. |
| | | | | |
| **TOURISM HOTSPOTS** | | | | |
| Selva Maya | MX, BZ and Peten area of GT | 2001 | Joep has a copy. | Tourism cost layer. It's composed of hexagon-shaped polygons of 100 ha each and an attribute "Qualification" (*Calificacia*) that indicates what part of these 100 ha is under threat. Nearly all of the areas under threat are predominantly mangroves. |

## Appendix 4: Ecosystem Map land cover classification

The table below shows the classifications for the original 2003 Ecosystem Map for Central America (22 classes), the 2004 Ecosystem Map for Belize (18 classes) and the reclassified and reduced classification that was adopted for the MAR land use change simulations.

| 2003 Ecosystem map Central America | 2004 Ecosystem map Belize | Reclassified / Reduced Classification |
|---|---|---|
| 2003 Ecosystem Map | Ecosystem Belize 2004 | Reclassified / Reduced Ecosystem Map |
| Bosques siempreverdes de coníferas | Lowland broad-leaved dry forest | Other/Unknown |
| Bosques siempreverdes y semisiempreverdes de latifoliadas | Lowland broad-leaved moist forest | Broad-leaved Forest |
| Bosques siempreverdes y semisiempreverdes mixtos | Lowland broad-leaved wet forest | Pine forest |
| Bosques semideciduos de latifoliadas | Lowland pine forest | Agriculture/Pasture |
| Bosques semideciduos mixtos | Submontane pine forest | Scrub |
| Bosques deciduos de latifoliadas | Submontane broad-leaved moist forest | Savanna |
| Bosques manglares | Submontane broad-leaved wet forest | Wetland/Swamp |
| Arbustales de coníferas | Lowland savanna | Mangroves |
| Arbustales de latifoliadas | Mangrove and littoral forest | Urban |
| Arbustales mixtos | Shrubland | Water |
| Arbustales xeromórficos subdesérticos | Wetland | |
| Sabanas | Open sea | |
| Pastizales naturales | Coral reef | |
| Páramos | Seagrass | |
| Pantanos y humedales | Sparse Algae | |
| Sistemas agropecuarios | Agricultural uses | |
| Plantaciones forestales | Water | |
| Arrecifes coralinos | Urban | |
| Cuerpos de agua | | |
| Sistemas productivos acuáticos (camaroneras, salineras) | | |
| Urbano | | |
| Areas con escasa vegetación | | |
| Sin datos | | |

## Appendix 5. Land use requirements for future scenarios

The 16 tables below give the land use requirements, in ha, for all combinations of four scenarios and the four countries (the third scenario, Security First was not simulated but was calculated for assessment purposes). These land requirements were calculated using outputs from the International Futures and IMAGE models. Bear in mind that the reported areas apply to the parts of the countries that fall within the MAR region, not the whole countries (although for Belize that almost the same). Data are rounded to integer values so that they fit these tables better, however, in the source spreadsheet and CLUE-S input files the numbers have four decimals and the row totals are precisely identical each year.

### Belize – Markets First (1)

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | | | | | | | | | | |
| 2000 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2001 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2002 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2003 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2004 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2005 | 1350 | 1266094 | 77034 | 424658 | 27701 | 189098 | 93403 | 71868 | 19489 | 15319 |
| 2006 | 1350 | 1264534 | 76939 | 426287 | 27622 | 188862 | 93286 | 71779 | 20036 | 15319 |
| 2007 | 1350 | 1262814 | 76834 | 427859 | 27539 | 188601 | 93157 | 71682 | 20858 | 15319 |
| 2008 | 1350 | 1261095 | 76729 | 429430 | 27456 | 188341 | 93029 | 71584 | 21679 | 15319 |
| 2009 | 1350 | 1259541 | 76635 | 431054 | 27377 | 188105 | 92912 | 71496 | 22224 | 15319 |
| 2010 | 1350 | 1257987 | 76540 | 432676 | 27298 | 187870 | 92796 | 71408 | 22769 | 15319 |
| 2011 | 1350 | 1254227 | 76312 | 437724 | 27166 | 186599 | 92168 | 71194 | 23954 | 15319 |
| 2012 | 1350 | 1250765 | 76101 | 442918 | 27039 | 185368 | 91560 | 70998 | 24595 | 15319 |
| 2013 | 1350 | 1247279 | 75889 | 448148 | 26912 | 184128 | 90948 | 70800 | 25240 | 15319 |
| 2014 | 1350 | 1243608 | 75665 | 453355 | 26781 | 182856 | 90319 | 70592 | 26168 | 15319 |
| 2015 | 1350 | 1239913 | 75441 | 458596 | 26648 | 181576 | 89687 | 70382 | 27101 | 15319 |
| 2016 | 1350 | 1234418 | 75106 | 463740 | 26539 | 181659 | 89728 | 70070 | 28084 | 15319 |
| 2017 | 1350 | 1228869 | 74769 | 468934 | 26429 | 181743 | 89770 | 69755 | 29076 | 15319 |
| 2018 | 1350 | 1222781 | 74398 | 473991 | 26307 | 181756 | 89776 | 69409 | 30926 | 15319 |
| 2019 | 1350 | 1217122 | 74054 | 479284 | 26195 | 181841 | 89818 | 69088 | 31942 | 15319 |
| 2020 | 1350 | 1211407 | 73706 | 484630 | 26082 | 181927 | 89860 | 68764 | 32968 | 15319 |
| 2021 | 1350 | 1206852 | 73429 | 489062 | 26230 | 181567 | 89683 | 68505 | 34016 | 15319 |
| 2022 | 1350 | 1202247 | 73149 | 493541 | 26380 | 181203 | 89503 | 68244 | 35076 | 15319 |
| 2023 | 1350 | 1197593 | 72866 | 498069 | 26532 | 180836 | 89321 | 67980 | 36148 | 15319 |
| 2024 | 1350 | 1192887 | 72579 | 502646 | 26686 | 180464 | 89138 | 67713 | 37231 | 15319 |
| 2025 | 1350 | 1187643 | 72260 | 507064 | 26830 | 180015 | 88916 | 67415 | 39201 | 15319 |

**Belize – Policy First (2)**

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | | | | | | | | | | |
| 2000 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2001 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2002 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2003 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2004 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2005 | 1350 | 1266863 | 77080 | 424586 | 27660 | 188608 | 93160 | 71912 | 19475 | 15319 |
| 2006 | 1350 | 1266174 | 77038 | 425261 | 27666 | 188298 | 93007 | 71873 | 20027 | 15319 |
| 2007 | 1350 | 1265486 | 76997 | 425936 | 27671 | 187988 | 92854 | 71833 | 20578 | 15319 |
| 2008 | 1350 | 1264797 | 76955 | 426611 | 27677 | 187679 | 92702 | 71794 | 21129 | 15319 |
| 2009 | 1350 | 1264109 | 76913 | 427285 | 27683 | 187370 | 92549 | 71755 | 21680 | 15319 |
| 2010 | 1350 | 1263260 | 76861 | 427905 | 27685 | 187037 | 92384 | 71707 | 22505 | 15319 |
| 2011 | 1350 | 1261364 | 76746 | 430321 | 27292 | 186154 | 91948 | 71600 | 23919 | 15319 |
| 2012 | 1350 | 1259950 | 76660 | 432909 | 26909 | 185340 | 91546 | 71519 | 24509 | 15319 |
| 2013 | 1350 | 1258532 | 76573 | 435505 | 26525 | 184525 | 91143 | 71439 | 25102 | 15319 |
| 2014 | 1350 | 1257110 | 76487 | 438107 | 26140 | 183706 | 90739 | 71358 | 25696 | 15319 |
| 2015 | 1350 | 1255684 | 76400 | 440717 | 25754 | 182886 | 90334 | 71277 | 26291 | 15319 |
| 2016 | 1350 | 1254525 | 76330 | 441286 | 25579 | 183098 | 90439 | 71211 | 26876 | 15319 |
| 2017 | 1350 | 1253202 | 76249 | 441798 | 25400 | 183287 | 90532 | 71136 | 27739 | 15319 |
| 2018 | 1350 | 1251877 | 76169 | 442311 | 25221 | 183476 | 90625 | 71061 | 28604 | 15319 |
| 2019 | 1350 | 1249742 | 76039 | 442539 | 25025 | 183546 | 90660 | 70940 | 30853 | 15319 |
| 2020 | 1350 | 1248574 | 75968 | 443110 | 24849 | 183760 | 90766 | 70874 | 31444 | 15319 |
| 2021 | 1350 | 1246838 | 75862 | 444761 | 24844 | 183533 | 90654 | 70775 | 32077 | 15319 |
| 2022 | 1350 | 1244933 | 75746 | 446362 | 24835 | 183282 | 90530 | 70667 | 32990 | 15319 |
| 2023 | 1350 | 1243020 | 75630 | 447969 | 24826 | 183029 | 90405 | 70558 | 33907 | 15319 |
| 2024 | 1350 | 1241098 | 75513 | 449582 | 24817 | 182776 | 90280 | 70449 | 34828 | 15319 |
| 2025 | 1350 | 1239169 | 75395 | 451203 | 24808 | 182521 | 90154 | 70340 | 35753 | 15319 |

**Belize – Security First (3)**

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | | | | | | | | | | |
| 2000 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2001 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2002 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2003 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2004 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2005 | 1350 | 1264703 | 76949 | 427174 | 27637 | 188452 | 93083 | 71789 | 19558 | 15319 |
| 2006 | 1350 | 1261107 | 76730 | 430766 | 27645 | 188321 | 93019 | 71585 | 20171 | 15319 |
| 2007 | 1350 | 1257329 | 76500 | 434322 | 27650 | 188166 | 92942 | 71370 | 21066 | 15319 |
| 2008 | 1350 | 1253531 | 76269 | 437896 | 27654 | 188009 | 92865 | 71155 | 21965 | 15319 |
| 2009 | 1350 | 1249876 | 76047 | 441546 | 27663 | 187876 | 92799 | 70947 | 22589 | 15319 |
| 2010 | 1350 | 1246201 | 75823 | 445216 | 27671 | 187743 | 92733 | 70739 | 23217 | 15319 |
| 2011 | 1350 | 1245291 | 75768 | 447368 | 27195 | 186551 | 92144 | 70687 | 24340 | 15319 |
| 2012 | 1350 | 1244706 | 75732 | 449635 | 26726 | 185408 | 91580 | 70654 | 24903 | 15319 |
| 2013 | 1350 | 1244121 | 75697 | 451901 | 26257 | 184265 | 91015 | 70621 | 25466 | 15319 |
| 2014 | 1350 | 1243536 | 75661 | 454167 | 25788 | 183123 | 90451 | 70588 | 26029 | 15319 |
| 2015 | 1350 | 1242952 | 75626 | 456433 | 25319 | 181981 | 89887 | 70554 | 26591 | 15319 |
| 2016 | 1350 | 1239775 | 75432 | 459462 | 25142 | 182032 | 89913 | 70374 | 27214 | 15319 |
| 2017 | 1350 | 1236422 | 75228 | 462443 | 24960 | 182060 | 89926 | 70184 | 28120 | 15319 |
| 2018 | 1350 | 1233057 | 75023 | 465435 | 24778 | 182088 | 89940 | 69993 | 29029 | 15319 |
| 2019 | 1350 | 1228870 | 74769 | 468132 | 24579 | 181996 | 89895 | 69755 | 31347 | 15319 |
| 2020 | 1350 | 1225640 | 74572 | 471208 | 24399 | 182048 | 89920 | 69572 | 31984 | 15319 |
| 2021 | 1350 | 1221861 | 74342 | 476170 | 24339 | 181130 | 89467 | 69357 | 32677 | 15319 |
| 2022 | 1350 | 1217893 | 74101 | 481105 | 24275 | 180181 | 88998 | 69132 | 33659 | 15319 |
| 2023 | 1350 | 1213895 | 73858 | 486076 | 24211 | 179226 | 88526 | 68905 | 34647 | 15319 |
| 2024 | 1350 | 1209868 | 73613 | 491083 | 24147 | 178263 | 88051 | 68676 | 35643 | 15319 |
| 2025 | 1350 | 1205812 | 73366 | 496127 | 24082 | 177293 | 87572 | 68446 | 36646 | 15319 |

**Belize – Sustainability First (4)**

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| YEAR | | | | | | | | | | |
| 2000 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2001 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2002 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2003 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2004 | 1350 | 1268419 | 77175 | 423513 | 27481 | 188638 | 93175 | 72000 | 18944 | 15319 |
| 2005 | 1350 | 1265979 | 77027 | 423865 | 27964 | 189559 | 93630 | 71861 | 19460 | 15319 |
| 2006 | 1350 | 1265681 | 77008 | 423094 | 28313 | 189728 | 93714 | 71845 | 19961 | 15319 |
| 2007 | 1350 | 1265386 | 76990 | 422328 | 28661 | 189896 | 93797 | 71828 | 20458 | 15319 |
| 2008 | 1350 | 1265092 | 76973 | 421565 | 29007 | 190063 | 93879 | 71811 | 20954 | 15319 |
| 2009 | 1350 | 1264799 | 76955 | 420807 | 29351 | 190229 | 93961 | 71795 | 21446 | 15319 |
| 2010 | 1350 | 1264349 | 76927 | 420000 | 29689 | 190371 | 94031 | 71769 | 22207 | 15319 |
| 2011 | 1350 | 1263655 | 76885 | 420523 | 29394 | 189923 | 93810 | 71730 | 23424 | 15319 |
| 2012 | 1350 | 1263439 | 76872 | 421204 | 29110 | 189548 | 93625 | 71717 | 23827 | 15319 |
| 2013 | 1350 | 1263224 | 76859 | 421885 | 28827 | 189173 | 93440 | 71705 | 24230 | 15319 |
| 2014 | 1350 | 1263010 | 76846 | 422565 | 28544 | 188799 | 93255 | 71693 | 24633 | 15319 |
| 2015 | 1350 | 1262556 | 76818 | 423165 | 28255 | 188389 | 93052 | 71667 | 25441 | 15319 |
| 2016 | 1350 | 1263376 | 76868 | 421240 | 28605 | 188323 | 93020 | 71714 | 26198 | 15319 |
| 2017 | 1350 | 1264192 | 76918 | 419324 | 28954 | 188258 | 92988 | 71760 | 26951 | 15319 |
| 2018 | 1350 | 1265004 | 76967 | 417417 | 29300 | 188193 | 92956 | 71806 | 27700 | 15319 |
| 2019 | 1350 | 1265812 | 77016 | 415519 | 29645 | 188129 | 92924 | 71852 | 28446 | 15319 |
| 2020 | 1350 | 1266617 | 77065 | 413631 | 29989 | 188065 | 92892 | 71898 | 29188 | 15319 |
| 2021 | 1350 | 1265925 | 77023 | 413303 | 29968 | 188292 | 93004 | 71858 | 29970 | 15319 |
| 2022 | 1350 | 1265234 | 76981 | 412975 | 29947 | 188519 | 93117 | 71819 | 30751 | 15319 |
| 2023 | 1350 | 1264545 | 76939 | 412649 | 29926 | 188746 | 93229 | 71780 | 31530 | 15319 |
| 2024 | 1350 | 1263858 | 76897 | 412322 | 29905 | 188972 | 93340 | 71741 | 32307 | 15319 |
| 2025 | 1350 | 1263171 | 76856 | 411997 | 29884 | 189198 | 93452 | 71702 | 33083 | 15319 |

**Mexico – Markets First (1)**

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | | | | | | | | | | |
| 2000 | 25170 | 3176090 | 0 | 339800 | 1499060 | 6230 | 192100 | 231680 | 14540 | 55540 |
| 2001 | 25170 | 3164869 | 0 | 339063 | 1511370 | 6245 | 192561 | 230861 | 14531 | 55540 |
| 2002 | 25170 | 3153630 | 0 | 338325 | 1523649 | 6260 | 193019 | 230042 | 14576 | 55540 |
| 2003 | 25170 | 3142325 | 0 | 337578 | 1535875 | 6274 | 193471 | 229217 | 14759 | 55540 |
| 2004 | 25170 | 3131021 | 0 | 336831 | 1548078 | 6289 | 193923 | 228392 | 14966 | 55540 |
| 2005 | 25170 | 3119670 | 0 | 336078 | 1560235 | 6304 | 194370 | 227564 | 15279 | 55540 |
| 2006 | 25170 | 3119057 | 0 | 337553 | 1558890 | 6308 | 194515 | 227556 | 15621 | 55540 |
| 2007 | 25170 | 3118443 | 0 | 339036 | 1557542 | 6313 | 194662 | 227547 | 15957 | 55540 |
| 2008 | 25170 | 3117821 | 0 | 340525 | 1556187 | 6318 | 194809 | 227538 | 16302 | 55540 |
| 2009 | 25170 | 3117190 | 0 | 342021 | 1554826 | 6323 | 194956 | 227529 | 16656 | 55540 |
| 2010 | 25170 | 3116554 | 0 | 343524 | 1553460 | 6327 | 195103 | 227519 | 17012 | 55540 |
| 2011 | 25170 | 3112825 | 0 | 350335 | 1550771 | 6304 | 194392 | 227415 | 17458 | 55540 |
| 2012 | 25170 | 3109001 | 0 | 357280 | 1548046 | 6281 | 193671 | 227310 | 17910 | 55540 |
| 2013 | 25170 | 3105082 | 0 | 364362 | 1545286 | 6257 | 192941 | 227203 | 18369 | 55540 |
| 2014 | 25170 | 3101063 | 0 | 371585 | 1542490 | 6233 | 192201 | 227095 | 18833 | 55540 |
| 2015 | 25170 | 3096943 | 0 | 378952 | 1539656 | 6209 | 191452 | 226985 | 19304 | 55540 |
| 2016 | 25170 | 3091923 | 0 | 385853 | 1536920 | 6226 | 191984 | 226800 | 19794 | 55540 |
| 2017 | 25170 | 3086790 | 0 | 392901 | 1534145 | 6244 | 192524 | 226612 | 20284 | 55540 |
| 2018 | 25170 | 3081537 | 0 | 400097 | 1531329 | 6262 | 193073 | 226422 | 20781 | 55540 |
| 2019 | 25170 | 3076173 | 0 | 407450 | 1528477 | 6280 | 193630 | 226229 | 21261 | 55540 |
| 2020 | 25170 | 3070681 | 0 | 414961 | 1525581 | 6298 | 194197 | 226034 | 21749 | 55540 |
| 2021 | 25170 | 3059017 | 0 | 420449 | 1532633 | 6279 | 193606 | 225334 | 22181 | 55540 |
| 2022 | 25170 | 3047250 | 0 | 426018 | 1539762 | 6260 | 193013 | 224631 | 22567 | 55540 |
| 2023 | 25170 | 3035316 | 0 | 431653 | 1546938 | 6240 | 192411 | 223918 | 23024 | 55540 |
| 2024 | 25170 | 3023252 | 0 | 437366 | 1554181 | 6220 | 191804 | 223199 | 23477 | 55540 |
| 2025 | 25170 | 3011053 | 0 | 443157 | 1561490 | 6201 | 191192 | 222474 | 23934 | 55540 |

**Mexico – Policy First (2)**

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| YEAR | | | | | | | | | | |
| 2000 | 25170 | 3176090 | 0 | 339800 | 1499060 | 6230 | 192100 | 231680 | 14540 | 55540 |
| 2001 | 25170 | 3167551 | 0 | 338953 | 1509124 | 6229 | 192064 | 231057 | 14522 | 55540 |
| 2002 | 25170 | 3159003 | 0 | 338104 | 1519148 | 6228 | 192026 | 230434 | 14558 | 55540 |
| 2003 | 25170 | 3150392 | 0 | 337248 | 1529106 | 6226 | 191983 | 229805 | 14739 | 55540 |
| 2004 | 25170 | 3141793 | 0 | 336394 | 1539035 | 6225 | 191940 | 229178 | 14935 | 55540 |
| 2005 | 25170 | 3133155 | 0 | 335535 | 1548908 | 6223 | 191893 | 228548 | 15238 | 55540 |
| 2006 | 25170 | 3131327 | 0 | 336049 | 1550242 | 6217 | 191703 | 228415 | 15547 | 55540 |
| 2007 | 25170 | 3129491 | 0 | 336563 | 1551576 | 6211 | 191514 | 228281 | 15864 | 55540 |
| 2008 | 25170 | 3127658 | 0 | 337078 | 1552914 | 6205 | 191324 | 228147 | 16174 | 55540 |
| 2009 | 25170 | 3125819 | 0 | 337593 | 1554252 | 6199 | 191134 | 228013 | 16491 | 55540 |
| 2010 | 25170 | 3123972 | 0 | 338108 | 1555589 | 6192 | 190943 | 227878 | 16817 | 55540 |
| 2011 | 25170 | 3133761 | 0 | 341959 | 1540817 | 6192 | 190943 | 228592 | 17235 | 55540 |
| 2012 | 25170 | 3143673 | 0 | 345856 | 1525869 | 6192 | 190943 | 229315 | 17650 | 55540 |
| 2013 | 25170 | 3153700 | 0 | 349800 | 1510738 | 6192 | 190943 | 230047 | 18078 | 55540 |
| 2014 | 25170 | 3163855 | 0 | 353793 | 1495425 | 6192 | 190943 | 230787 | 18504 | 55540 |
| 2015 | 25170 | 3174133 | 0 | 357835 | 1479924 | 6192 | 190944 | 231537 | 18934 | 55540 |
| 2016 | 25170 | 3178436 | 0 | 359441 | 1472715 | 6212 | 191535 | 231851 | 19311 | 55540 |
| 2017 | 25170 | 3182770 | 0 | 361058 | 1465463 | 6231 | 192130 | 232167 | 19681 | 55540 |
| 2018 | 25170 | 3187131 | 0 | 362684 | 1458167 | 6250 | 192728 | 232485 | 20054 | 55540 |
| 2019 | 25170 | 3191528 | 0 | 364322 | 1450830 | 6270 | 193332 | 232806 | 20413 | 55540 |
| 2020 | 25170 | 3195952 | 0 | 365970 | 1443447 | 6290 | 193938 | 233129 | 20774 | 55540 |
| 2021 | 25170 | 3194102 | 0 | 367852 | 1443411 | 6283 | 193737 | 232994 | 21120 | 55540 |
| 2022 | 25170 | 3192243 | 0 | 369744 | 1443375 | 6277 | 193536 | 232858 | 21467 | 55540 |
| 2023 | 25170 | 3190378 | 0 | 371646 | 1443341 | 6270 | 193333 | 232722 | 21809 | 55540 |
| 2024 | 25170 | 3188499 | 0 | 373558 | 1443305 | 6263 | 193129 | 232585 | 22160 | 55540 |
| 2025 | 25170 | 3186614 | 0 | 375481 | 1443271 | 6257 | 192924 | 232448 | 22505 | 55540 |

**Mexico – Security First (3)**

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| YEAR | | | | | | | | | | |
| 2000 | 25170 | 3176090 | 0 | 339800 | 1499060 | 6230 | 192100 | 231680 | 14540 | 55540 |
| 2001 | 25170 | 3164761 | 0 | 342164 | 1508816 | 6229 | 192081 | 230854 | 14596 | 55540 |
| 2002 | 25170 | 3153312 | 0 | 344543 | 1518632 | 6229 | 192059 | 230018 | 14707 | 55540 |
| 2003 | 25170 | 3141689 | 0 | 346930 | 1528483 | 6228 | 192032 | 229171 | 14967 | 55540 |
| 2004 | 25170 | 3129968 | 0 | 349336 | 1538405 | 6227 | 192005 | 228316 | 15244 | 55540 |
| 2005 | 25170 | 3118097 | 0 | 351753 | 1548376 | 6226 | 191973 | 227450 | 15625 | 55540 |
| 2006 | 25170 | 3111864 | 0 | 354597 | 1551612 | 6233 | 192184 | 226995 | 16015 | 55540 |
| 2007 | 25170 | 3105581 | 0 | 357470 | 1554884 | 6240 | 192397 | 226537 | 16393 | 55540 |
| 2008 | 25170 | 3099238 | 0 | 360370 | 1558187 | 6247 | 192611 | 226074 | 16774 | 55540 |
| 2009 | 25170 | 3092834 | 0 | 363297 | 1561521 | 6254 | 192828 | 225607 | 17159 | 55540 |
| 2010 | 25170 | 3086373 | 0 | 366253 | 1564890 | 6261 | 193048 | 225136 | 17540 | 55540 |
| 2011 | 25170 | 3098032 | 0 | 370351 | 1547864 | 6261 | 193057 | 225986 | 17949 | 55540 |
| 2012 | 25170 | 3109842 | 0 | 374500 | 1530628 | 6261 | 193067 | 226848 | 18355 | 55540 |
| 2013 | 25170 | 3121800 | 0 | 378701 | 1513175 | 6262 | 193077 | 227720 | 18766 | 55540 |
| 2014 | 25170 | 3133909 | 0 | 382956 | 1495501 | 6262 | 193087 | 228603 | 19182 | 55540 |
| 2015 | 25170 | 3146173 | 0 | 387265 | 1477601 | 6262 | 193097 | 229498 | 19604 | 55540 |
| 2016 | 25170 | 3148485 | 0 | 390238 | 1471169 | 6281 | 193668 | 229666 | 19993 | 55540 |
| 2017 | 25170 | 3150829 | 0 | 393242 | 1464678 | 6300 | 194245 | 229837 | 20369 | 55540 |
| 2018 | 25170 | 3153197 | 0 | 396276 | 1458121 | 6318 | 194827 | 230010 | 20749 | 55540 |
| 2019 | 25170 | 3155594 | 0 | 399342 | 1451501 | 6338 | 195416 | 230185 | 21125 | 55540 |
| 2020 | 25170 | 3158020 | 0 | 402438 | 1444817 | 6357 | 196011 | 230362 | 21496 | 55540 |
| 2021 | 25170 | 3155586 | 0 | 406655 | 1443540 | 6335 | 195330 | 230184 | 21871 | 55540 |
| 2022 | 25170 | 3153125 | 0 | 410919 | 1442248 | 6312 | 194641 | 230005 | 22250 | 55540 |
| 2023 | 25170 | 3150642 | 0 | 415230 | 1440944 | 6290 | 193945 | 229824 | 22624 | 55540 |
| 2024 | 25170 | 3148132 | 0 | 419590 | 1439626 | 6267 | 193241 | 229641 | 23003 | 55540 |
| 2025 | 25170 | 3145598 | 0 | 423999 | 1438296 | 6244 | 192530 | 229456 | 23378 | 55540 |

**Mexico – Sustainability First (4)**

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| YEAR | | | | | | | | | | |
| 2000 | 25170 | 3176090 | 0 | 339800 | 1499060 | 6230 | 192100 | 231680 | 14540 | 55540 |
| 2001 | 25170 | 3156301 | 0 | 336268 | 1523463 | 6244 | 192518 | 230237 | 14469 | 55540 |
| 2002 | 25170 | 3136665 | 0 | 332766 | 1547610 | 6257 | 192930 | 228804 | 14468 | 55540 |
| 2003 | 25170 | 3117149 | 0 | 329291 | 1571489 | 6270 | 193333 | 227381 | 14588 | 55540 |
| 2004 | 25170 | 3097804 | 0 | 325847 | 1595128 | 6283 | 193732 | 225969 | 14737 | 55540 |
| 2005 | 25170 | 3078590 | 0 | 322431 | 1618511 | 6296 | 194123 | 224568 | 14982 | 55540 |
| 2006 | 25170 | 3067062 | 0 | 319307 | 1634197 | 6284 | 193758 | 223727 | 15164 | 55540 |
| 2007 | 25170 | 3055652 | 0 | 316217 | 1649715 | 6272 | 193397 | 222895 | 15353 | 55540 |
| 2008 | 25170 | 3044366 | 0 | 313159 | 1665072 | 6260 | 193040 | 222071 | 15532 | 55540 |
| 2009 | 25170 | 3033193 | 0 | 310132 | 1680267 | 6249 | 192687 | 221256 | 15716 | 55540 |
| 2010 | 25170 | 3022137 | 0 | 307138 | 1695303 | 6238 | 192337 | 220450 | 15898 | 55540 |
| 2011 | 25170 | 3030211 | 0 | 308811 | 1684418 | 6245 | 192565 | 221039 | 16211 | 55540 |
| 2012 | 25170 | 3038337 | 0 | 310496 | 1673469 | 6253 | 192795 | 221632 | 16518 | 55540 |
| 2013 | 25170 | 3046513 | 0 | 312191 | 1662453 | 6260 | 193027 | 222228 | 16828 | 55540 |
| 2014 | 25170 | 3054743 | 0 | 313896 | 1651373 | 6268 | 193260 | 222828 | 17131 | 55540 |
| 2015 | 25170 | 3063023 | 0 | 315612 | 1640226 | 6275 | 193495 | 223432 | 17437 | 55540 |
| 2016 | 25170 | 3053430 | 0 | 312442 | 1654360 | 6250 | 192709 | 222733 | 17577 | 55540 |
| 2017 | 25170 | 3043955 | 0 | 309310 | 1668329 | 6225 | 191932 | 222041 | 17708 | 55540 |
| 2018 | 25170 | 3034595 | 0 | 306216 | 1682135 | 6200 | 191165 | 221359 | 17830 | 55540 |
| 2019 | 25170 | 3025346 | 0 | 303158 | 1695779 | 6175 | 190407 | 220684 | 17951 | 55540 |
| 2020 | 25170 | 3016213 | 0 | 300136 | 1709268 | 6151 | 189658 | 220018 | 18056 | 55540 |
| 2021 | 25170 | 3016022 | 0 | 299869 | 1709171 | 6162 | 190010 | 220004 | 18262 | 55540 |
| 2022 | 25170 | 3015836 | 0 | 299603 | 1709076 | 6174 | 190361 | 219990 | 18460 | 55540 |
| 2023 | 25170 | 3015654 | 0 | 299337 | 1708983 | 6185 | 190713 | 219977 | 18652 | 55540 |
| 2024 | 25170 | 3015475 | 0 | 299071 | 1708893 | 6196 | 191065 | 219964 | 18836 | 55540 |
| 2025 | 25170 | 3015301 | 0 | 298806 | 1708804 | 6208 | 191416 | 219951 | 19013 | 55540 |

**Guatemala – Markets First (1)**

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | | | | | | | | | | |
| 2000 | 825 | 1732256 | 84038 | 1050588 | 429225 | 31 | 1344 | 75 | 11831 | 79219 |
| 2001 | 825 | 1727615 | 83812 | 1051491 | 433175 | 31 | 1348 | 75 | 11840 | 79219 |
| 2002 | 825 | 1722851 | 83581 | 1052325 | 437101 | 31 | 1353 | 75 | 12070 | 79219 |
| 2003 | 825 | 1718051 | 83348 | 1053143 | 441025 | 32 | 1357 | 74 | 12356 | 79219 |
| 2004 | 825 | 1713246 | 83115 | 1053962 | 444954 | 32 | 1362 | 74 | 12642 | 79219 |
| 2005 | 825 | 1708377 | 82879 | 1054746 | 448873 | 32 | 1366 | 74 | 13040 | 79219 |
| 2006 | 825 | 1705308 | 82730 | 1058393 | 447985 | 32 | 1366 | 74 | 13500 | 79219 |
| 2007 | 825 | 1702261 | 82582 | 1062066 | 447103 | 32 | 1365 | 74 | 13906 | 79219 |
| 2008 | 825 | 1699178 | 82433 | 1065728 | 446210 | 32 | 1365 | 74 | 14368 | 79219 |
| 2009 | 825 | 1696061 | 82282 | 1069381 | 445309 | 32 | 1364 | 73 | 14886 | 79219 |
| 2010 | 825 | 1692936 | 82130 | 1073041 | 444406 | 32 | 1364 | 73 | 15406 | 79219 |
| 2011 | 825 | 1683917 | 81692 | 1084489 | 441814 | 31 | 1353 | 73 | 16018 | 79219 |
| 2012 | 825 | 1674867 | 81253 | 1096030 | 439213 | 31 | 1342 | 73 | 16578 | 79219 |
| 2013 | 825 | 1665701 | 80809 | 1107609 | 436581 | 31 | 1332 | 72 | 17254 | 79219 |
| 2014 | 825 | 1656504 | 80363 | 1119282 | 433938 | 31 | 1321 | 72 | 17877 | 79219 |
| 2015 | 825 | 1647219 | 79912 | 1131012 | 431271 | 30 | 1310 | 71 | 18562 | 79219 |
| 2016 | 825 | 1638214 | 79475 | 1141983 | 429025 | 30 | 1309 | 71 | 19281 | 79219 |
| 2017 | 825 | 1629121 | 79034 | 1153060 | 426757 | 30 | 1308 | 71 | 20006 | 79219 |
| 2018 | 825 | 1619912 | 78587 | 1164224 | 424459 | 30 | 1307 | 70 | 20797 | 79219 |
| 2019 | 825 | 1610614 | 78136 | 1175497 | 422139 | 30 | 1306 | 70 | 21594 | 79219 |
| 2020 | 825 | 1601224 | 77681 | 1186881 | 419797 | 30 | 1305 | 69 | 22400 | 79219 |
| 2021 | 825 | 1591320 | 77200 | 1195258 | 420970 | 30 | 1299 | 69 | 23241 | 79219 |
| 2022 | 825 | 1581344 | 76716 | 1203695 | 422152 | 30 | 1293 | 68 | 24089 | 79219 |
| 2023 | 825 | 1571269 | 76227 | 1212171 | 423335 | 30 | 1286 | 68 | 25000 | 79219 |
| 2024 | 825 | 1561149 | 75737 | 1220731 | 424534 | 30 | 1280 | 68 | 25860 | 79219 |
| 2025 | 825 | 1550927 | 75241 | 1229330 | 425734 | 30 | 1273 | 67 | 26785 | 79219 |

## Guatemala – Policy First (2)

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | | | | | | | | | | |
| 2000 | 825 | 1732256 | 84038 | 1050588 | 429225 | 31 | 1344 | 75 | 11831 | 79219 |
| 2001 | 825 | 1728690 | 83864 | 1051060 | 432491 | 31 | 1345 | 75 | 11831 | 79219 |
| 2002 | 825 | 1725007 | 83686 | 1051462 | 435728 | 31 | 1346 | 75 | 12052 | 79219 |
| 2003 | 825 | 1721296 | 83506 | 1051847 | 438958 | 31 | 1346 | 75 | 12329 | 79219 |
| 2004 | 825 | 1717586 | 83326 | 1052231 | 442186 | 31 | 1347 | 74 | 12605 | 79219 |
| 2005 | 825 | 1713848 | 83144 | 1052597 | 445407 | 31 | 1348 | 74 | 12937 | 79219 |
| 2006 | 825 | 1710972 | 83005 | 1055067 | 445505 | 31 | 1346 | 74 | 13387 | 79219 |
| 2007 | 825 | 1708094 | 82865 | 1057538 | 445604 | 31 | 1344 | 74 | 13838 | 79219 |
| 2008 | 825 | 1705213 | 82726 | 1060012 | 445703 | 31 | 1342 | 74 | 14288 | 79219 |
| 2009 | 825 | 1702329 | 82586 | 1062487 | 445801 | 31 | 1339 | 74 | 14740 | 79219 |
| 2010 | 825 | 1699443 | 82446 | 1064965 | 445900 | 31 | 1337 | 74 | 15191 | 79219 |
| 2011 | 825 | 1696717 | 82313 | 1073311 | 439878 | 31 | 1332 | 73 | 15732 | 79219 |
| 2012 | 825 | 1694006 | 82182 | 1081718 | 433831 | 31 | 1326 | 73 | 16219 | 79219 |
| 2013 | 825 | 1691253 | 82048 | 1090149 | 427747 | 31 | 1321 | 73 | 16765 | 79219 |
| 2014 | 825 | 1688485 | 81914 | 1098624 | 421632 | 31 | 1315 | 73 | 17314 | 79219 |
| 2015 | 825 | 1685675 | 81778 | 1107122 | 415478 | 30 | 1310 | 73 | 17922 | 79219 |
| 2016 | 825 | 1683253 | 81660 | 1111849 | 412744 | 30 | 1311 | 73 | 18467 | 79219 |
| 2017 | 825 | 1680793 | 81541 | 1116575 | 409992 | 31 | 1313 | 73 | 19070 | 79219 |
| 2018 | 825 | 1678323 | 81421 | 1121320 | 407230 | 31 | 1315 | 73 | 19676 | 79219 |
| 2019 | 825 | 1675842 | 81301 | 1126085 | 404455 | 31 | 1317 | 73 | 20284 | 79219 |
| 2020 | 825 | 1673323 | 81178 | 1130850 | 401663 | 31 | 1318 | 72 | 20952 | 79219 |
| 2021 | 825 | 1668245 | 80932 | 1136153 | 401073 | 31 | 1315 | 72 | 21566 | 79219 |
| 2022 | 825 | 1663146 | 80685 | 1141478 | 400481 | 31 | 1312 | 72 | 22183 | 79219 |
| 2023 | 825 | 1657998 | 80435 | 1146806 | 399879 | 30 | 1309 | 72 | 22859 | 79219 |
| 2024 | 825 | 1652827 | 80184 | 1152156 | 399275 | 30 | 1305 | 72 | 23538 | 79219 |
| 2025 | 825 | 1647635 | 79932 | 1157528 | 398668 | 30 | 1302 | 71 | 24220 | 79219 |

**Guatemala – Security First (3)**

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | | | | | | | | | | |
| 2000 | 825 | 1732256 | 84038 | 1050588 | 429225 | 31 | 1344 | 75 | 11831 | 79219 |
| 2001 | 825 | 1723440 | 83610 | 1057614 | 431413 | 31 | 1342 | 75 | 11864 | 79219 |
| 2002 | 825 | 1714458 | 83174 | 1064607 | 433583 | 31 | 1340 | 74 | 12120 | 79219 |
| 2003 | 825 | 1705399 | 82735 | 1071621 | 435758 | 31 | 1337 | 74 | 12433 | 79219 |
| 2004 | 825 | 1696290 | 82293 | 1078673 | 437945 | 31 | 1335 | 73 | 12748 | 79219 |
| 2005 | 825 | 1687074 | 81846 | 1085726 | 440129 | 31 | 1333 | 73 | 13176 | 79219 |
| 2006 | 825 | 1679359 | 81471 | 1093292 | 440161 | 31 | 1332 | 73 | 13669 | 79219 |
| 2007 | 825 | 1671596 | 81095 | 1100905 | 440193 | 31 | 1331 | 72 | 14165 | 79219 |
| 2008 | 825 | 1663813 | 80717 | 1108584 | 440233 | 31 | 1329 | 72 | 14608 | 79219 |
| 2009 | 825 | 1655923 | 80334 | 1116275 | 440258 | 31 | 1328 | 72 | 15167 | 79219 |
| 2010 | 825 | 1648012 | 79951 | 1124033 | 440291 | 31 | 1327 | 71 | 15673 | 79219 |
| 2011 | 825 | 1646196 | 79862 | 1132191 | 433491 | 31 | 1321 | 71 | 16224 | 79219 |
| 2012 | 825 | 1644373 | 79774 | 1140387 | 426660 | 31 | 1315 | 71 | 16778 | 79219 |
| 2013 | 825 | 1642541 | 79685 | 1148619 | 419799 | 30 | 1309 | 71 | 17334 | 79219 |
| 2014 | 825 | 1640701 | 79596 | 1156889 | 412906 | 30 | 1302 | 71 | 17892 | 79219 |
| 2015 | 825 | 1638824 | 79505 | 1165175 | 405976 | 30 | 1296 | 71 | 18511 | 79219 |
| 2016 | 825 | 1634743 | 79307 | 1171696 | 403096 | 30 | 1296 | 71 | 19148 | 79219 |
| 2017 | 825 | 1630637 | 79108 | 1178257 | 400199 | 30 | 1297 | 71 | 19790 | 79219 |
| 2018 | 825 | 1626505 | 78907 | 1184858 | 397284 | 30 | 1297 | 70 | 20435 | 79219 |
| 2019 | 825 | 1622319 | 78704 | 1191480 | 394344 | 30 | 1297 | 70 | 21143 | 79219 |
| 2020 | 825 | 1618107 | 78500 | 1198143 | 391385 | 30 | 1297 | 70 | 21855 | 79219 |
| 2021 | 825 | 1610703 | 78141 | 1206793 | 389790 | 30 | 1289 | 70 | 22573 | 79219 |
| 2022 | 825 | 1603222 | 77778 | 1215477 | 388177 | 30 | 1280 | 69 | 23355 | 79219 |
| 2023 | 825 | 1595693 | 77412 | 1224216 | 386554 | 30 | 1271 | 69 | 24142 | 79219 |
| 2024 | 825 | 1588116 | 77045 | 1233012 | 384921 | 29 | 1262 | 69 | 24933 | 79219 |
| 2025 | 825 | 1580490 | 76675 | 1241865 | 383277 | 29 | 1253 | 68 | 25730 | 79219 |

## Guatamala – Sustainability First (4)

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | | | | | | | | | | |
| 2000 | 825 | 1732256 | 84038 | 1050588 | 429225 | 31 | 1344 | 75 | 11831 | 79219 |
| 2001 | 825 | 1727351 | 83800 | 1047148 | 437810 | 31 | 1352 | 75 | 11821 | 79219 |
| 2002 | 825 | 1722339 | 83556 | 1043644 | 446351 | 32 | 1359 | 75 | 12032 | 79219 |
| 2003 | 825 | 1717308 | 83312 | 1040129 | 454868 | 32 | 1367 | 74 | 12297 | 79219 |
| 2004 | 825 | 1712286 | 83069 | 1036621 | 463369 | 32 | 1375 | 74 | 12562 | 79219 |
| 2005 | 825 | 1707245 | 82824 | 1033102 | 471846 | 32 | 1383 | 74 | 12882 | 79219 |
| 2006 | 825 | 1705087 | 82719 | 1028997 | 477795 | 32 | 1384 | 74 | 13298 | 79219 |
| 2007 | 825 | 1702967 | 82617 | 1024926 | 483729 | 32 | 1385 | 74 | 13658 | 79219 |
| 2008 | 825 | 1700826 | 82513 | 1020853 | 489633 | 32 | 1387 | 74 | 14071 | 79219 |
| 2009 | 825 | 1698693 | 82409 | 1016796 | 495513 | 32 | 1388 | 74 | 14482 | 79219 |
| 2010 | 825 | 1696569 | 82306 | 1012755 | 501370 | 32 | 1390 | 73 | 14892 | 79219 |
| 2011 | 825 | 1696163 | 82286 | 1017167 | 496929 | 32 | 1388 | 73 | 15349 | 79219 |
| 2012 | 825 | 1695755 | 82267 | 1021590 | 492477 | 32 | 1386 | 73 | 15807 | 79219 |
| 2013 | 825 | 1695318 | 82245 | 1026007 | 488006 | 32 | 1384 | 73 | 16321 | 79219 |
| 2014 | 825 | 1694908 | 82226 | 1030452 | 483532 | 32 | 1382 | 73 | 16782 | 79219 |
| 2015 | 825 | 1694468 | 82204 | 1034891 | 479039 | 32 | 1381 | 73 | 17298 | 79219 |
| 2016 | 825 | 1693259 | 82146 | 1030031 | 484714 | 32 | 1379 | 73 | 17754 | 79219 |
| 2017 | 825 | 1692082 | 82089 | 1025210 | 490371 | 32 | 1378 | 73 | 18153 | 79219 |
| 2018 | 825 | 1690883 | 82030 | 1020393 | 495994 | 32 | 1377 | 73 | 18604 | 79219 |
| 2019 | 825 | 1689661 | 81971 | 1015582 | 501584 | 32 | 1376 | 73 | 19108 | 79219 |
| 2020 | 825 | 1688473 | 81913 | 1010809 | 507157 | 32 | 1375 | 73 | 19555 | 79219 |
| 2021 | 825 | 1687962 | 81889 | 1010764 | 507229 | 32 | 1378 | 73 | 20061 | 79219 |
| 2022 | 825 | 1687422 | 81862 | 1010703 | 507292 | 32 | 1380 | 73 | 20622 | 79219 |
| 2023 | 825 | 1686910 | 81838 | 1010658 | 507364 | 32 | 1383 | 73 | 21129 | 79219 |
| 2024 | 825 | 1686396 | 81813 | 1010613 | 507436 | 32 | 1386 | 73 | 21638 | 79219 |
| 2025 | 825 | 1685854 | 81786 | 1010552 | 507500 | 32 | 1389 | 73 | 22201 | 79219 |

**Honduras – Markets First (1)**

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | | | | | | | | | | |
| 2000 | 23288 | 2055531 | 1219894 | 4372044 | 15156 | 111469 | 47213 | 8269 | 13050 | 58481 |
| 2001 | 23288 | 2059250 | 1222101 | 4365121 | 15320 | 112025 | 47448 | 8284 | 13076 | 58481 |
| 2002 | 23288 | 2062933 | 1224286 | 4358064 | 15484 | 112581 | 47684 | 8299 | 13295 | 58481 |
| 2003 | 23288 | 2066580 | 1226451 | 4350871 | 15649 | 113136 | 47919 | 8313 | 13707 | 58481 |
| 2004 | 23288 | 2070241 | 1228623 | 4343650 | 15814 | 113693 | 48155 | 8328 | 14120 | 58481 |
| 2005 | 23287 | 2073916 | 1230805 | 4336401 | 15980 | 114253 | 48392 | 8343 | 14536 | 58481 |
| 2006 | 23288 | 2072257 | 1229820 | 4338736 | 15933 | 114102 | 48328 | 8336 | 15113 | 58481 |
| 2007 | 23288 | 2070651 | 1228867 | 4341178 | 15887 | 113953 | 48265 | 8330 | 15496 | 58481 |
| 2008 | 23287 | 2068994 | 1227883 | 4343510 | 15840 | 113802 | 48201 | 8323 | 16072 | 58481 |
| 2009 | 23288 | 2067338 | 1226900 | 4345841 | 15793 | 113651 | 48137 | 8316 | 16648 | 58481 |
| 2010 | 23287 | 2065683 | 1225918 | 4348171 | 15746 | 113500 | 48073 | 8310 | 17224 | 58481 |
| 2011 | 23288 | 2048100 | 1215484 | 4377905 | 15595 | 112195 | 47520 | 8239 | 17586 | 58481 |
| 2012 | 23288 | 2030467 | 1205019 | 4407339 | 15444 | 110888 | 46967 | 8168 | 18333 | 58481 |
| 2013 | 23287 | 2012934 | 1194614 | 4436798 | 15293 | 109588 | 46416 | 8097 | 18885 | 58481 |
| 2014 | 23287 | 1995450 | 1184238 | 4466174 | 15143 | 108291 | 45867 | 8027 | 19436 | 58481 |
| 2015 | 23287 | 1978016 | 1173891 | 4495466 | 14993 | 106998 | 45319 | 7957 | 19985 | 58481 |
| 2016 | 23287 | 1957775 | 1161878 | 4527918 | 14852 | 106477 | 45098 | 7876 | 20751 | 58481 |
| 2017 | 23287 | 1937585 | 1149896 | 4560475 | 14712 | 105958 | 44879 | 7794 | 21326 | 58481 |
| 2018 | 23288 | 1917352 | 1137889 | 4592913 | 14571 | 105437 | 44658 | 7713 | 22092 | 58481 |
| 2019 | 23288 | 1897169 | 1125911 | 4625458 | 14431 | 104919 | 44438 | 7632 | 22667 | 58481 |
| 2020 | 23288 | 1876944 | 1113908 | 4657884 | 14290 | 104399 | 44218 | 7550 | 23433 | 58481 |
| 2021 | 23288 | 1857687 | 1102480 | 4689035 | 14288 | 103589 | 43875 | 7473 | 24199 | 58481 |
| 2022 | 23287 | 1838434 | 1091053 | 4720180 | 14286 | 102779 | 43532 | 7395 | 24965 | 58481 |
| 2023 | 23288 | 1819184 | 1079629 | 4751319 | 14284 | 101970 | 43189 | 7318 | 25731 | 58481 |
| 2024 | 23287 | 1799938 | 1068207 | 4782453 | 14282 | 101161 | 42847 | 7241 | 26496 | 58481 |
| 2025 | 23287 | 1780651 | 1056761 | 4813464 | 14280 | 100349 | 42503 | 7163 | 27453 | 58481 |

## Honduras – Policy First (2)

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | | | | | | | | | | |
| 2000 | 23288 | 2055531 | 1219894 | 4372044 | 15156 | 111469 | 47213 | 8269 | 13050 | 58481 |
| 2001 | 23287 | 2060471 | 1222825 | 4363631 | 15296 | 111725 | 47321 | 8289 | 13066 | 58481 |
| 2002 | 23287 | 2065373 | 1225734 | 4355090 | 15436 | 111980 | 47429 | 8308 | 13275 | 58481 |
| 2003 | 23288 | 2070235 | 1228620 | 4346421 | 15575 | 112232 | 47536 | 8328 | 13677 | 58481 |
| 2004 | 23288 | 2075110 | 1231513 | 4337731 | 15715 | 112485 | 47643 | 8348 | 14079 | 58481 |
| 2005 | 23288 | 2079997 | 1234413 | 4329020 | 15856 | 112739 | 47751 | 8367 | 14482 | 58481 |
| 2006 | 23288 | 2079798 | 1234295 | 4329061 | 15855 | 112528 | 47661 | 8366 | 15058 | 58481 |
| 2007 | 23288 | 2079651 | 1234208 | 4329209 | 15855 | 112320 | 47573 | 8366 | 15442 | 58481 |
| 2008 | 23287 | 2079453 | 1234090 | 4329251 | 15855 | 112110 | 47484 | 8365 | 16017 | 58481 |
| 2009 | 23287 | 2079305 | 1234003 | 4329399 | 15855 | 111902 | 47396 | 8364 | 16400 | 58481 |
| 2010 | 23288 | 2079107 | 1233885 | 4329440 | 15855 | 111692 | 47307 | 8364 | 16975 | 58481 |
| 2011 | 23288 | 2069837 | 1228384 | 4345162 | 15586 | 110852 | 46951 | 8326 | 17527 | 58481 |
| 2012 | 23288 | 2060596 | 1222900 | 4360835 | 15318 | 110014 | 46596 | 8289 | 18076 | 58481 |
| 2013 | 23287 | 2051434 | 1217462 | 4376567 | 15052 | 109181 | 46244 | 8252 | 18433 | 58481 |
| 2014 | 23287 | 2042249 | 1212011 | 4392144 | 14785 | 108349 | 45891 | 8215 | 18980 | 58481 |
| 2015 | 23288 | 2033093 | 1206578 | 4407673 | 14520 | 107518 | 45539 | 8178 | 19525 | 58481 |
| 2016 | 23288 | 2025100 | 1201834 | 4420186 | 14389 | 107402 | 45490 | 8146 | 20078 | 58481 |
| 2017 | 23288 | 2017124 | 1197100 | 4432672 | 14258 | 107285 | 45441 | 8114 | 20631 | 58481 |
| 2018 | 23288 | 2009115 | 1192347 | 4445025 | 14128 | 107166 | 45390 | 8082 | 21372 | 58481 |
| 2019 | 23287 | 2001171 | 1187633 | 4457460 | 13997 | 107050 | 45341 | 8050 | 21922 | 58481 |
| 2020 | 23288 | 1993244 | 1182928 | 4469870 | 13868 | 106934 | 45292 | 8018 | 22471 | 58481 |
| 2021 | 23288 | 1981527 | 1175974 | 4488621 | 13816 | 106427 | 45077 | 7971 | 23212 | 58481 |
| 2022 | 23288 | 1969879 | 1169062 | 4507447 | 13764 | 105923 | 44864 | 7924 | 23761 | 58481 |
| 2023 | 23288 | 1958252 | 1162162 | 4526240 | 13713 | 105420 | 44651 | 7877 | 24310 | 58481 |
| 2024 | 23287 | 1946599 | 1155246 | 4544890 | 13661 | 104915 | 44437 | 7831 | 25047 | 58481 |
| 2025 | 23287 | 1935013 | 1148370 | 4563615 | 13610 | 104414 | 44225 | 7784 | 25594 | 58481 |

**Honduras – Security First (3)**

| LUC | 0<br>Unknown | 1<br>B.L. forest | 2<br>Pine for. | 3<br>Agr/Past | 4<br>Scrub | 5<br>Savanna | 6<br>Wetland | 7<br>Mangroves | 8<br>Urban | 9<br>Water |
|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | | | | | | | | | | |
| 2000 | 23288 | 2055531 | 1219894 | 4372044 | 15156 | 111469 | 47213 | 8269 | 13050 | 58481 |
| 2001 | 23288 | 2050113 | 1216678 | 4380899 | 15228 | 111259 | 47124 | 8247 | 13077 | 58481 |
| 2002 | 23288 | 2044621 | 1213419 | 4389684 | 15299 | 111046 | 47034 | 8225 | 13297 | 58481 |
| 2003 | 23288 | 2039057 | 1210117 | 4398397 | 15371 | 110830 | 46942 | 8202 | 13711 | 58481 |
| 2004 | 23288 | 2033469 | 1206801 | 4407145 | 15442 | 110612 | 46850 | 8180 | 14126 | 58481 |
| 2005 | 23288 | 2027859 | 1203471 | 4415930 | 15514 | 110394 | 46757 | 8157 | 14543 | 58481 |
| 2006 | 23288 | 2019251 | 1198363 | 4429521 | 15489 | 110104 | 46635 | 8123 | 15140 | 58481 |
| 2007 | 23288 | 2010676 | 1193273 | 4443249 | 15464 | 109817 | 46513 | 8088 | 15544 | 58481 |
| 2008 | 23288 | 2002033 | 1188144 | 4456896 | 15438 | 109526 | 46390 | 8054 | 16144 | 58481 |
| 2009 | 23287 | 1993422 | 1183034 | 4470681 | 15413 | 109238 | 46268 | 8019 | 16550 | 58481 |
| 2010 | 23287 | 1984744 | 1177884 | 4484384 | 15388 | 108946 | 46144 | 7984 | 17151 | 58481 |
| 2011 | 23288 | 1977435 | 1173546 | 4497318 | 15091 | 108024 | 45754 | 7955 | 17502 | 58481 |
| 2012 | 23288 | 1970111 | 1169200 | 4510082 | 14795 | 107105 | 45364 | 7925 | 18044 | 58481 |
| 2013 | 23287 | 1962868 | 1164901 | 4522899 | 14501 | 106192 | 44977 | 7896 | 18391 | 58481 |
| 2014 | 23288 | 1955610 | 1160593 | 4535548 | 14208 | 105280 | 44591 | 7867 | 18929 | 58481 |
| 2015 | 23288 | 1948384 | 1156305 | 4548139 | 13916 | 104372 | 44207 | 7838 | 19464 | 58481 |
| 2016 | 23288 | 1937390 | 1149781 | 4565638 | 13780 | 104112 | 44097 | 7794 | 20033 | 58481 |
| 2017 | 23288 | 1926453 | 1143290 | 4583234 | 13645 | 103855 | 43988 | 7750 | 20411 | 58481 |
| 2018 | 23287 | 1915478 | 1136776 | 4600703 | 13509 | 103596 | 43878 | 7705 | 20979 | 58481 |
| 2019 | 23288 | 1904512 | 1130268 | 4618158 | 13374 | 103336 | 43768 | 7661 | 21548 | 58481 |
| 2020 | 23288 | 1893509 | 1123738 | 4635484 | 13238 | 103075 | 43657 | 7617 | 22307 | 58481 |
| 2021 | 23288 | 1877794 | 1114412 | 4661557 | 13143 | 102066 | 43230 | 7554 | 22869 | 58481 |
| 2022 | 23287 | 1862101 | 1105099 | 4687596 | 13047 | 101058 | 42803 | 7491 | 23429 | 58481 |
| 2023 | 23288 | 1846383 | 1095771 | 4713485 | 12952 | 100050 | 42376 | 7427 | 24181 | 58481 |
| 2024 | 23288 | 1830732 | 1086482 | 4739454 | 12857 | 99045 | 41950 | 7364 | 24740 | 58481 |
| 2025 | 23287 | 1815058 | 1077180 | 4765271 | 12761 | 98039 | 41524 | 7301 | 25489 | 58481 |

## Honduras – Sustainability First (4)

| LUC | 0 Unknown | 1 B.L. forest | 2 Pine for. | 3 Agr/Past | 4 Scrub | 5 Savanna | 6 Wetland | 7 Mangroves | 8 Urban | 9 Water |
|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | | | | | | | | | | |
| 2000 | 23288 | 2055531 | 1219894 | 4372044 | 15156 | 111469 | 47213 | 8269 | 13050 | 58481 |
| 2001 | 23288 | 2063188 | 1224438 | 4357898 | 15517 | 112537 | 47665 | 8300 | 13083 | 58481 |
| 2002 | 23288 | 2070832 | 1228974 | 4343575 | 15879 | 113608 | 48118 | 8330 | 13308 | 58481 |
| 2003 | 23287 | 2078463 | 1233503 | 4329074 | 16242 | 114681 | 48573 | 8361 | 13728 | 58481 |
| 2004 | 23288 | 2086132 | 1238055 | 4314501 | 16607 | 115759 | 49030 | 8392 | 14149 | 58481 |
| 2005 | 23288 | 2093839 | 1242628 | 4299855 | 16974 | 116843 | 49489 | 8423 | 14573 | 58481 |
| 2006 | 23288 | 2100999 | 1246877 | 4286923 | 17237 | 117294 | 49680 | 8452 | 15163 | 58481 |
| 2007 | 23287 | 2108217 | 1251161 | 4274086 | 17501 | 117749 | 49872 | 8481 | 15559 | 58481 |
| 2008 | 23288 | 2115389 | 1255417 | 4261130 | 17764 | 118201 | 50064 | 8510 | 16150 | 58481 |
| 2009 | 23288 | 2122620 | 1259709 | 4248268 | 18029 | 118656 | 50257 | 8539 | 16547 | 58481 |
| 2010 | 23288 | 2129806 | 1263973 | 4235289 | 18293 | 119109 | 50449 | 8568 | 17138 | 58481 |
| 2011 | 23287 | 2126064 | 1261753 | 4241690 | 18091 | 118699 | 50275 | 8552 | 17501 | 58481 |
| 2012 | 23287 | 2122281 | 1259507 | 4247966 | 17890 | 118287 | 50100 | 8537 | 18056 | 58481 |
| 2013 | 23288 | 2118562 | 1257300 | 4254328 | 17690 | 117880 | 49928 | 8522 | 18416 | 58481 |
| 2014 | 23288 | 2114802 | 1255069 | 4260564 | 17490 | 117470 | 49754 | 8507 | 18968 | 58481 |
| 2015 | 23287 | 2111054 | 1252845 | 4266782 | 17290 | 117062 | 49582 | 8492 | 19518 | 58481 |
| 2016 | 23288 | 2114174 | 1254696 | 4260809 | 17530 | 117192 | 49637 | 8505 | 20083 | 58481 |
| 2017 | 23288 | 2117290 | 1256545 | 4254844 | 17769 | 117321 | 49691 | 8517 | 20647 | 58481 |
| 2018 | 23288 | 2120453 | 1258423 | 4248992 | 18008 | 117453 | 49747 | 8530 | 21019 | 58481 |
| 2019 | 23288 | 2123560 | 1260266 | 4243045 | 18246 | 117582 | 49802 | 8542 | 21582 | 58481 |
| 2020 | 23288 | 2126662 | 1262107 | 4237106 | 18484 | 117711 | 49856 | 8555 | 22144 | 58481 |
| 2021 | 23287 | 2123524 | 1260245 | 4241333 | 18474 | 117872 | 49925 | 8542 | 22709 | 58481 |
| 2022 | 23288 | 2120390 | 1258385 | 4245555 | 18464 | 118034 | 49993 | 8530 | 23274 | 58481 |
| 2023 | 23288 | 2117259 | 1256527 | 4249773 | 18455 | 118195 | 50061 | 8517 | 23838 | 58481 |
| 2024 | 23288 | 2114132 | 1254671 | 4253986 | 18445 | 118356 | 50129 | 8504 | 24402 | 58481 |
| 2025 | 23288 | 2111007 | 1252817 | 4258194 | 18435 | 118517 | 50198 | 8492 | 24965 | 58481 |

**Appendix 6. CLUE-S Training Package (Exercises)**

# ICRAN-MAR Watershed Management Workshop

## Training Course
## *"Land cover change modelling using the CLUE-S model"*

## Friday 18 August


**Dr. Joep Luijten**

**Consultant to the UNEP World Conservation Monitoring Centre**

# Land cover change modeling using the CLUE-S model

## Friday 18 August
## Training schedule (revised)

09:00 Introduction to land use change modelling and the CLUE-S model

- Different types of land use change models
- History and applications of CLUE-S in the world
- CLUE-S model structure and key input files
- Separate regression analysis of driving factors in SPSS

10:00 Introduction to case study area (Sibuyan island, Philippines)

10:15 Break

10:30 Practical CLUE-S

- System requirements and installation. Demo *vs* full version
- Exercise 1: Learning to know the user-interface and displaying results.
- Overview of input data files and model parameters files
- Exercise 2: Parameter files and simulating alternative scenarios

12:00 Lunch

13:00 Practical CLUE-S (continued)

- Regression equation parameters files and probability surfaces
- Land use conversion matrix and conversion sequences
- Creating land use requirement (demand) files
- Spatial policies and area restriction files
- Conversion elasticities and crop rotations
- Exercise 3: Creating new area restriction and land requirement files

14:30 Background on the MAR land use change scenario simulations, and CLUE-S data sets for Belize, Guatemala, Mexico and Honduras

- Separate data and simulation per country
- Calculation of the land demand for different scenarios
- Dynamic and static driving factors; protected areas data

14:45 Break

15:00 MAR simulations, continued

- Regression equations and probability surfaces
- Exercise 4: Working with actual scenario data for Belize

16:30 End

## More information about CLUE-S model

http://www.cluemodel.nl/

## Software used

For the training we will use the latest version of CLUE-S, also named Dyna-CLUE. This version was released in February 2006 is a further development of v2.4
For visualization we use ArcGIS 9.1 with Spatial Analyst extension (ArcView 3 with the Spatial Analyst extension can also be used in combination with CLUE-S).

## Further reading

Below is a list of selected further reading related to the land use change modeling, technical documentation of CLUE-S and its applications, and the development and application of scenarios. All papers are included in PDF format on the data CD. The technical report that describes the MAR scenarios and land use modeling in detail is:

> **Luijten, J., L. Miles and E. Cherrington, 2006. Land use change modeling for scenarios for the MAR region. Technical report. ICRAN-MAR Project, UNEP-WCMC.**


Land use change modelling (in general)

- Verburg, P.H., P.P. Schot, M.J. Dijst and A. Veldkamp, 2004. Land use change modelling: current practice and research priorities. GeoJournal 61: 309-324.
- Parker, D.C., S.M. Manson, M.A. Jansen, M.J. Hoffman and P. Deadman, 2003. Multi-agent systems for the simulation of land-use and land-cover change: A review. Annuals of the Association of American Geographers 93(2): 413-337.
- Verburg, P.H. and A. Veldkamp, 2005. Introduction to the Special Issue on spatial modelling to explore land use dynamics. Intl. J. of Geog. Info. Science 19(2) 99-102.
- Briassoulis, H, 2004. Analysis of Land Use Change: Theoretical and Modeling Approaches. In: The Web Book of regional Science.

Land use change modelling in Central America

- Farrow, A., M. Winograd, 2001. Land use modelling at the regional scale: an input to rural sustainability indicators for Central America. *Agric. Ecosyst. & Environ.* 85: 249-268.
- Kok, K., M. Winograd, 2002. Modelling land-use change for Central America, with special reference to the impact of Hurricane Mitch. *Ecological Modelling 149*: 53-69.
- Kok, K., A. Veldkamp, 2001. Evaluating impact of spatial scales on land use pattern analysis in Central America. *Agric. Ecosyst. & Environ. 85:* 205-221.
- Kok, K., 2004. The role of population in understanding Honduran land use patterns. *J. of Environmental Management 72*: 73-89.
- Wassenaar, T., P. Gerber, M. Rosales, M. Ibrahim, P.H. Verburg, H. Steinfield, 1996. Projecting land use changes in the Neotropics: the geography of pasture expansion into forest. Global Environmental Change (in press)

CLUE-S and its applications

- Verburg, 2004. Manual for the CLUE-S model. Wageningen University, the Netherlands.
- Verburg, P.H., W. Soepboer, R.L.V. Espaldon, 2002. Modeling the spatial dynamics of regional land use: The CLUE-S model. *Environmental Management 30*(3): 391-405.
- Verburg, P.H., C.J.E. Schulp, N. Witte, A. Veldkamp, 2005. Downscaling of land use scenarios to assess the dynamics of European landscapes. In: Special issue: Future land use in Europe: Scenario based studies on land use and environmental impact.
- Verburg, P.H., K.P. Overmars, M.G.A. Huigen, W.T. de Groot, and A. Veldkamp, 2006. Analysis of the effects of land use change on protected areas in the Phillippines. Applied Geog. 26: 153-173.
- Verburg, P.H., A. Veldkamp, 2004. Projecting land use transitions at forest fringes in the Philippines at two spatial scales. *Landscape Ecology 19* (1): 77-98 (2004).

Statistical analysis of land use change and explanatory factors

- Koning, G.H.J., A. veldkamp, L.O. Fresco, 1998. Land use in Ecuador: a statistical analysis at different aggregation levels. *Agric. Ecosyst. & Environ. 70:* 231-247.
- Verburg, P.H., 2004. CLUE exercise - How to do the statistical analysis. September 2004. Downloaded from http://www.cluemodel.nl/
- Lessschen, J.P., P.H. Verburg and S.J. Stall, 2005. Statistical methods for analysing the spatial dimension of changes in land use and farming systems. LUCC report series No. 7. ILRI and Wageningen University, Nairobi and Wageningen.
- SPSS 2004. SPSS Regression models 13.0.

Developing future scenarios and empowering stakeholders

- Miles, L., 2006. GEO-4 scenarios and the ICRAN MAR project. UNEP World Conservation Monitoring Centre. Project report. 14 August 2006.
- Verburg, P.H., C.J.E. Schulp, N. Witte, A. Veldkamp, 2006. Downscaling of land use change scenarios to assess the dynamics of European landscapes. Agriculture, Ecosystems and Environment 114: 39-56.
- Rounsevell, M.D.A. et al, 2006. A coherent set of future land use change scenarios for Europe. Agriculture, Ecosystems and Environment 114: 57-68.
- Potting, J. and J. Bakkes, J. (eds), 2004. The GEO-3 scenarios 2002-2032: Quantification and analysis of environmental impacts. UNEP-DEWA/RS.03-4 and RIVM 402001022.

Selected data for Central America

- Balk, D., M. Brickman, B. Anderson, F. Pozzi and G. Yetman, 2005. A global distribution of future population: Estimates to 2015. (GPW v3). CIESEN, Columbia University.
- Balk, D. and G. Yetman, 2004. The global distribution of population: Evaluating the gains in resolution refinement. (GPW v3). CIESEN, Columbia University.
- CIAT, 2005. Latin America and the Carribean (LAC) population database. International Center for Tropical Agriculture, Colombia.
- Vreugdenhill, D., J. Meerman, A. Meyrat, L.D. Gomez and D.J. Graham, 2002. Map of the ecosystems of Central America. Final report. World Bank, Washington, D.C.
- Meerman, J. and W. Sabido. 2001. Central American Ecosystems: Belize. Programme for Belize, Belize City. 2 volumes 50 + 88 pp. http://biological-diversity.info/Ecosystems.htm
- Batjes, N.H., 2005. SOTER-based soil parameter estimates for Latin America and the Caribbean (version 1.0). ISRIC – World Soil Information, Wageningen, the Netherlands.

PDF files for all readings ca be found in *..\ Training\Documentation*

# What is included on the CLUE-S training CD?

Everyone who participates in the training on Friday will receive a data CD that includes the following files organized in several folders:

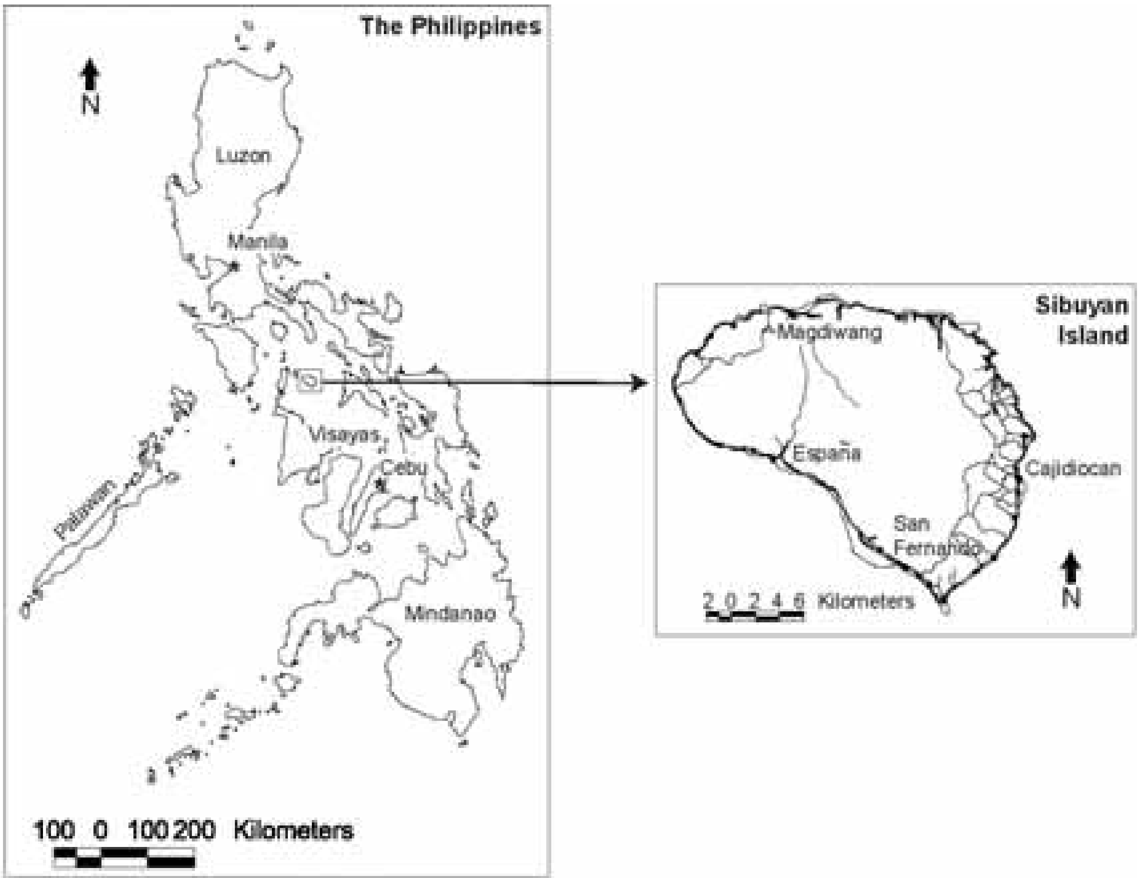
| Directory on CD | Description |
|---|---|
| **Software** | |
| ..\CLUE-S\Dyna_CLUE_full\ | Installation package of the full Dyna-CLUE model (latest version of CLUE-S released in January 2006). It includes the sample data for Sibuyan Island. |
| ..\CLUE-S\MAR_executable\ | A specially compiled version of the Dyna-CLUE main executable for use in the ICRAN-MAR project. It has been optimized for memory usage and execution speed. |
| ..\Other\ | Installers for supporting software that we will used during the training: TextPad 4.7, WinZip 9, and Adobe Reader. |
| **CLUES_BZ** | Complete Dyna-CLUE model (program files and all data files) for Belize, which will be used during the training.<br><br>**Please note: If you copy this folder from CD, all files will be read-only. You must right-click the folder, select Properties, uncheck "read-only", and apply it to all subfolders and files.** |
| **Documentation** | |
| ..\MAR_Modeling\ | Full technical report of the land use modeling for the MAR region, along with the CLUE-S user manual. |
| ..\Readings\ | Scientific publications and documents related to some source data that serve as (optional) further reading. |
| **Scenario_results** | Land cover grid for the base year and for the three simulated scenarios in 2025. There are also three grids that show the areas of change in land cover. |
| **Data**<br>..\CLUE-S &<br>..\CLUE-S\MAR\ | Location factor grids, dynamic factor grids, and land use grids for the entire MAR (in the subfolder), as separate files for Belize, Mexico, Honduras and Guatemala. These files are the actual input files for CLUE-S. Files have been compressed in *.zip files. Please note, metadata have been included with the combined MAR data, not the individual country datasets. |
| ..\Clipmask\ | Raster datasets of the precise spatial extent and resolution for the MAR and the four countries, as they were used to prepare (clip) all CLUE-S input data. |
| ..\Basedata\ | Vector and raster datasets that were used for creating the location factor grid for the MAR. These include original, third party data dataset and derived datasets. All data have been loaded in ***MAR Data Master.MXD*** |
| .\Avenue Scripts\ | ArcView Avenue scripts for (i) creating dynamic factor grids for protected areas, (ii) calculating the length of the dry season, and (iii) for filling *NoData* gaps in grids. |
| **Maps** | PDF files of two large format (A0) maps. |

# Background of the demonstration case study area, Sibuyan Island, the Philippines

For the first two exercises the case study of Sibuyan Island is used. This is the same case study area for which data are included with the demo version of CLUE-S. The datasets are relatively small and simulations execute quickly, so it is ideal to start with.

Sibuyan Island is located in the Romblon Province in the Philippines. The island measures 28 km east to west at its widest point and 24 km north to south, with a land area of approximately 456 $km^2$ surrounded by deep water. Steep mountain slopes covered with forest canopy characterize the island. The land surrounding the high mountains slopes gently to the sea and is mainly used for agricultural, mining and residential activities.

The island was selected as a case study because of its very rich biodiversity. About 700 vascular plant species live on Sibuyan Island including 54 endemic to the island and 180 endemic to the Philippine archipelago. Fauna diversity is low, but endemism is high. This makes the island a 'hot spot' for nature conservation and relevant for a detailed study of land use change. For this application a spatial resolution of 250 × 250 meter is used.




*Location of Sibuyan Island*

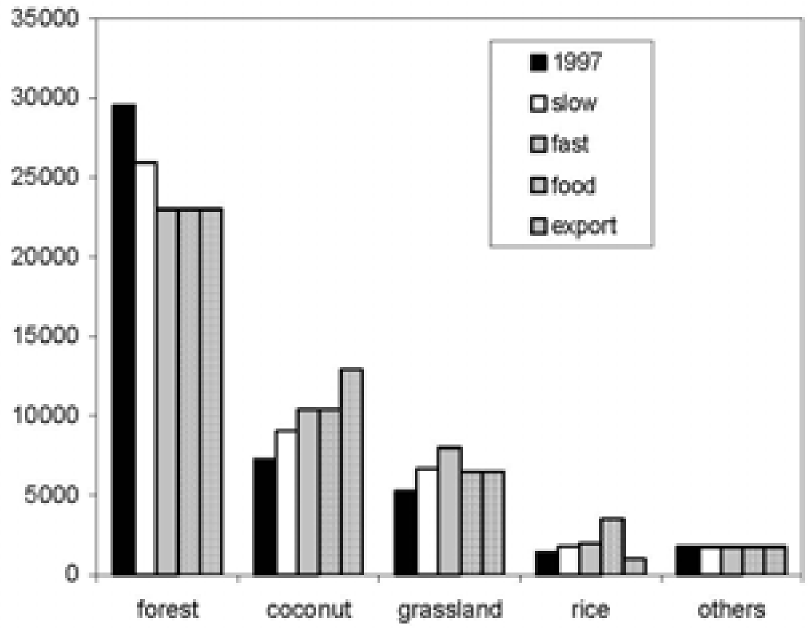
Five different land use types are distinguished for the simulation (see table below). **Important: for CLUE-S the land use numbering must start at 0, not 1.**

*Land use types on Sibuyan Island.*

| Land use code | Land use type |
|---|---|
| 0 | Forest |
| 1 | Coconut plantations |
| 2 | Grassland |
| 3 | Rice fields |
| 4 | Others (mangrove/beach/villages/etc) |

Four different files with land requirements (demand) scenarios have been created for the period from 1997 to 2011. The land requirements are not very realistic for this short time period, but allow us to clearly analyze the differences between the scenarios. Figure 2 summarizes the land requirements defined in the four scenarios:

1. **Slow growth scenario**, in this scenario a continuation of the land transformation rates of the past ten years is assumed, meaning deforestation and an increase in the area of coconut plantations, grassland and rice-area.
2. **Fast growth scenario**, in this scenario a higher rate of land transformation is assumed, leading to rapid conversions of forest to coconut, grassland and rice fields.
3. **Food-focus scenario**, a high rate of land transformation is foreseen, however, compared to the 'fast growth scenario' relatively more land is dedicated to rice cultivation in order to supply food for the population of the island.
4. **Export oriented scenario**, the same high land conversion rate applies. However, it is assumed that high copra prices make it profitable to dedicate most land to coconut plantations and less land to food crops.




*Demands for each land use type, for the base year (1997) and four scenarios. The combined demand of all land use types is the same each year (45162.5 ha).*

# Exercise 1: Learning the CLUE-S user-interface and displaying results in ArcGIS

*<u>Objective:</u> This exercise makes you familiar with the user-interface of CLUE-S and how you can display the simulation results in ArcGIS/ArcMap. The precise definition of the different parameters and input files is discussed Exercise 2 and in the user manual.*

### 1.0 INSTALLING CLUE-S

CLUE-S (Dyna-CLUE) has been pre-installed on all computers in the training lab and the data on the training CD have been copied to the folder **<u>C:\Training\</u>**.
If you are using your own laptop, or if want to install CLUE-S and the training data later in your office, then you can install them as follows:

- Open Windows Explorer and browse to the training CD.
- Double-click *Clues_Training.exe* and extract all files to a location on the hard disk. The default location is "C:" but you may specify another one.
- Double-click ***setup.exe*** from the *Training\Software\CLUE-S\Dyna_CLUE_Full* to install CLUE-S. Keep the default destination directory of "C:\CLUES".
- [MAR simulations only]. A 'tailored' main executable was compiled for use in this project. Copy *Training\Software\CLUE-S\MAR_executable**clues.exe*** to the installation directory and overwrite the existing file.

### 1.1 START CLUE-S

CLUE-S can be started in two different ways:
1. Click Start | Programs | CLUE-S tools | CLUE-S
2. Open the directory where CLUE-S is installed with explorer and double-click '*clues.exe'*

The user-interface should appear on the screen (Figure 1-1).
The "Neighborhood Result" and "Neighborhood setting" buttons only appear after checking the "Neighborhood variables" checkbox. These functions are not used in the exercises. A description of the functions can be found in the CLUE-S manual.

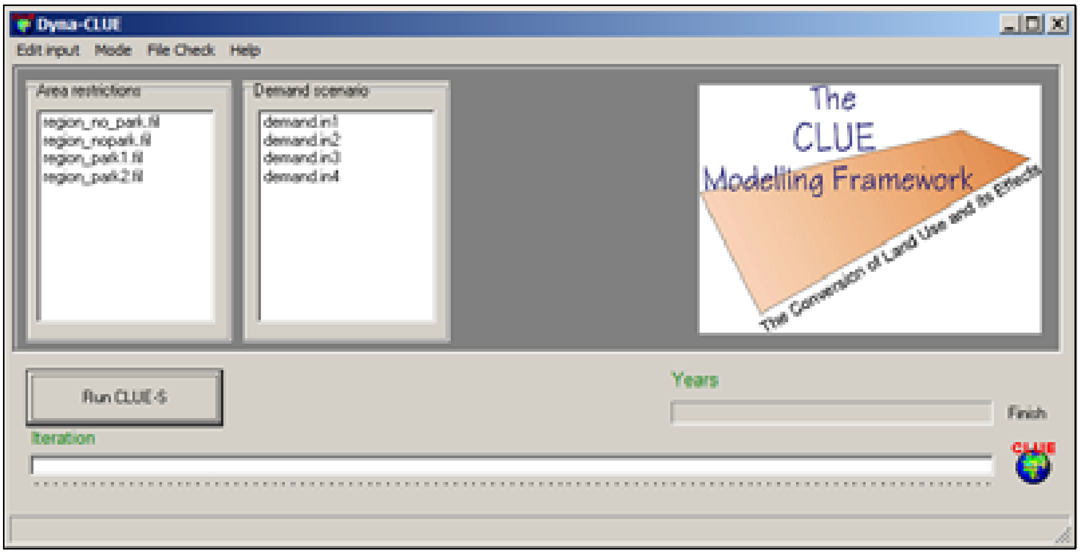



***Figure 1-1.*** *Interface of the CLUE-S v2.4 (Dyna-CLUE) model*

## 1.2 MAIN FUNCTIONS

The user interface makes it possible to edit the main input files through a built-in text editor and allows the user to choose the scenario conditions. When all parameters are set the simulation can start by clicking the 'Run CLUE-S' button. Simulation results will be saved to output files that can be imported by a GIS for display and analysis (CLUE-S does not have any built-in graphical capabilities).

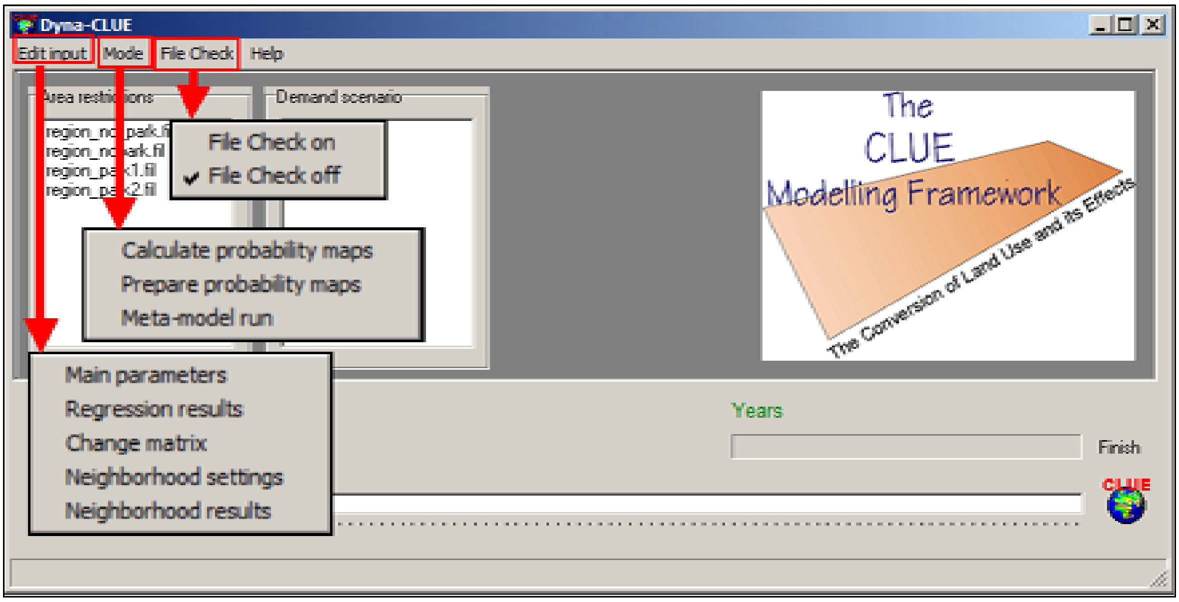



***Figure 1-2.*** *Explanation of the menu options of the CLUE-S interface*

Most commonly used menu options are

<u>Main parameters</u>: Edit the main settings of the model (file: *main.1*)
<u>Regression results</u>: Edit the regression equations (*alloc1.reg*)
<u>Change matrix</u>: Edit the land use conversion matrix (*allow.txt*)
<u>Calculate probability maps</u>: Create probability maps for every land use types
<u>Neighborhood settings</u>: Edit the neighborhood settings (*neighmat.txt*)
<u>Neighborhood results</u>: Edit the neighborhood results (*alloc2.reg*)

## 1.3 START THE SIMULATION

• Make sure that all input files are correctly defined (correct input files for Sibuyan Island are supplied with both the demo version full version of CLUE-S)

• Select an '**area restriction'** input file

The 'area restriction' file indicates which cells of a rectangular grid are part of the case-study area and can also contain information on the locations that belong to an area with restrictions to land use conversion, e.g. a natural park. You must always create and select an area restriction file, even if there are no actual restrictions. In exercise 2 you will learn more about this file.

• Select a '**land requirements'** (demand) input file

The 'land requirements' file contains for each year that is simulated the required area of the different land use types. These claims can be calculated in other models or can be based on trend extrapolation and demographic projections. Different land requirements are possible for different scenarios. The demand values must always be expressed in hectares.

• Click 'Run CLUE-S'.

The simulations will now start and the status bars show the progress (Fig. 1-3).

**NOTE:** The status-bar for the iterative procedure shows the average difference between the allocated area of the different land use types and the required allocation of the different land use types. The simulation of one year is finished if the allocated area deviates less than the specified maximum allowed deviation. Only when one of the land use types exceeds the specified maximum deviation between allocation and requirements for one of the land use types the iterations will continue and a special indicator will appear on the screen.

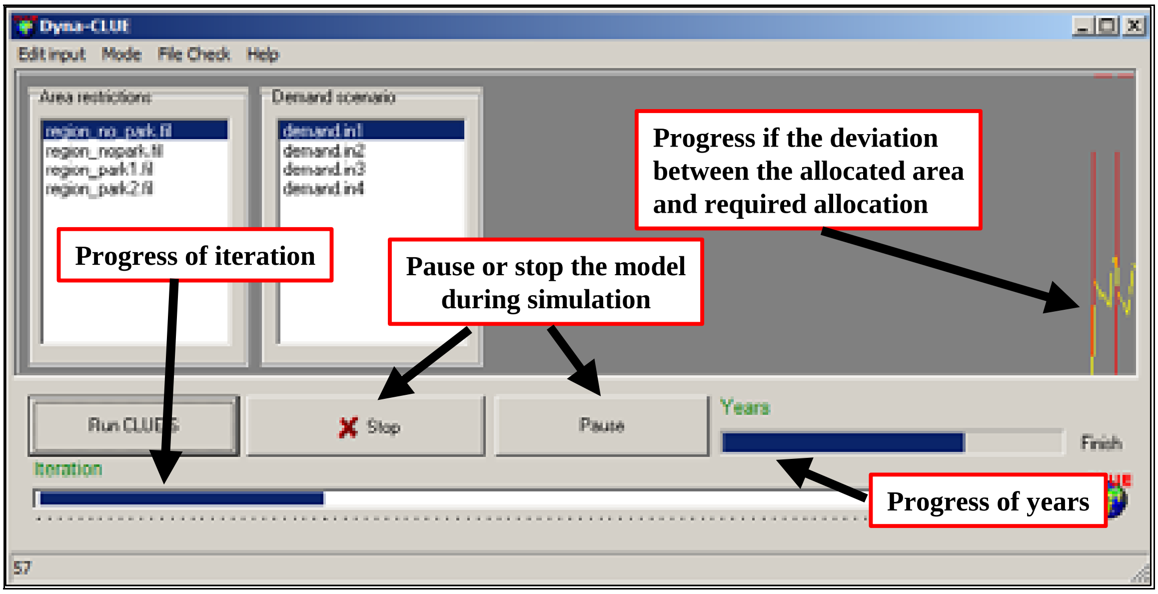



***Figure 1-3.*** *Explanation of the CLUE-S model run and progress information*

## 1.4 END OF THE SIMULATION

When all simulations are made successfully the model will display the message ‘finished’ and a button that gives access to the LOG-file will appear (Fig. 1-4). The log file contains information on the input files and run-time information on the iterations and may be consulted when errors occur or unexpected results are found.

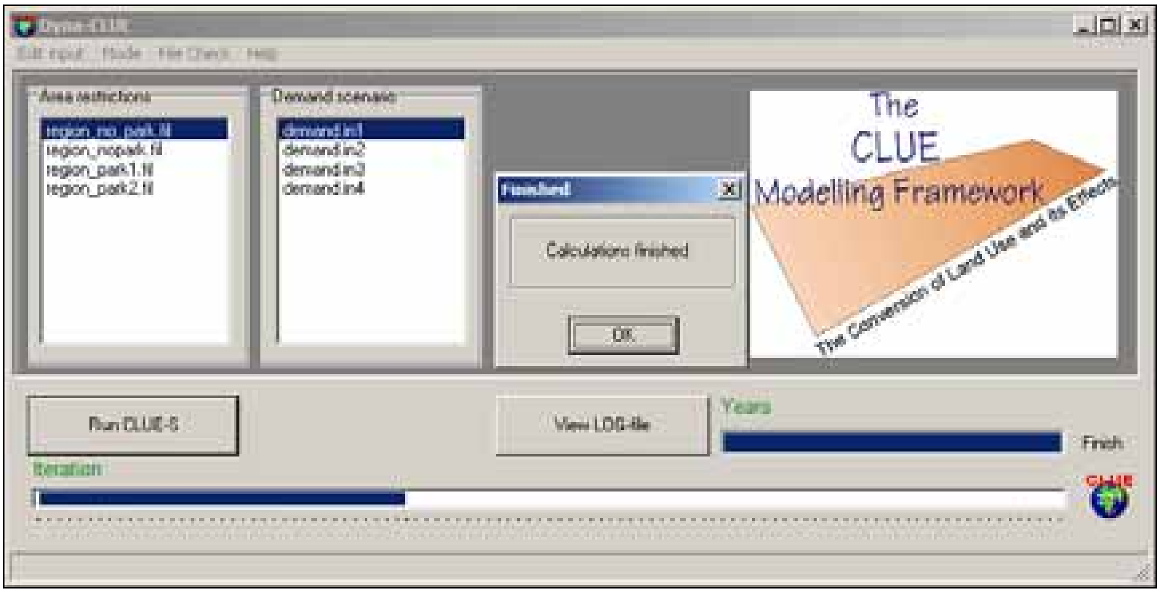



***Figure 1-4.*** *Interface after successfully finishing the simulation*

## 1.5 DISPLAY OF SIMULATION RESULTS & ASCII TO RASTER CONVERSION

All results of the simulation are saved in the installation directory. To display the simulation results it is needed to use a GIS package. In this tutorial we will use ArcGIS 9.x with the Spatial Analyst Extension.

CLUE-S saves the simulated land use data in ASCII GRID format. This can easily be imported in both ArcView 3.x and ArcGIS 8.x/9.x. The simulation results are stored in files called: cov_all.* where * indicates the year after the start of the simulation. Select the file you want, e.g. cov_all.14 and click 'OK'. One minor complication is that CLUE-S does not save the files with an *.asc extension but with the year numbers as the extensions (.e.g, ***cov_all.0, cov_all.1, cov_all.2,*** …, ***cov_all.14***, where year 0 is the start year and year 14 is the end year of the simulation). We have to manually add the extension .asc otherwise the GIS import routine will not recognize the file:

► Follow the steps below to display a land use map generated by the CLUE-S model:

- Rename the simulation output file: Go to My Computer and browse to the CLUE-S installation directory. Right-click the cov_all.* file that has the highest number and add ".asc". For Sibuyan, you would rename **cov_all.14** to **cov_all.14.asc**.
- Open ArcMap: Click Start | Programs | ArcGIS | ArcMap.
- Activate Spatial Analyst extension: Tools | Extensions | Check 'Spatial Analyst' | and click OK.
- Open ArcToolBox (the red icon on the Standard toolbar) and import the simulated land use grid: Conversion Tools | To Raster | ASCII to Raster. The menu shown in Fig. 1-5 will now appear. Specify the following information:
  - ❑ Input ASCII raster file: from the CLUE-S directory select a cov_all.*.asc file. Set File of Types to "File (*.ASC)
  - ❑ Output raster: you may specify any name, but make sure you use a temporary directory. It is important that you do not save the file in the CLUE-S directory because if you do that many times the directory becomes cluttered with temporary files and CLUE-S program files.
  - ❑ Output data type: keep the default setting INTEGER.
  - ❑ Click OK when all data have been entered.

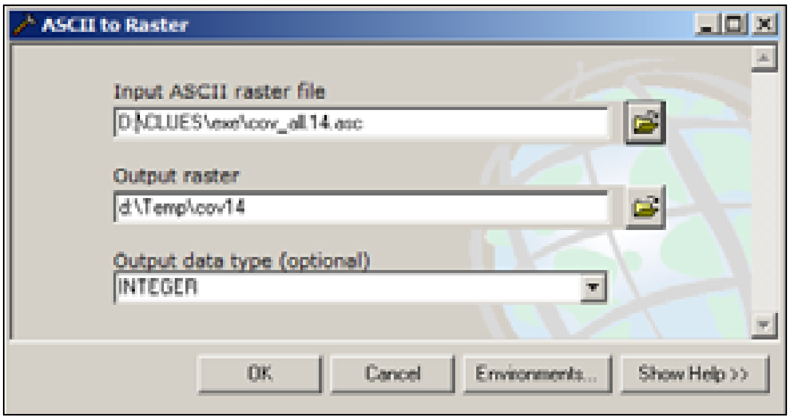



***Figure 1-5.*** *Convert ASCII grid to raster using ArcToolBox*

The result of the simulation can now be seen and analysed using ArcMap (Fig. 1-6).

It is now possible to change the graphical presentation by changing the colours of the map into colors that are easily associated with the different land use type. For Sibuyan Island the suggested colors is the table below can be used.

***Table 1-1**: Land use types and suggested colors for Sibuyan Island.*

| Land use code | Land use type | Color |
|---|---|---|
| 0 | Forest | Dark green |
| 1 | Coconut plantations | Orange |
| 2 | Grassland | Light green |
| 3 | Rice fields | Blue |
| 4 | Others (mangrove/beach/villages/etc) | Red |

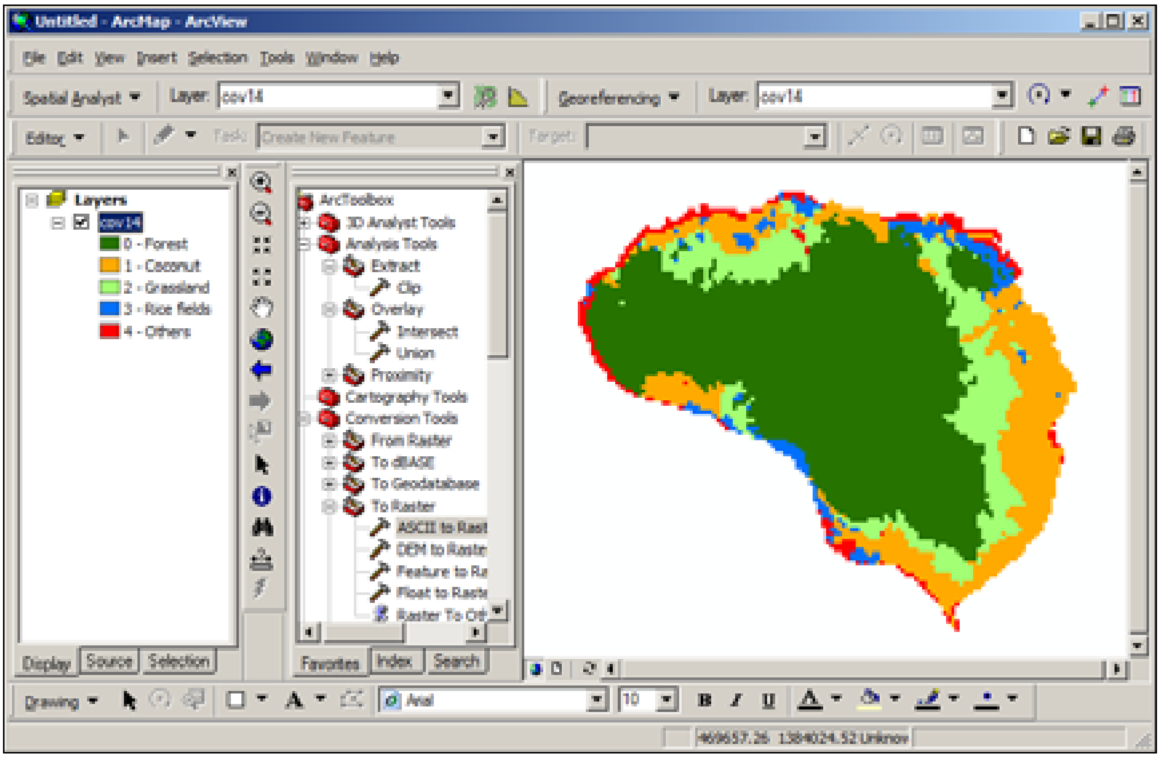



***Figure 1-6.** Simulation result displayed in ArcMap*

► Repeat the above steps for the results for different years of the simulation (for example, years 0, 5, 10 in addition to 14) with the Sibuyan data supplied with CLUE-S and see how results change over time.

**[End of exercise 1]**

# Exercise 2: Parameter and input data files and simulating alternative scenarios

*<u>Objective</u>: In this exercise you will learn about the different parameter and region-specific data files used by CLUE-S. You will run simulations using different scenario data files and modify some parameters, and then compare the results in ArcMap.*

### 2.1 PARAMETER AND OTHER DATA FILES USED BY CLUE-S

CLUE-S stores model parameters and region-specific data files in various files. The table below gives an overview of all files that you may use. All files are plain text files that can be edited using CLUE-S or a text editor such as Notepad or TextPad. All files are located in the CLUE-S installation directory, **C:\Clues**.

► Please review the table below to get a general idea of the parameters being used.

***Table 2-1.*** *Input files used by CLUE-S. The "created" column indicates what software is used to create the files and the "required" column indicates if the file is required. All files created CLUE-S are plain text files and may also be edited in a text editor.*

| Filename | Description | Created | Required |
|---|---|---|---|
| Main.1 | **Main parameters file**. Listed on exactly 19 lines. Some parameters settings will dictate whether the optional files must be specified or not. | CLUE-S | yes |
| Alloc1.reg | **Regression parameters**. The length of file depends on number of land use types and location factors. | CLUE-S | yes |
| Alloc2.reg | **Neighbourhood results**. Additional regression parameters based on the enrichment factor equation. | CLUE-S | no |
| Allow.txt | **Change matrix**. The number of rows and columns equal the land cover types, here 10x10. | CLUE-S | yes |
| Neighmat.txt | **Neighbourhood settings**. Defines the shape and size (in the form of a small weight matrix) of the analysis neighbourhood for every land use type. | CLUE-S | no |
| Regi*.* | **Area restriction file**. A grid that defines where land use changes can and cannot occur. The * is a wildcard here; it does not indicate the simulated year. All active cells must have the value 0, restricted cells a value of –9998, and all others cells –9999 (NoData). | ArcView | yes |
| Demand.in* | **Land use requirements**. Calculated at the aggregate level and organized by rows (simulated years starting at 0) and columns (for every land use types). The * denotes a unique number, not simulated year. | Excel / Textpad | yes |
| Cov_all.0 | **Initial land use**. A grid of all land use types at the start (year 0). Grid values must match the land use codes in the main parameters file and numbering starts at 0. | GIS | yes |
| Sc1gr#.fil | **Static location factor grid**, where # is the number of the location factor; | GIS | yes |
| Sc1gr#.* | **Dynamic location factor grid**, where # is the number of a location factor. The * is the simulated year starting at 0, not a wildcard. Note that also the file src1gr#.fill is needed and it is identical to src1gr#.0. | GIS | no |

## 2.1 SCENARIO CONDITIONS

The CLUE-S model has a number of parameters that need to be specified before a simulation can be made. The setting of these parameters is dependent on the assumptions made for a particular scenario. In this exercise we will explore four different scenario conditions, i.e., one or more of these settings will be different among scenarios.

1. Land requirements
2. Spatial policies (area restrictions)
3. Conversion elasticity
4. Land use conversion sequences

Different scenarios allow the comparison of different possible developments and give insight in the functioning of the model. Such analysis is most easy by visual comparison or through the calculation of the differences between the two scenarios in a GIS.

In this exercise you will first run the model with the baseline scenario: use the original settings of the 'main parameters', select '***region_nopark'*** and '***demand.in1'***. Import the results (e.g. for the start and end of the simulation, year 0 and year 14). Next, run the model again with four alternative settings as specified in the following sections (2.2 to 2.5). Compare the results in ArcView.

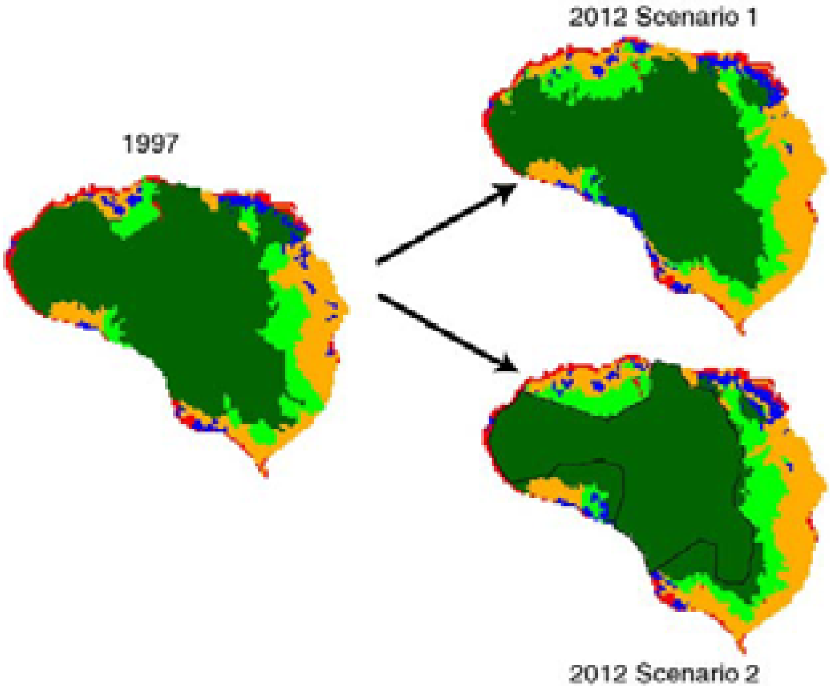



***Figure 2-1.*** *Simulation results for two different scenarios*

## 2.2 LAND REQUIREMENTS (DEMAND)

The land requirements are input to the model. For each year of the simulation these requirements determine the total area of each land use type that needs to be allocated by the model. The iterative procedure will ensure that the difference between allocated land cover and the land requirements is minimized. Land requirements are calculated independently from the CLUE-S model itself, which calculates the spatial allocation of land use change only. The calculation of the land use requirements can be based on a range of methods, depending on the case study and the scenario. The extrapolation of trends of land use change of the recent past into the near future is a common technique to calculate the land use requirements. When necessary, these trends can be corrected for changes in population growth and/or diminishing land resources.

For policy analysis it is also possible to base the land use requirements on advanced models of macro-economic changes, which can serve to provide scenario conditions that relate policy targets to land use change requirements. For example, land demand for the Mesoamerican Barrier Reef (MAR) region were calculated using the IMAGE model.

### *2.2.1 Simulating scenarios with different land requirements*

Four different files with land requirements are provided with the model for the period from 1997 to 2011. The land requirements in these scenarios are not very realistic for this short time period but allow us to clearly analyse the differences between the scenarios. The scenarios are based on the following assumptions:

**demand.in1: Slow growth scenario**, in this scenario a continuation of the land transformation rates of the past ten years is assumed, meaning deforestation and an increase in the area of coconut plantations, grassland and rice fields.

**demand.in2: Fast growth scenario**, in this scenario a higher rate of land transformation is assumed, leading to rapid conversions of forest to coconut, grassland and rice fields.

**demand.in3: Food-focus scenario**, a high rate of land transformation is foreseen, however, compared to the 'fast growth scenario' relatively more land is dedicated to rice cultivation in order to supply food for the population of the island.

**demand.in4: Export oriented scenario**, the same high land conversion rate applies. However, it is assumed that high copra prices make it profitable to dedicate most land to coconut plantations and less land to food crops.

► Select one of the land requirement scenarios and run the model keeping all other settings equal to the first run of the model. Analyze the results in ArcMap through displaying the land use pattern at the start of the simulation and at the end of the simulation. Repeat this for another scenario of land requirements and compare the results.

**NOTE:** Each simulation, the model will overwrite the results of a previous simulation. If you want to save the results, rename the output files or move the output files to another directory.

## 2.3 SPATIAL POLICIES (AREA RESTRICTIONS)

This option indicates areas where land use changes are restricted through spatial (land use) policies or tenure status. Maps that indicate the areas for which the spatial policy is implemented must be supplied. Some spatial policies restrict all land use change in a certain area, e.g., when in a forest reserve all logging is banned. Other land use policies restrict a set of specific land use conversions, e.g., residential construction in designated agricultural areas. In this exercise we will only address policies that restrict all land use changes in designated areas.

With the DEMO version of the model we supply three area restriction files that can be selected through the user-interface. Each file contains a map designating the areas where land use change is restricted. The maps are shown in Figure 14 but can also be imported in ArcView as ASCII Raster file similar to the procedure used to import the results of the simulations. The files are located in the installation directory.

*Area restriction files:*

region_nopark.fil: no spatial policies included

region_park1.fil: one large nature park following the boundaries of the Department of Environment and Natural Resources of the Philippines

region_park2.fil: instead of one large nature park protection is proposed for small areas which are assumed to face large land use change pressure.

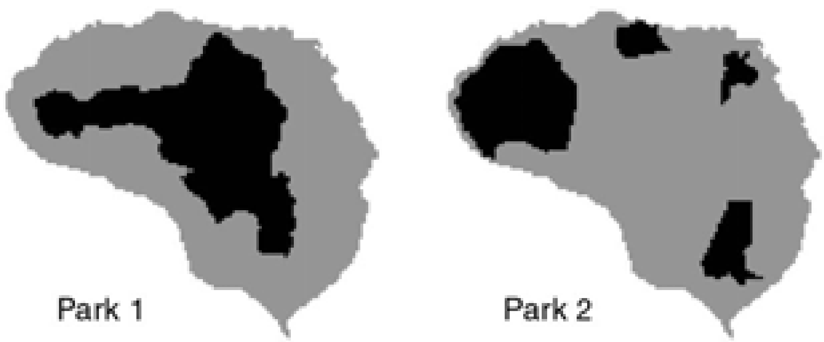



***Figure 2-2.*** *Maps of restricted areas (in black)*

► Run the CLUE-S model with the different area restriction files keeping all other settings equal to the first run of the model. Compare the results with the initial situation (1997, year 0) and compare the impact of the different area restrictions.

- ❑ Q: Is strict protection of the nature reserve needed for the developments until 2011 as simulated by the model?
- ❑ Q: Do the protected areas in 'park 2' protect areas that would otherwise be deforested? What is the consequence of strictly protecting these areas?

**NOTE:** Each simulation, the model will overwrite the results of a previous simulation. If you want to save the results, rename the output files or move the output files to another directory.

## 2.4 CONVERSION ELASTICITY

The conversion elasticity is one of the land use type specific settings that determine the temporal dynamics of the simulation. The conversion elasticity is related to the reversibility of land use changes. Land use types with high capital investment or irreversible impact on the environment will not easily be converted in other uses as long as there are land requirements for those land use types. Such land use types are therefore more 'static' than other land use types. Examples of relatively static land use types are residential areas, but also plantations with permanent crops (e.g., fruit trees). Other land use types are more easily converted when the location becomes more suitable for other land use types. Arable land often makes place for urban development while expansion of agricultural land can occur at the same time at the forest frontier. An extreme example is shifting cultivation: for this land use system the same location is mostly not used for periods exceeding two seasons as a consequence of nutrient depletion of the soil.

These differences in behavior towards conversion of the different land use types can be approximated by the conversion costs. However, costs cannot represent all factors that influence the decisions towards conversion such as nutrient depletion, esthetical value etc. Therefore, in the model we have assigned each land use type a dimensionless factor that represents the relative elasticity to conversion, ranging from 0 (easy conversion) to 1 (irreversible change). The user should specify this factor based on expert knowledge or observed behaviour in the recent past. An extended explanation of the possible values of the conversion elasticity and how behaviour changes when the land requirements increase or decrease in time is given below.

0: Means that all changes for that land use type are allowed, independent from the current land use of a location. This means that a certain land use type can be removed at one place and allocated at another place at the same time, e.g. shifting cultivation.

>0 and <1: Means that changes are allowed, however, the higher the value, the higher the preference that will be given to locations that are already under this land use type. This setting is relevant for land use types with high conversion costs.

1: Means that grid cells with one land use type can never be added and removed at the same time. This is relevant for land use types that are difficult to convert, e.g., urban settlements and primary forests. A value of one stabilizes the system and prevents that in case of deforestation other areas are reforested at the same time.

The conversion elasticities of all land use types are specified in the 'Main Parameters' input file (main.1, line 11) that can be edited through the user interface (click the 'Main Parameters' button). An explanation of all other parameters in this file can be found in the user manual). The first conversion elasticity corresponds with land use type 0, the second with land use type 1, etc.

***Table 2-3.*** *Current settings of the conversion elasticities*

| Land use code | Land use type | Conversion elasticity |
|---|---|---|
| 0 | Forest | 1.0 |
| 1 | Coconut plantations | 0.8 |
| 2 | Grassland | 0.2 |
| 3 | Rice fields | 0.2 |
| 4 | Others | 1 |

► Run the baseline scenario for Sibuyan island with the CLUE-S model with the current settings and with alternative settings for the conversion elasticity. Change the conversion elasticity by:

- Click on the ‘Main Parameters’ button. The main parameters can now be edited.
- Line 11 contains the conversion elasticity settings of the different land use types in the same order as the land use type coding. Change these values to new values.
- Click on ‘Save’.
- Run the model after selecting the ‘Area restrictions file’ and the ‘Land requirements’ file (similar to the first run of the model).
- Display the results with ArcView.
- Compare the differences in spatial pattern of land use change as result of the changes in conversion elasticity.

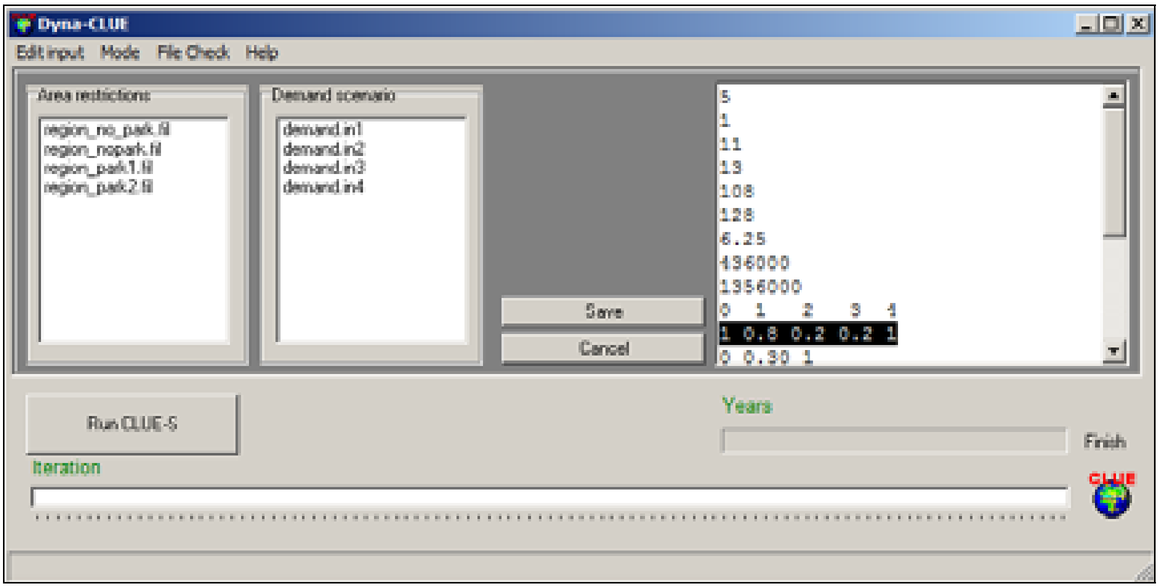



***Figure 2-3.*** *Conversion elasticities are listed on line 11 in the parameter file main.1*

**NOTE:** Each simulation, the model will overwrite the results of a previous simulation. If you want to save the results, rename the output files or move the output files to another directory.

## 2.5 LAND USE CONVERSION SEQUENCES

Not all land use changes are possible and some land use changes are very unlikely (e.g., arable land cannot be converted into primary rain forest). Many land use conversions follow a certain sequence or cycle, e.g. fallow land and forest regrowth often follow shifting cultivation. Figure 2-4 indicates a number of possible land use trajectories identified on Sibuyan island.

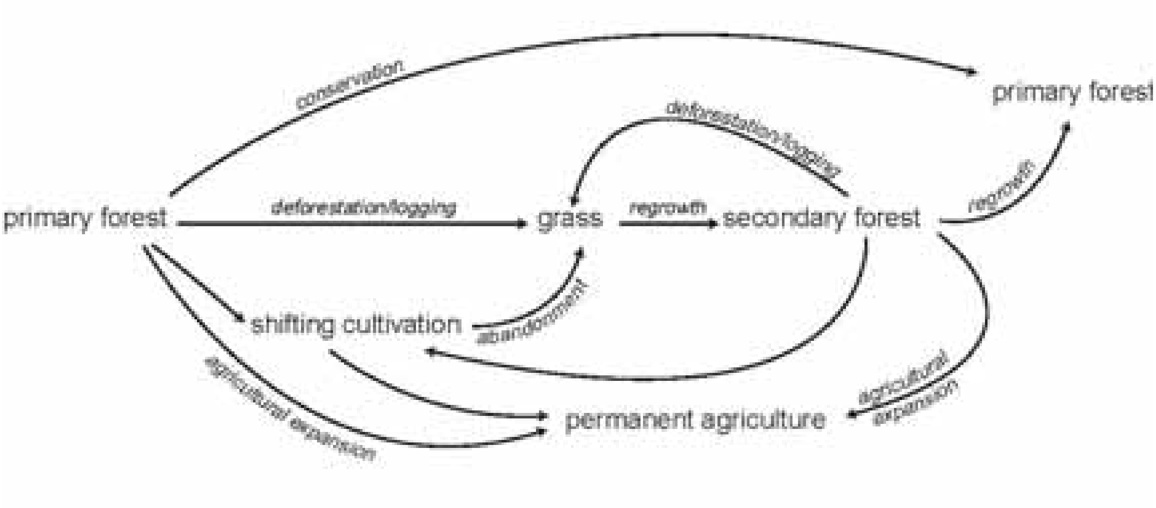
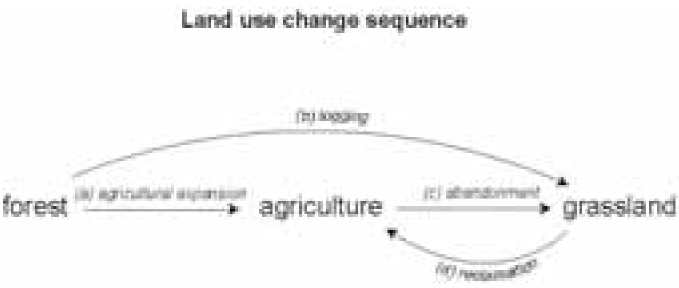



***Figure 2-4.*** *Possible land use trajectories on Sibuyan island.*

The conversions that are possible and impossible are specified in a land use conversion matrix. For each land use type it is indicated in what other land use types it can be converted during the next time step. Figure 2-5 provides a simplified example of a land use transition sequence. Forest can be converted in either agricultural land or grassland, while it is impossible to obtain new (primary) forest through the conversion of agricultural land or grassland directly. The figure also illustrates the translation of these conversion sequences into a land use conversion matrix, which can be used by the model. Depending on the definition of this conversion matrix and the time-steps chosen, complex land use sequences are possible.




**Land use conversion matrix**

| future land use → / present land use ↓ | Forest | Agriculture | Grassland |
|---|---|---|---|
| Forest | + | + (a) | + (b) |
| Agriculture | - | + | + (c) |
| Grassland | - | + (e) | + |

\+ conversion possible
\- conversion not possible

***Figure 2-5.*** *Land use transition sequence*

The land use conversion matrix can be edited by clicking the ‘Change matrix’ button. It is also possible to use a text editor (e.g. Notepad) to edit the file ‘***allow.txt’*** in the installation directory. The rows of this matrix indicate the land use types during time step *t* and the columns indicate the land use types in time step *t+1*. If the value of a cell is 1 the conversion is allowed while a 0 indicates that the conversion is not possible. The rows and columns follow the number code of the land use types.

Example: in the matrix below all conversion are possible except the conversion from coconut plantation into rice fields.

| From ↓ To → | Forest | Coconut | Grassland | Ricefields | Others |
|---|---|---|---|---|---|
| Forest | 1 | 1 | 1 | 0 | 1 |
| Coconut | 1 | 1 | 1 | 1 | 1 |
| Grassland | 1 | 1 | 1 | 1 | 1 |
| Rice fields | 1 | 1 | 1 | 1 | 1 |
| Others | 1 | 1 | 1 | 1 | 1 |

► Run the baseline scenario for Sibuyan island with a different setting of the conversion matrix (keeping all other settings equal) and analyse the differences in outcome with ArcView. We suggest to compare a model run that allows all changes with a model run in which the conversion of grassland into agricultural land (coconut plantation and rice fields) is no longer possible due to soil degradation. Compare the results.

**Note:** Some land use conversion settings will have no effect because they are overruled by the conversion elasticity and land requirement settings. In the baseline scenario we have assumed that the 'others' land use type is not changing and forest cannot 're-grow' from other land use types as long as its total land area is decreasing. Consequently, changing the conversion settings for these land use types in the conversion matrix will have no effect on the simulation results.

**[End of exercise 2]**

# Exercise 3: Defining spatial policies and creating new land requirements

*<u>Objective:</u> In this exercise you will learn how to prepare a new land requirements file and also a new area restrictions file. The combination of these new files represents a new scenario and you will then simulate your own scenario.*

### 3.1 INTRODUCTION

For some scenarios it is interesting to define areas where land use changes are restricted because of spatial policies, e.g. the conservation of nature. In the previous we have seen that spatial policies should be defined in an ‘area restriction’ file. This file contains a map of the study area indicating the extent of the case-study area and the zones of the case-study area where spatial restrictions apply.

The ‘area restriction’ file is located in the installation directory and called ‘**region*.fil’** where * can be defined by the user to indicate the conditions specified in the file. With the demo version of CLUE-S three different area restriction files are supplied, one without any spatial policy and two file indicating different extents of a nature reserve.

► Import these ‘area restriction’ files in ArcMap using the procedure as you used for the land cover grid in Exercise 1.5. It is best to copy these files to a temporary directory and then rename them there by adding “.asc” to the file.

- ❑ Question: What are the different grid values in the area restriction files? What value is used for a restricted area? And what value for a non-restricted area?

### 3.2 PREPARATION OF A NEW AREA RESTRICTION FILE

In this exercise you will create a new ‘area restriction’ file to simulate a scenario of the effects of a strict protection of all remaining lowland forest on Sibuyan island. Therefore we assume that during the simulations it is not possible to convert any of the remaining forest areas below an altitude of 100 meter.

To make the area restriction file we need to identify:

- The extent of the case study
- The locations below 100 meter altitude
- The locations with forest at the start of the simulations

Therefore it is needed to import the land use map of year 0 (the start of the simulation) in ArcView. This land use map shows the extent of the study area (all grid-cells that are designated to a land use type) and the locations with forest at the start of the simulations. This land use map can be found in the installation directory (C:\Clues) and is called ‘**cov_all.0’**.

To identify the locations below 100 meter an altitude map is needed. Since altitude is one of the location factors used in the simulations for Sibuyan island this map is already present in the installation directory. For this case study altitude is location factor number 7, so the elevation dataset in file ‘**sc1gr7.fil’**.

► Import both files using the *ASCII to Raster* option in ArcToolBox.

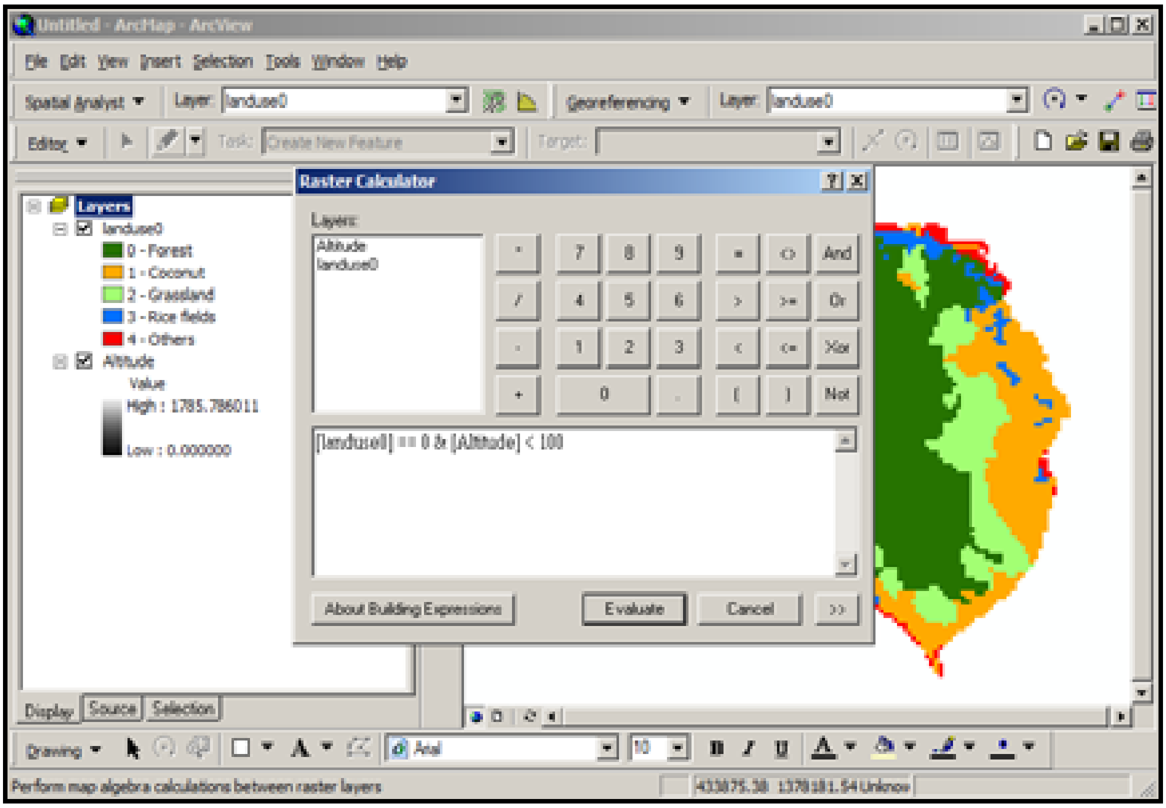



***Figure 3-1.*** *Map query with the Raster Calculator in ArcMap*

In the 'area restriction' file the following coding should be used:

| | |
|---|---|
| 0 | all grid cells that belong to the study area outside the 'restricted area'. These are the grid cells that are allowed to change. |
| -9998 | all grid cells for which land use conversions are not allowed during the simulation (the 'restricted area') |
| -9999 (No Data) | all other grid cells (outside the simulation area) |

► Prepare an 'area restriction' file to prevent any forest areas below an altitude of 100 meter from changing. You can follow the steps below or use your own procedure:

- ❑ Select all locations with forest located below an altitude of 100 meter at the start of the simulation by a 'map query' (Spatial Analyst | Raster Calculator) (Fig. 3-1). This will result in a new temporary theme '*Calculation'* indicating all selected locations by a value of 1.
- ❑ Classify the results of the previous step to the coding system of the area restriction file, as listed above (Spatial Analyst | Reclassify) (Fig. 3-2). This should create new temporary layer '*Reclass of Calculation'* with values of –9998 and 0.
- ❑ Export the result of the previous step as an ASCII file '**region5.asc'** in the CLUE-S installation folder (ArcToolBox | Conversion Tools | From Raster | Raster to ASCII). Note that you must specify either a *.txt* or *.asc* extension
- ❑ Using Windows Explorer browse to the installation directory and rename the file region5.asc to region5.fil (you may use a different number but you must use the **region*.fil** naming convention otherwise CLUE-S does not recognize it).

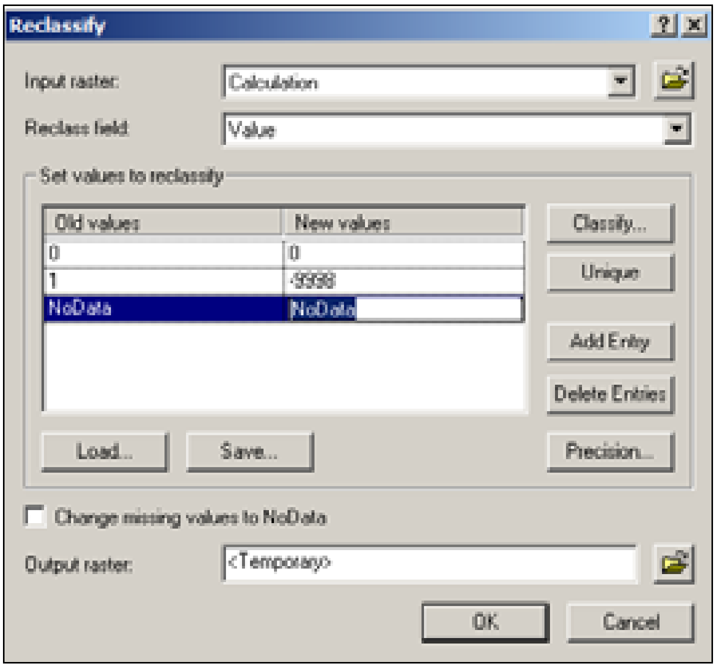



***Figure 3-2.*** *Reclassifying a grid as an area restriction file.*

► Restart the CLUE-S model and the new area restriction file should appear in the list of area restriction files and can be selected for the simulation. Run the model with this file and compare the result with a simulation without protection of forest resources.

► Prepare your own area restriction file based on a hypothetical spatial policy. You can also prepare area restriction files by delineating areas in ArcView that need to be converted to grid cells.

**Note:** If the area restrictions violate the land requirements specified in the 'land requirements' file the model will not succeed in allocating land use changes and stop the simulation. This can occur when all forest is assumed to be protected while at the same time a decrease in land requirements for forest is specified.

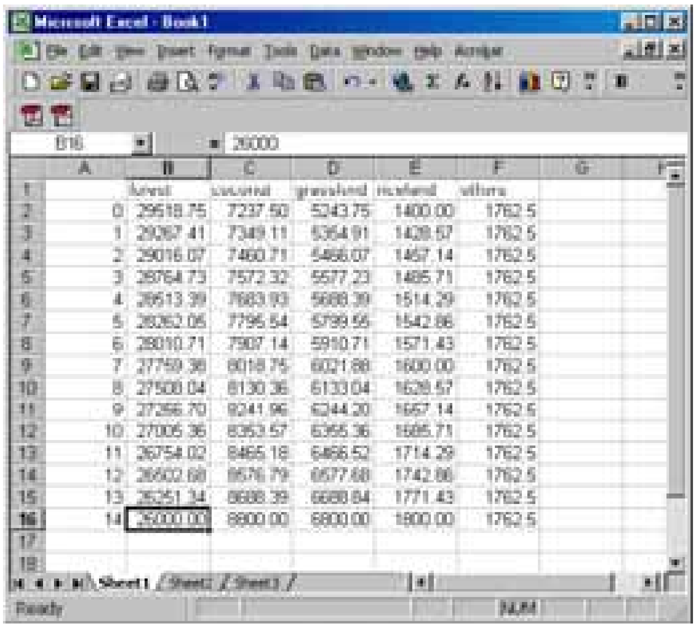
### 3.3 CREATING YOUR OWN LAND REQUIREMENTS FILE

► You will now start defining your own scenario by generating a new land requirements input file for CLUE-S. Follow the steps and data guidelines below:

- Open Microsoft Excel to facilitate the calculations.
- Specify for each year (1997-2011) the land requirements of the different land use types in a table following the specifications below:
  **Please note: Demand must always be expressed in hectares (10 000 m$^2$).**
- Each row indicates a year; each column a land use type following the order of the land use coding.
- Make sure to include also the land requirements for 1997 (year 0). These should be similar to the land use map of 1997 (29518.75, 7237.5, 5243.75, 1400, 1762.5 ha for respectively forest, coconut, grassland, rice and others).
- The total land area required should equal the size of the island (45162.5 ha), i.e., the sum of the values on each row should equal 45162.5 for each year.

  Suggestion: you can temporarily add an extra column G or H and use a formula to verify that the row totals are always equal (for example: *G2 = SUM(A2:F2)).*

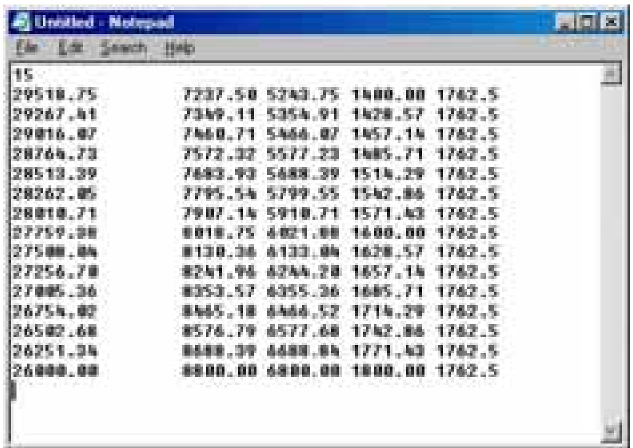
- We suggest not to change the land use requirements for the 'others' land use class and to create logical scenarios without sharp increases or decreases. This should prevent problems or very long run times during the simulation.



| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | | forest | coconut | grassland | riceland | others | |
| 2 | 0 | 29518.75 | 7237.50 | 5243.75 | 1400.00 | 1762.5 | |
| 3 | 1 | 29267.41 | 7349.11 | 5354.91 | 1428.57 | 1762.5 | |
| 4 | 2 | 29016.07 | 7460.71 | 5466.07 | 1457.14 | 1762.5 | |
| 5 | 3 | 28764.73 | 7572.32 | 5577.23 | 1485.71 | 1762.5 | |
| 6 | 4 | 28513.39 | 7683.93 | 5688.39 | 1514.29 | 1762.5 | |
| 7 | 5 | 28262.05 | 7795.54 | 5799.55 | 1542.86 | 1762.5 | |
| 8 | 6 | 28010.71 | 7907.14 | 5910.71 | 1571.43 | 1762.5 | |
| 9 | 7 | 27759.38 | 8018.75 | 6021.88 | 1600.00 | 1762.5 | |
| 10 | 8 | 27508.04 | 8130.36 | 6133.04 | 1628.57 | 1762.5 | |
| 11 | 9 | 27256.70 | 8241.96 | 6244.20 | 1657.14 | 1762.5 | |
| 12 | 10 | 27005.36 | 8353.57 | 6355.36 | 1685.71 | 1762.5 | |
| 13 | 11 | 26754.02 | 8465.18 | 6466.52 | 1714.29 | 1762.5 | |
| 14 | 12 | 26502.68 | 8576.79 | 6577.68 | 1742.86 | 1762.5 | |
| 15 | 13 | 26251.34 | 8688.39 | 6688.84 | 1771.43 | 1762.5 | |
| 16 | 14 | 26000.00 | 8800.00 | 6800.00 | 1800.00 | 1762.5 | |

**Figure 3-3.** *Entering land use requirements in a spreadsheet.*

- When all values have been defined, select the values (without land use type names and year numbers) and paste the contents into a text editor (e.g. Notepad). Insert a line at the top of the file with the number of lines (years) for which the land requirements are specified (15 in our example).



```
15
29518.75	7237.50 5243.75 1400.00 1762.5
29267.41	7349.11 5354.91 1428.57 1762.5
29016.07	7460.71 5466.07 1457.14 1762.5
28764.73	7572.32 5577.23 1485.71 1762.5
28513.39	7683.93 5688.39 1514.29 1762.5
28262.05	7795.54 5799.55 1542.86 1762.5
28010.71	7907.14 5910.71 1571.43 1762.5
27759.38	8018.75 6021.88 1600.00 1762.5
27508.04	8130.36 6133.04 1628.57 1762.5
27256.70	8241.96 6244.20 1657.14 1762.5
27005.36	8353.57 6355.36 1685.71 1762.5
26754.02	8465.18 6466.52 1714.29 1762.5
26502.68	8576.79 6577.68 1742.86 1762.5
26251.34	8688.39 6688.84 1771.43 1762.5
26000.00	8800.00 6800.00 1800.00 1762.5
```

**Figure 3-3.** *Land use requirements copied to a text file demand.in**

- Save this file in the installation directory as '**demand.in***' where * can be defined by the users, e.g. demand.in5.
- Restart the CLUE-S model; it is now possible to select the new land requirement file and simulate the land use changes.
- Import and analyse the results in ArcMap.

**[End of exercise 3]**

# Background on the MAR Land Use Change Simulations

In the previous exercises you worked with data for Sibuyan Island. This is a very small dataset and simulations ran very quickly, which made it very suitable for a relatively short training day and allowed you to quickly inspect the changes in simulation outcomes after you made adjustments in area restriction files, land demand and conversion elasticities. Now you will start working with some actual data for that we used for the MAR.

The MAR catchment is approximately 190,400 km$^2$ large, with 41% of the area in Honduras, 29% in Mexico, 18% in Guatemala and 12% in Belize. Those 12% represent the entire country of Belize whereas only parts of the other countries are included.

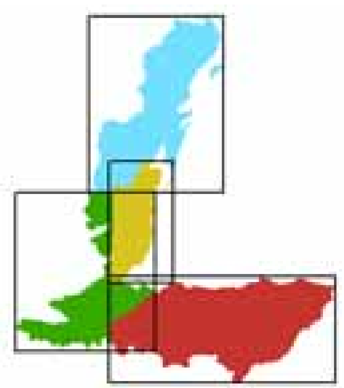
Dataset prepared for each country
First of all, it is important to know for that the regression analysis and the CLUE-S simulations were done separately for each country (or part of it). The reasons are:

- Land use pattern and the drivers of land use change are different for the countries because of different policies, biophysical conditions or other factors, so performing a separate analysis allows a more accurate analysis.
- Smaller data files by country facilitate easier data management.

Nevertheless, these size of the data even for an individual country is much larger that for Sibuyan Island. For all four countries the smallest possible spatial extent was defined and the country grid were clipped to these extents.

*Size of the grid for Sibuyal Island and the MAR countries. Cell size is 250 m. Simulation times are observed on a laptop with a 2GHz Pent. M processor and 2GB of RAM*

| **Country** | **# Rows in grid** | **# Columns in grid** | **# Data cells (not Null)** | **Average time for a simulation run** |
|---|---|---|---|---|
| | | | | |
| Sibuyal | 108 | 128 | 7,226 | < 10 seconds |
| | | | | |
| Belize | 1151 | 604 | 349,762 | ½ - 1 hour |
| Guatemala | 1503 | 1310 | 542,309 | 2 - 3 hours |
| Mexico | 1674 | 1262 | 886,433 | 3 - 4 hours |
| Honduras | 1005 | 2131 | 1,267,903 | 4 - 5 hours |
| | | | | |
| All of MAR | 3484 | 3016 | 3,046,407 | N/A |



| | **West (xmin)** | **East (xmax)** |
|---|---|---|
| Belize | 261,500 | 412,500 |
| Mexico | 213,250 | 528,750 |
| Guatemala | 41,250 | 368,750 |
| Honduras | 260,250 | 793,000 |

| | **South (ymin)** | **North (ymax)** |
|---|---|---|
| Belize | 1,757,500 | 2,045,250 |
| Mexico | 1,971,250 | 2,389,750 |
| Guatemala | 1,596,500 | 1,972,250 |
| Honduras | 1,521,000 | 1,772,250 |

*Figure 1: Spatial extents and mask for raster datasets for the four MAR counties. Coordinates are in UTM zone 16 with NAD 1927 Central American datum.*

GEO-4 Scenarios

We adapted three of the four Global Environment Outlook 4 (GEO-4) scenarios Latin America and the Caribbean for use within the ICRAN MAR project. The scenarios envisage differing social, political and economic trajectories, emphasizing outcomes for the environment and human well-being.

1. **Markets First**: Under this scenario economic growth is prioritized over social and environmental objectives. Everything becomes merchandise, including natural resources and basic goods such as water and culture. In general, regional environmental degradation continues to worsen.

2. **Policy First:** Environmental awareness develops within government more rapidly than in the private sector or amongst the general public. The resource base is better managed, with policies being developed to alleviate the more serious environmental problems.

3. **Sustainability First:** In this world, economic, social and environmental dimensions combine to shift the trajectory towards environmentally sustainable development. International cooperation within the region increases, with policies being directed to achievement of the Millennium Development Goals and sound natural resource management.

More details about the scenarios can be found in Miles (2006), which is included in the readings list and as a PDF file on the CD.

Land requirements

Land requirements for every scenario were calculated using the IMAGE model. In the next exercise we will focus on Belize. The table below gives the distribution of land use at present and the calculated land demand under the scenarios in 2025 for Belize. The total area is *21860.13* $km^2$. The area of land use types 0 and 9 is assumed to remain constant.

*Land use distribution at present and for the scenarios in Belize.*

| | Present (2004) | Markets First 2025 | Policy First 2025 | Sustainability First 2025 |
|---|---|---|---|---|
| 0. Other/Unknown | 0.06% | 0.06% | 0.06% | 0.06% |
| 1. Broad-leaved forest | 58.02% | 54.33% | 56.69% | 57.78% |
| 2. Pine forest | 3.53% | 3.31% | 3.45% | 3.52% |
| 3. Agriculture/pasture | 19.37% | 23.20% | 20.64% | 18.85% |
| 4. Scrub | 1.26% | 1.23% | 1.13% | 1.37% |
| 5. Savanna | 8.63% | 8.23% | 8.35% | 8.65% |
| 6. Wetland/Swamp | 4.26% | 4.07% | 4.12% | 4.27% |
| 7. Mangroves | 3.29% | 3.08% | 3.22% | 3.28% |
| 8. Urban | 0.87% | 1.79% | 1.64% | 1.51% |
| 9. Water | 0.70% | 0.70% | 0.70% | 0.70% |

# Exercise 4: Working with actual scenario data for Belize

*<u>Objective:</u> In this exercise you will learn some of the actual data that were used for the Belize simulations, and how dynamic location factors were used. You will also create and review probability surfaces. At the end of the day you should have a sufficient knowledge of the data to simulate and analyze the actual different scenarios yourself.*

### 4.0 COPY THE CLUE-S MODEL AND DATA FOR BELIZE FROM CD

- ❑ Using Windows Explorer, browse to the folder *C:\Training\Data\CLUE-S* on your computer (or the CD). This folder has 4 zip files that contain all land use and location factor grids in regular grid and ASCII format.
- ❑ Double-click BZ.ZIP and unzip (extract) the file in a temporary location on your computer, e.g., c:\temp. Remember where you extracted the file.
- ❑ Also copy the entire CLUE_BZ folder from the CD to a place on the harddisk. Then right-click the folder, select Properties,uncheck "read-only", and apply it to all subfolders and files. CLUE-S will give an error if the folder is read-only!

### 4.1 REVIEW OF THE LAND USE DATA

The baseline land cover map was based on the 2004 version of the Belize Ecosystem Map and the revised 2003 Ecosystem Map for Central America land use data. The original land cover classification was reduced to 10 classes (Table 4-1) and the data was converted from a vector to a raster format with a 250 m grid cell size.

Note: CLUE-S requires that the land use numbering to start at 0, not 1.

***Table 4-1***: *Reduced land use classification used for the MAR*

| Value | Land use type | Value | Land use type |
|---|---|---|---|
| 0 | Other/unknown | 5 | Savanna |
| 1 | Broad-leaved forest | 6 | Wetland/Swap |
| 2 | Pine forest | 7 | Mangroves |
| 3 | Agriculture/pasture | 8 | Urban |
| 4 | Scrub | 9 | Water |

► Let's now look at the reclassified 2004 land use data for Belize:

- ❑ Open ArcMap and load the layer file '*Belize Present land Cover (2004).lyr'* that is in the BZ data folder (the layer file source grid is *..\BZ\grid\bzecomap*).
- ❑ Review the land cover data. Keep in mind that these data were based on the 2004 Ecosystem Map for Belize (Meerman & Sabido. 2001), reclassified and converted from vector to raster data with a cell resolution of 250 m.

### 4.2 STATIC AND DYNAMIC LOCATION FACTORS

For every region you must specify a number of driving factors of land use change. These 'location factors' were determined by a statistical regression analysis. Table 4-2 lists all location factors that were analyzed for the MAR. The numbering must starts at 0.
A location factor can be static of dynamic, as is indicated in the last column of the table.

- ❑ **Static**: the location factor is constant over the entire simulation grid. The grid is saved in ASCII format with the following naming convention: SR<u>**x**</u>GR.FIL

- **Dynamic**: the location factor changed over time. Instead of a single ASCII grid we have to prepared a grid for every year: SR**x**GRD.**y**

  where
  **x** = the number of the location factor (0 to 11)
  **y** = the simulated year started at 0 (for belize, 0 to 21)

For the MAR land use simulations only one location factor was dynamic: No. 11, protected areas with partial protection. Of course, population density will also change over time, and accessibility to markets and road may also change if no roads are built. However, the scenario descriptions that were developed described the future changes for the country as a whole and did not provide sufficient details about exactly what, where and how changes might occur on a regional or local scale.

**Table 4-2**: Location factors (LF) used for the MAR land use simulations.

| No | Description [unit] | CLUE-S file | Original GRID file | Dynamic |
|---|---|---|---|---|
| 0 | Population density [# per km$^2$] | **SC1GR0.FIL** | **POPDEN** | No |
| 1 | Soil depth [meter] | **SC1GR1.FIL** | **SDEPTH** | No |
| 2 | Soil drainage [0-1] | **SC1GR2.FIL** | **SDRAIN** | No |
| 3 | Mean annual rainfall [mm] | **SC1GR3.FIL** | **RAINYR** | No |
| 4 | Length dry period [consecutive months with < 60 mm rain] | **SC1GR4.FIL** | **DRYMON** | No |
| 5 | Elevation [meter] | **SC1GR5.FIL** | **ELEVAT** | No |
| 6 | Slope [degrees] | **SC1GR6.FIL** | **SLPDGS** | No |
| 7 | Accessibility to markets [travel time in hours] | **SC1GR7.FIL** | **ACSMKT** | No |
| 8 | Accessibility to roads [travel time in hours] | **SC1GR8.FIL** | **ACSRDS** | No |
| 9 | Coastal area / tourism hotspots [0/1] | **SC1GR9.FIL** | **TOURIS** | No |
| 10 | Protected areas / full protection [0/1] | **SC1GR10.FIL** | **WDPAR1** | No |
| 11 | Protected area / partial protection [0/1] | **(SC1GR11.FIL)** **SC11GR.0** **-----** **SC11GRD.21** | **WDPAR2** | Yes |

► You will now review the location factor grids.

- Browse to the 'BZ' folder that you just extracted. You should see two sub-folders, "*ascii*" and "*grid*". Both folders contain the same dataset but in different formats. It is easier to work with the data in the "*grid*" folder because these data can be readily loaded as a layer in ArcMap.
- Open a new ArcMap document and load location factor 8, "Accessibility to Markets" (*bz*ACSMKT). The unit of this data is travel time in hours. It was calculated using a methodology developed by researchers at CIAT, Colombia. Do you think the travel times are fairly realistic?
- Also load location factor grid 10 (*bz*WDPAR1) and 11 (bzWDPAR2). A grid value of 1 means that the grid cell is a protected area, a value of 0 not. Are you familiar with the protected areas in the country?
- Load all other grids location factor (i.e., don't load the "bzLUC_" grids – these are grids for individual land use types). Review all location factor grids and make sure that you understand these grids and their units.

### 4.3 REGRESSION EQUATIONS AND PROBABILITY SURFACES

**Note: in this part of the exercise you will be learning about some of the more advanced features of CLUE-S. Nonetheless, you will need to understand these features if you are planning to use CLUE-S for actual simulation modeling of land use change.**

The allocation of land across the region is done by CLUE-S based on probabilities, which, in turn, are calculated using regression equations that account for the effect of one or more location factors. For example, the regression analysis showed a significant relationship with Urban land and three location factors, as follows:

Probability $LU_8 = 0.5 + 0.01\ LF_0 - 0.37\ LF_7 + 0.70\ LF_9$

where $LU_8$ = Land use type 8, Urban
$LF_0$ = Population density
$LF_7$ = Accessibility to markets
$LF_9$ = Coastal area / tourism hotspot

Note the negative relationship for $LF_7$. Thus, the farther away a grid cell is from a market, the lower the probability that land use at that location changes to Urban.

► The regression equation above and similar equation for other land use types are specified in the file **alloc1.reg**. You will now briefly review that file.

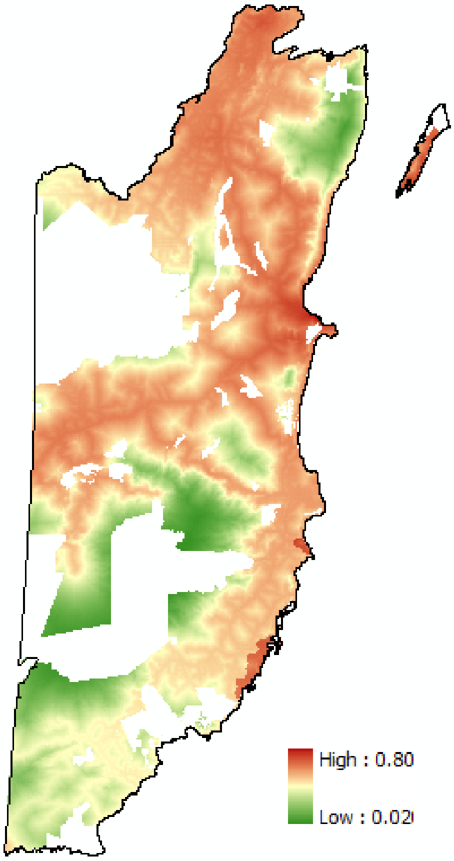
- Browse to the folder CLUE_BZ that contains all files for Belize.
- Right-click on the file ***alloc.1reg*** and open the file in a text editor such as Notepad or Textpad. You can select NotePad by choosing "*Open With*" and the selecting Notepad from the list of available programs.
- Scroll to the end of the file. Do you recognize the parameters from the equation above? Please refer to pages 22-23 of the CLUE-S user manual for more information about the precise format of this file.

The regression equations are important because during run-time CLUE-S uses these equations to create probability surface for every land use type. These surfaces show the probability of changes towards that land use type across the entire study area.

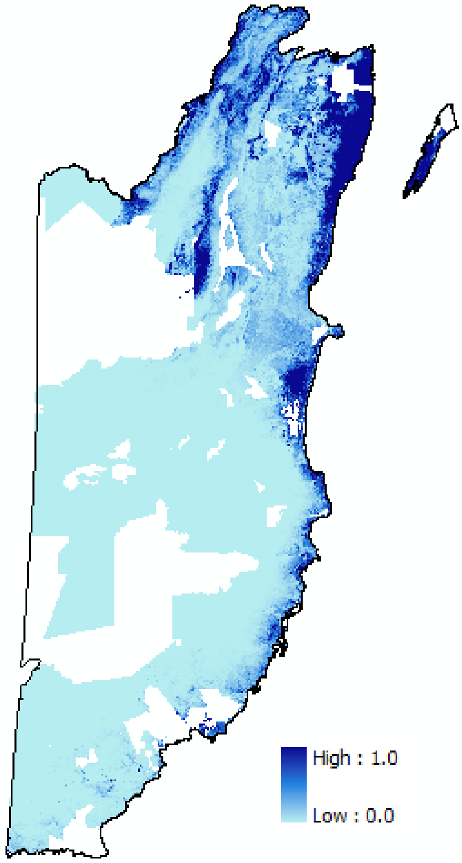
► Let's look at some of these probability surfaces.

- Using Windows Explorer, browse to the *..\Training/CLUES_BZ* directory and double-click **clues.exe** to start the model.
- Select "*Calculate Probability Maps*" from the Mode main menu.
- Select one of the area restriction files and one of the demand files.
- Press the "Run CLUE-S" button to start the model. The model will now only calculate the probability maps. This will take about 1-2 minutes. Press the "Calculations Finished" button but do not close the application.
- Go back to Windows Explorer in the CLUE_BZ folder and refresh the contents of the folder view. You should now see the probability surfaces that were created with the names ***prob1_0.1***, ***prob1_1.1***, …, and ***prob1_9.1***.
- Rename the extension of all ten probability files from ".1" to ".asc".
- Open ArcMap and ArcToolBox. Use the "ASCII to Raster" tool to import the files ***prob1_6.asc*** (probability for Wetland) and ***prob1_8.asc*** (probability surface for Urban). Make sure to select "FLOAT" as the Output data type.

- Review the output. It should look like the next figure (colors may be different). The highest probability for Urban should be near Belize City, near some other coastal areas, and close to the main highways. The probability for Wetland should be highest in the northeastern part of the country.




Probability surface for Urban




Probability surface for Wetland

**Note:** No probabilities are calculated for restricted areas ("no change" areas). These are *NoData* cells and are white coloured in the maps below. The probability surfaces are very useful for verification of the validity (significance) of regression equations and the restricted areas: Areas with the higher probabilities should correspond to where the land use type presently is.

## 4.3 Running a complete simulation run

► A full simulation run for Belize may take ½ to 1 hour, so it is unlikely that there is enough time during the training day to do this. However, you can try it, of course.

- In CLUE-S, unselect "*Calculate Probability Maps*" from the Mode main menu.
- Select an area restriction files and a land demand files. Note that you must combine files that have the same number (1 = Markets First; 2 = Policy First; 4 = Sustainability First). Then click the "Run CLUE-S button.
- When the simulation has completed, rename the file ***cov_all.21*** to ***cov_all_21.asc*** and import this file in ArcMap. Make sure to select "INTEGER" as the Output data type.Review the land use pattern.

**[End of exercise 4]**