Monitoring and Interpreting Landscape Change

Objectives:

Develop geospatial approaches for detecting, highlighting, and summarizing landscape change as might be observed in a long-term conservation monitoring program.

- Change in land cover type: development encroaching on natural areas
- Change in habitat condition: successional changes in forested natural areas

Introduction:

Once a reserve network has been established, conservation effort cannot cease. Adequate monitoring of the protected areas is required to ensure that conditions in the areas remain conducive to the missions of the project. In this exercise, we explore two monitoring strategies, both based on using remotely sensed datasets.

The setting for this exercise is our backyard, the Triangle Area here in North Carolina, where will be examining the status of Significant Natural Heritage Areas (SNHAs). SNHAs are areas of ecological importance that the NC Natural Heritage program has worked to protect, and we will examine just how well these areas have been protected by examining land cover trends over the period of 1985 to 2005.

First, we will use a **discrete change analysis** technique to assess the encroachment of development onto each SNHA over a span of 20 years. Which SNHA's are seeing more nearby land being converted from natural or agricultural cover types into residential and commercial land uses?

Second, we'll use a **continuous change analysis** technique to examine patterns of deforestation, afforestation, and succession within the Triangle region, and particularly within the SNHAs themselves. This will allow us to determine which SNHAs appear more "healthy" in terms of forest regrowth and/or succession, and which SNHA's appear to be losing forest.

Assignment:

At the end of each section is a set of questions. Answer the questions as they are posed to you. There is no need for a formal report, but some questions may be best answered by including a map. Please keep answers brief and to the point.

Discrete change in land cover: encroaching development

Using the National Land Cover Dataset (NLCD) for monitoring change

Monitoring change in the US is facilitated by the National Land Cover Dataset (NLCD) which includes classified land cover datasets for 1992, 2001, 2006, and most recently 2011. Having multiple snapshots of land cover across time allows us to simply query pixel values for a given location to see whether its assigned class has changed, and if so, how it has changed.

Of course, it's not altogether that easy. First of all, there have been some changes in the classification algorithms and resulting schemes among releases of the NLCD. For a while, the Multi-Resolution Land Characteristic Consortium (MLRC), who oversees the NLCD, did not recommend pixel-to-pixel comparisons between the 1992 and 2001 datasets for fear that observed changed may be a result of methodological differences and not actual ground cover change (http://www.epa.gov/mrlc/change.html). So, oddly enough, one of the key uses of having a multi-year dataset was scuttled.

The MLRC's solution to this was to produce a simplified change product for comparing 2001 to 1992 land cover (http://www.mrlc.gov/nlcdrlc.php). This dataset reduced the land cover classifications to a common denominator - Level I of the Anderson classification scheme (http://landcover.usgs.gov/pdf/anderson.pdf) - which allowed a per-pixel change analysis, but only at a crude thematic scale. This is still quite useful and informative, but not quite ideal.

The 2006 version of the NLCD, however, *is* compatible for comparison to the 2001 version. Likewise, the 2011 dataset with 2006. In fact, the MLRC distributes land cover change datasets saving you the effort of doing the analysis yourself. (See http://www.mrlc.gov/nlcd06_data.php.) They provide this change in two formats: the NLCD2006 Land Cover Change product, which contains only those pixels identified as changed between NLCD2001 Land Cover Version and NLCD2006 Land Cover products for the conterminous United States, and the NLCD2006 Maximum Potential Spectral Change, contains all pixels identified in the raw change detection process. Raw change includes areas of biomass increase and biomass decrease. Only a portion of these pixels were ultimately selected as real change during our final protocols.

When the NLCD doesn't quite fit your needs

In sum, the NLCD versions provide an excellent baseline for detecting changes in land cover within the US, particularly in comparing cover from 2006 to 2001 and 2011 to 2006. But what if you need land cover change data outside of the US? Or for times beyond 2001, 2006 or 2011? For that you need to look elsewhere, and if you don't find the data, you likely need to create the change datasets yourself using remote sensing techniques reviewed in class.

Land cover change datasets for the Triangle region

Joe Sexton, (Duke PhD, 2009) analyzed land cover change in the Triangle region and did need more than what the NLCD could offer. So, he and a Duke MEM (Mike Donahue, '08) "reverse engineered" the NLCD classification algorithm to derive NLCD equivalent datasets for several years between 1985 and 2005. (See http://www.sciencedirect.com/science/article/pii/S0034425712003926.)

These are the data we'll be using in our analysis of land use change in this exercise…

There are 10 land cover classes, simplified somewhat from the Anderson Level II classes in the NLCD, but certainly adequate for our task. The land cover maps and other files we'll need for this exercise are located in the Exercise6_ChangeAnalysis workspace, located in the Exercise6_ChangeAnalysis.zip file.

Analysis

Begin the analysis downloading the data and preparing your workspace.

1. Open the *ChangeAnalysis.mxd* map document.
2. Verify/set the model environment settings.
   - Set the Current Workspace to \Data and the Scratch Workspace to \Scratch
3. Enable the Spatial Analysis extension.
4. Create a new geoprocessing toolbox.
   - Add two new geoprocessing models to the Change Tools toolbox.
   - Name them "*Encroachment*" and "*Succession*"

Workflow Logic - Encroachment:

Our task here is to summarize the amount of development that has encroached near areas identified as Significant Natural Heritage Areas (SNHAs) by state conservation officials. To do this, we will need to:

1. Use the 1985 and the 2005 land cover datasets to identify areas: (i) where development has occurred, (ii) where development has subsided, or (iii) where no change has been observed in those 20 years.
2. Tabulate the net amount of development (newly developed areas minus lost developed areas) within a specified distance (1km) of each SNHA.

Step 1 – Creating the Change Sector Map

Step 1 can be accomplished multiple ways, but the overall simplest may be to create two binary rasters (developed = 1; everything else = 0) for both 1985 and 2005. Once those are created we can create a change map simply by subtracting the 1985 binary dataset from the 2005 one. The resulting dataset, we'll call this our "**change sector map**", will have a value of -1 where developed areas have been lost, 0 where no change has occurred, and 1 where land has been developed.

	2005	
1985	***Developed***	***Non-Developed***
Developed	0	-1
Not-Developed	1	0

- *In your Encroachment model, add the necessary geoprocessing tools to convert the 1985 and 2005 land cover datasets into binary developed/not-developed datasets, respectively. Note that "developed" categories in both datasets include values of 21, 22, 23, and 24.*
- *Add an additional tool to subtract the 1985 binary dataset from the 2005 one. The result will be the change sector map with values falling into one of the four "sectors" in the above table.*

- ➢ Create a simple map* zoomed to the William B. Umstead State Park SNHA displaying the SNHA boundary and the change sector map results. Add a sentence to your map *qualitatively* describing the amount of change occurring within the SNHA boundaries compared to what's just outside of it.

  **By simple, I mean there's no need for cartographic elements beyond showing the boundaries of Umstead State Park and the change sector categories - enough so that your description of change is understood.*

Step 2

Step 2 in the workflow, tabulating the amount of development that is encroaching the SNHAs, can also be done multiple ways. We will explore two approaches and then weigh the pros and cons of each.

The first approach involves finding all the cells within 1 km of each SNHA using the Euclidean Allocation tool, and then averaging the values of the change sector map created in step 1 within these areas to estimate the level of development encroaching on a given SNHA.

- *Add the <u>Euclidean Allocation</u> tool to the Encroachment model and configure it to label all pixels within 1 km of a SNHA to the value of the nearest SNHA.*
- *Add the necessary tool(s) to compute the mean value of the change sector map (the result of step 1 above) within these SNHA allocation* zones. *(Note that you ideally want to exclude the areas within the SNHAs and just use the areas 1km beyond their edge.) These mean values for each SNHA represent the area-weighted amount of development occurring within the 1 km buffer of the respective SNHA, i.e., "encroaching development".*

The above method extends the area of each SNHA and tabulates the net development occurring within these areas. However, we can approach this problem from the other end by creating a surface where each pixel represents the proportion of new development occurring within 1 km of it, and then use the existing SNHA areas to tabulate how much net encroaching development is found within its extent. In other words, we are finding areas within 1 km of development rather than finding areas within 1 km of a SNHA.

- *Add the <u>Focal Statistics</u> tool to your Encroachment model and set it to calculate the mean of all the binary difference map pixels within a 1km radius of a given cell.*
- *Add the necessary tool(s) to compute the mean values of the above focal statistics result for each SNHA. These values also reflect the amount of development within 1 km of the SNHA.*

Comparing Approaches:

Create two maps of the SNHA locations – one displaying encroachment values derived from the Euclidean Allocation approach and one displaying the values derived from the Focal Statistics approach. Display both with the encroachment values displayed in 5 quantiles using the same color ramp to facilitate *quantitative* comparison. Refer to these maps in answering the following questions:

- ➢ Create a simple map showing encroachment of development on SNHAs over the period of 1985 to 2005. Display mean encroachment values of the SNHAs classified as 5 quantiles (quintile). Include the legend in your map (so that we can see the breaks between the quantiles).

- Do both approaches indicate the exact same SNHAs in the most encroached quintile? Does this make sense?
- What drawbacks, if any, are there in using the Euclidean distance approach?
- What drawbacks, if any, are there in using the focal statistic approach?
- A third approach involves creating 1km *vector* buffers from each SNHA polygon. What would be the major challenge in using this approach? Can this challenge be overcome? If so how? If not, why not.

Continuous change in habitat condition: Forest succession

Discrete changes in land cover *type* are rather drastic, and often we are interested in more subtle changes in the *condition* of the land or particular habitats. In this exercise, we will assess changes in forest condition in terms of a vegetation index (NDVI) related to canopy leaf area. Increases in NDVI should reflect forest growth (or succession), while decreases might reflect natural thinning, disturbances (we have had two hurricanes, a tornado or two, and a few major ice storms over the past couple of decades!), or human activities. Because we have winter and summer pairs of NDVI indices, we also can separate deciduous leaf area from evergreens (almost entirely pines, in this study area). The pines that now characterize much of the Piedmont are historical transients, as the pines established during agricultural abandonment around the 1930's; these pine stands are now succeeding to second-growth hardwoods, and so we might expect to see this in changes in winter as compared to summer NDVI.

Workflow Logic – Continuous change:

In this analysis, we will measure and summarize the amount of change in NDVI (winter and summer) on a cell-by-cell basis, and then average this change within SNHAs. Successional change from pines to hardwoods would have some implications for the capacity of these forests to support pine specialists such as the pine warbler.

The logic of this tool echoes the Encroachment tool, in that we begin by creating new rasters that capture forested land in 1985 and 2005. Because we are interested in any lands that were forested at *either* date, we first need to isolate pixels that were classified as forest at either date. This can take a couple **Con** tools and the **Boolean Or** tool to create a single raster coded 1 for any pixel that was forested in *either* 1985 or 2005.

- *Create a binary raster dataset where forest cells from* **either** *the 1985* or *2005 data sets are coded as 1 and all other cells as 0. You may find it easiest to use two* ***Con*** *tools to isolate the forest values (41, 42, 43, & 95) from the 1985 and 2005 land cover datasets, respectively, and then us something like the* ***Boolean Or*** *tool to set forest pixels in either dataset to a value of 1. Ultimately, you want to create a mask of pixels that were classified as forest in either 1985 or 2005. (See Figure 1.)*

Next we create two difference maps for NDVI, one to capture the difference for <u>winter</u> between 1985 and 2005, and another for the NDVI difference in <u>summer</u> across the same time span. The winter difference reveals changes exclude deciduous trees, while the summer difference include both coniferous and deciduous trees. These are saved as cell-level difference maps ("**Summer NDVI difference**" and "**Winter NDVI difference**"). These cell-level differences are then masked to highlight only those areas that were forested (all pixels—even developed lands and water—show some change in "greenness" over time, but most of this is not interesting ecologically!).

- *Subtract the 1985 NDVIs from the 2005 NDVIs for the summer and then for the winter datasets.*
- *Mask out areas that are not forest, as defined by the dataset created above.*

Run the model, examining intermediate products as necessary to understand the processing. Can you see any general patterns in changes in winter or summer NDVI at this level of resolution? In particular, can you find areas that seem to be converting from pine to hardwood forest?

> ➢ Zoom to the extent of William B. Umstead State Park and create a map layout that shows the 1985-2005 NDVI per-pixel change for both the summer and the winter periods. Provide a brief interpretation of your map with respect to:
> - Any patterns of forest gain/loss within park boundaries vs. immediately surrounding it; and
> - Any patterns of succession you can determine in the park boundaries and surrounding areas.

Our last step is to summarize changes in NDVI for the SNHA regions. This is a straightforward Zonal Statistics averaging, using the raster version of the SNHAs.

- *Calculate zonal averages of the summer and winter NDVI differences for each SNHA region*

Run the model, again examining intermediate products as needed to understand the processing. Compare changes in winter and summer NDVI. Can you find SNHAs with comparatively high or low rates of forest change? Recall that a big increase in summer NDVI over time indicates general forest growth (deciduous or evergreen) while a big increase in winter NDVI over time indicated only evergreen growth.

If we subtract winter change from summer change then the differences logically reflect only changes in deciduous forest (since we deducted changes in evergreen) between 2005 and 1985. And since, generally speaking, deciduous trees often replace evergreen through the natural process of forest succession, large values in the difference between winter and summer change infer succession is occurring.

Change Analysis:

> ➢ Make a map with two map frames. In the first one, highlight two SNHAs – one healthy one that appears to have gained forest land over the period 1985-2005, and one un-healthy one that appears to have lost a good deal of forest cover over the same period.
>
> ➢ In the second map frame, again highlight two SNHAs. But this time, find one that appears to have undergone succession (i.e. where deciduous trees are appearing), and another where succession has not been as prominent. (Note you may have to create an additional data set to answer this…)

Summary:

In this lab, we have looked at discrete and continuous change at high resolution over a large study area. Discrete change, as measured by changes in categorical cover types, is by far the most common form of monitoring using remotely sensed imagery. Continuous change, by contrast, is much more sensitive to changes in ecological condition or ecological processes, but it is also more difficult (it requires more information in the remotely sensed data products) and it is more sensitive to signal:noise issues in the data. Still, it seems likely that monitoring will focus increasingly on continuous change as better imagery become available from new sensor platforms. Monitoring programs also will work harder on data fusion, merging field sampling programs with remote sensing technologies. These data will be managed, modeled, and interpreted in GIS.

Figure 1. Model to create a mask of pixels classified in either 1985 or 2005.