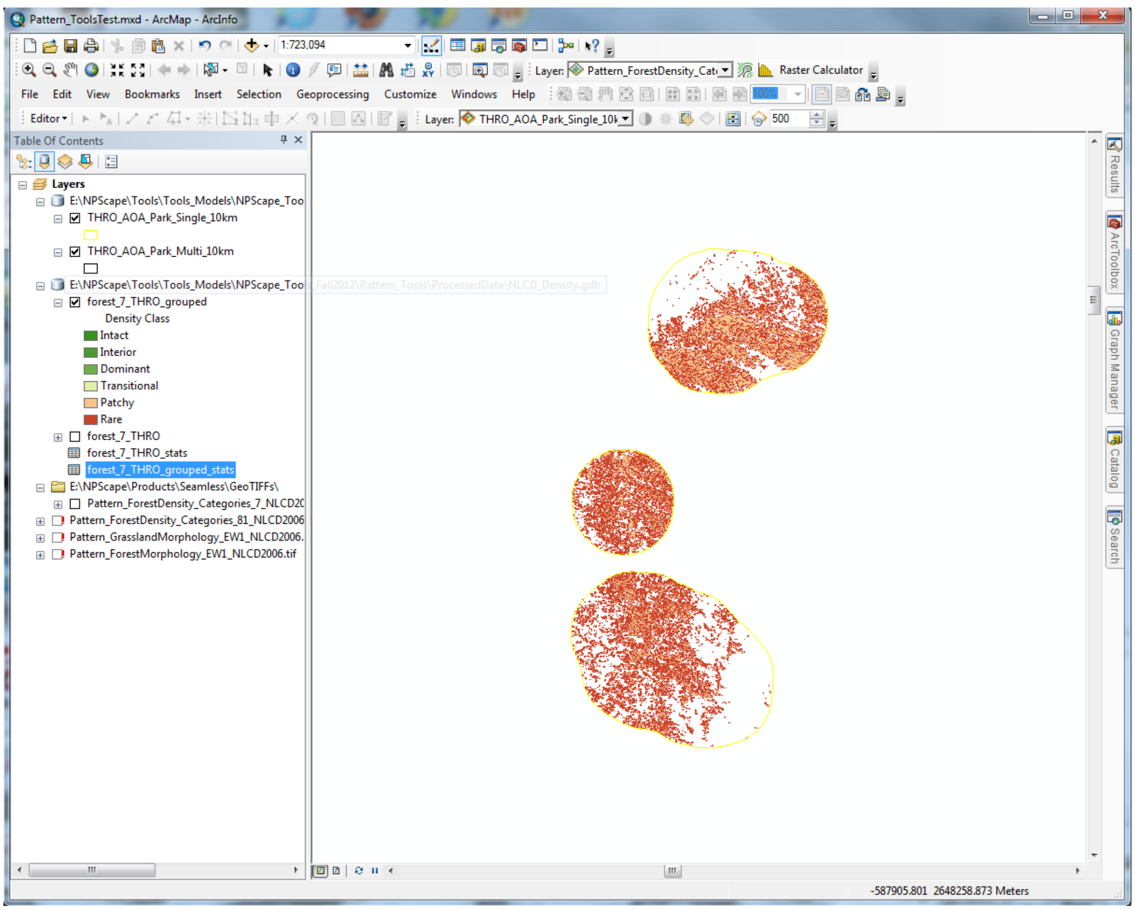
National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

NOTE: There may be revised processes and documentation available.

Check the NPScape methods webpage
(http://science.nature.nps.gov/im/monitor/npscape/methods.cfm)
for the most current version.

NPScape Standard Operating Procedure: Pattern Measure – Area Density



Suggested Citation: National Park Service. 2013. NPScape Standard Operating Procedure: Pattern Measure – Area Density. Version 2014-01-06. National Park Service, Natural Resource Stewardship and Science. Fort Collins, Colorado.

Contents

Version History		
Version	Update Date	Changes
20130313	20130213	Final draft to reflect seamless density data for NLCD 2006 and NALC 2005 (forest and grassland land cover types); added appendices to explain how to calculate density metrics on other cover types and/or source data
20130315	20130315	Note added regarding an issue in Geoprocessing Options between ArcMap 10.0 and 10.1 that could cause a script to fail in 10.1
20131223	20131223	Tool optimized for ArcMap 10.1, and tested for use with 10.2

Overview

NPScape is a landscape dynamics monitoring project that provides landscape-level data, tools, and evaluations for natural resource management, planning, and interpretation (NPS 2013). This standard operating procedure (SOP) provides guidance on how to process NPScape area density metrics used in classifying and describing spatial characteristics such as intact vs. patchy habitat, where cover type density is calculated based on different sizes of moving windows. NPScape offers pre-processed area density source data for forest and grassland cover types, estimated from the National Land Cover Dataset, NLCD (2006; 30 m resolution; Lower 48) and the North American Land Change Monitoring System, NALC (2005; 250 m resolution; AK, Canada, Lower 48, Mexico). Additional methods presented in the Appendices provide guidance on how to replicate these density metrics for other cover types or sources of land cover data. Download the tool(s) and a copy of this SOP here: [http://science.nature.nps.gov/im/monitor/npscape/methods.cfm.](http://science.nature.nps.gov/im/monitor/npscape/methods.cfm) The zip file includes an ArcGIS™ toolbox containing NPScape pattern script tools and a copy of this SOP document.

The purpose of this SOP is threefold. First, because these directions were followed in the processing of the NPS datasets, it provides detailed documentation on the methodology used by NPScape to calculate area density metrics for the Pattern measure. Second, this SOP provides any user with the ability to replicate the creation of these data for custom areas of analysis. Finally, if an I&M park or network has a need to analyze data other than forest of grassland density from NLCD or NALC, this SOP provides a processing template for recalculating focal metrics associated with the Pattern measure.

NPScape forest and grassland area density are calculated using a moving window analysis. First, a square neighborhood (window) for analysis is defined by the number of pixels on each side. The proportion of pixels in the window of a particular cover type (e.g., forest or grassland in this case) is calculated and assigned to the pixel in the center of the window (Riitters et al. 2000, 2002; Wickham et al. 2007, 2008). Because density is computed over (typically) large windows or areas, compared to other pattern metrics it is relatively insensitive to change (e.g., compared to a pixel-level pattern classification such as morphological spatial pattern analysis [MSPA]).

Riitters et al. (2003) and Riitters (2005) discuss and provide a method for scaling and mapping / interpreting clusters of pixels with similar scale-dependent characteristics. Results from the NPScape categorization of density values can be used to identify areas where the target cover type range from intact to rare.

NPScape pattern density metrics are intended to assist with monitoring questions related to habitat condition. In general, the value of this metric will be greatest when used in interpretations with other landscape metrics. See the NPScape Interpretive Guide for additional guidance (Monahan et al. 2012).

The National Land Cover Dataset (NLCD) is a high resolution raster of land cover for the continental United States. Pattern density metrics derived from NLCD and NALC include the following rasters, where <*> is the moving window size in pixels per edge (see Appendix 2 for thematic class details):

Pattern_<*Forest/Grassland*>Density_Categories_<*>_<NLCD2006/NALC2005>_Focal.tif

Grouped Density Class Definitions

Density Class	Density Category (p)
Intact	p = 1.0
Interior	$0.9 \le p < 1.0$
Dominant	$0.6 \le p < 0.9$
Transitional	$0.4 \le p < 0.6$
Patchy	$0.1 \le p < 0.4$
Rare	$0.0 \le p < 0.1$
None	p = 0.0

Preprocessed source data are available for the following window sizes (in number of pixels per edge): NLCD 7x7, 13x13, 27x27, 81x81, 243x243, and 729x729; NALC 7x7, 11x11, 15x15, 27x27, and 39x39. See Appendix 2 for detailed area values for these window sizes.

This document summarizes the methods used to generate these outputs for any area of analysis from the NPScape preprocessed source data. For details on how the preprocessed source data were created, see Appendix 5.

Using an ArcGIS™ toolbox, processing steps include clipping the input density source raster to the area of analysis (AOA), reclassifying the raster using an input reclassification table, calculating the total and class areas (km^2), and producing table summarizing area totals and percent total area for the AOA.

Any AOA can be used as long as its spatial reference matches that of the tool input data.

This SOP may be used with other (non-NLCD2006) tool input data if source density pre-processing is completed and specific criteria are met. For specific instructions for generating density source data from other sources or for other indicator cover types, see the Cover Type Extraction and Indicator Raster Creation section of Appendix 5, and Appendix 3 for additional details. The data sources were produced and tools tested using ESRI ArcGIS™ version 10.0 Service Pack 5.

Software Requirements

ArcGIS software is required to generate the metric outputs. The data sources and tools used are assumed to be in ESRI ArcGIS™ format, version 10 Service Pack 5 or higher.

Data Requirements

Forest and Grassland Density Rasters

Pattern_<*Forest/Grassland*>Density_Categories_<*>_NLCD2006_Focal.tif
Pattern_<*Forest/Grassland*>Density_Categories_<*>_NALC2005_Focal.tif
Download path: http://science.nature.nps.gov/im/monitor/npscape/gis_data.cfm

Note: tools can be run using NALC-derived pattern inputs instead of NLCD-derived data. NALC covers North America to the Mexico border and is available from the link above.

If you are a NPS user, you can contact the NPScape team to request a custom clipped extent: mailto:NRSS_NRPC_NPScape@nps.gov

See the Frequently Asked Questions section for other data access options.

Area of Analysis polygon

AOA polygons for boundaries and 3 km and 30 km buffers of parks, CEC ecoregions, FWS LCC polygons, and upstream watersheds (for selected parks) are available as NPScape datasets:
http://science.nature.nps.gov/im/monitor/npscape/methods.cfm

Alternatively, user-defined AOA polygons can be used if they conform to the input spatial reference.

Reclassification Tables:

NPScape uses reclassification (recode) tables to thematically group density pattern data into grouped density classes. See Appendix 2 for details. These tables are bundled with the NPScape Pattern Metrics tools zip file in the ToolData folder.

Input data spatial reference

For CONUS areas, the NPScape project uses USA Contiguous Albers Equal Area Conic USGS as its standard spatial reference. A local (i.e. custom, non-NPScape sourced) area of analysis polygon may be used if its spatial reference matches the NPScape-provided tool input raster or vector data. In this scenario, re-project your local AOA data (if necessary) and run repair geometry on it before running the tool(s). See the Frequently Asked Questions section for more details on re-projecting tool outputs or tool inputs.

Input Data Pre-Processing

Determine AOA polygon

If using an NPScape-sourced AOA, download the appropriate AOA geodatabase from the link in the Data Requirements section.

Re-project user-defined input datasets (if needed)

All user-defined, custom, non-NPScape sourced tool inputs (e.g. AOA polygon) must be in the USA Contiguous Albers Equal Area Conic USGS spatial reference if used with NPScape-sourced tool inputs.

1. Open ArcCatalog or ArcMap. Click the search button and search for 'Project'. Open the Project tool and re-project your data to USA Contiguous Albers Equal Area Conic USGS.
2. Search for 'Repair Geometry' and run that tool on your re-projected dataset.
3. See the Frequently Asked Questions section for more details.

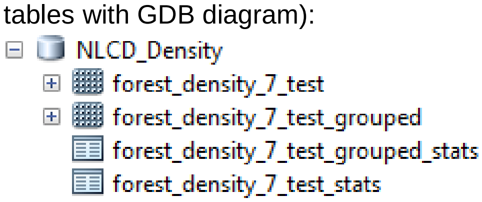
Download tool input dataset(s)

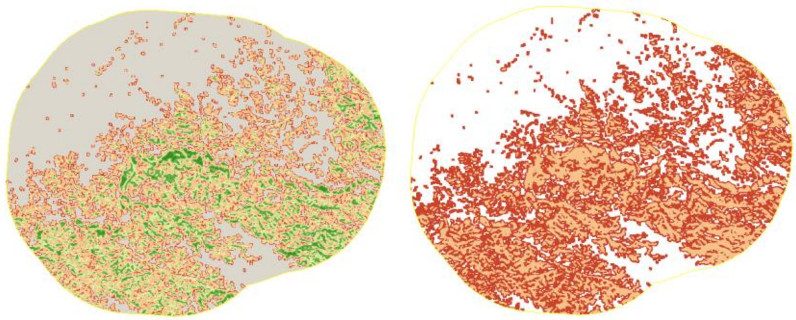
Download the forest and/or grassland Density tool input dataset (for desired edge width) from the link in the Data Requirements section. These datasets are seamless across the maximum available extent of the source data.

Run PatternDensity_Metric tool

This tool generates a file geodatabase containing Land Cover-derived density raster datasets and summary tables. These outputs correspond to the NPScape pattern density metric.

Example tool outputs (maps and tables with GDB diagram):

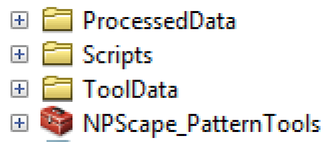




Ungrouped and grouped forest density classes for window size 7 at Theodore Roosevelt National Park

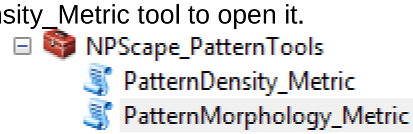
Add toolbox to ArcMap

1. Check Geoprocessing Options settings: Geoprocessing → Geoprocessing Options → 'Overwrite the Outputs of Geoprocessing Operations' should be checked. This addresses an issue in ArcGIS 10.1 Service Pack 1 when using feature layers.
2. Extract the tools zip file downloaded from the methods link in the Overview section above. The following folder structure will be created:



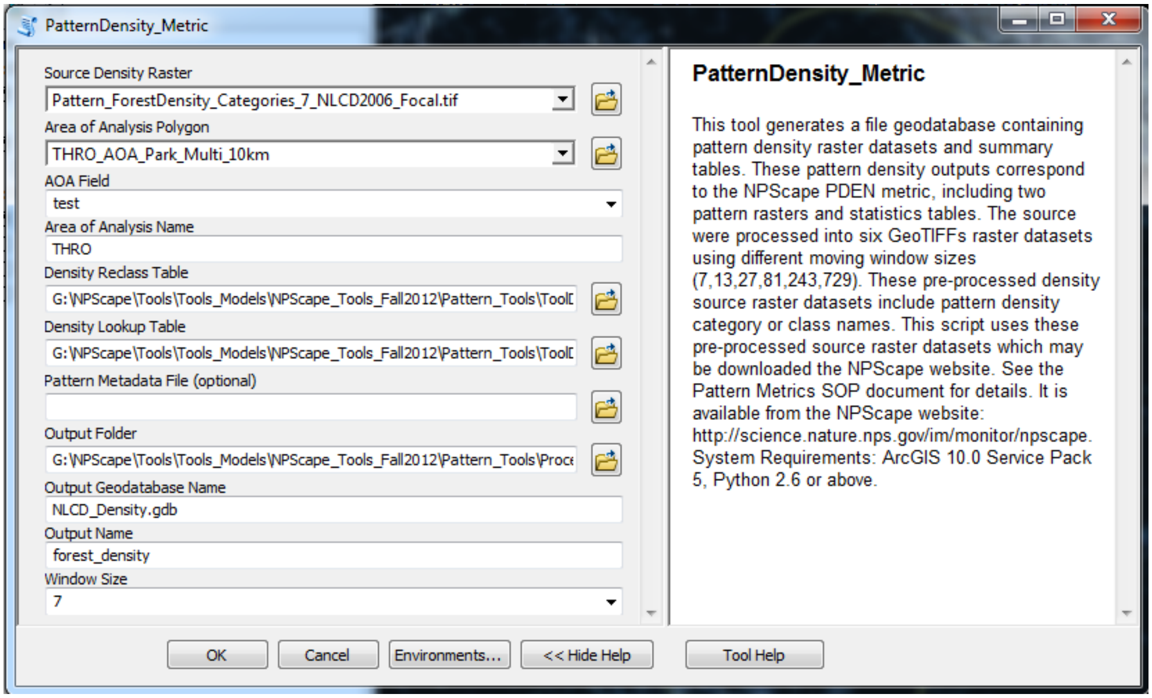
ProcessedData contains ArcMap layer files and is the default tool output folder. Scripts contains the Python code used by the NPScape_PatternTools.tbx toolbox.

3. Open ArcMap use the Catalog window to navigate to the folder where the tools were extracted. Open the NPScape_PatternTools toolbox.
4. Double-click on the PatternDensity_Metric tool to open it.



Run the PatternDensity_Metric Tool

1. Add input data to the map:
   - Tool input data: forest or grassland density GeoTIFF for desired window size
   - Polygon feature class for AOA (singlepart or multipart)
2. Populate values for each of the required parameters in the tool:



<u>Source Density Raster</u>: full path to the preprocessed NPScape density source raster (varies by focal cover type and window size setting)
<u>Area of Analysis Polygon</u>: location and name of the AOA polygon feature class
<u>AOA Field</u>: Text format attribute from Area of Analysis polygon. Used to label output rasters and tables for multi-feature AOAs. If AOA polygon is a single feature, only one output raster and output table will be generated.
<u>AOA Name</u>: name of the area of analysis (60 character limit)
<u>Density Reclass Table</u>: full path to the pattern reclassification table; located in Pattern_Tools\ToolData
<u>Pattern Metadata File</u> (optional): full path to the pattern metadata XML file
<u>Output Folder</u>: full path location of output folder; defaults to Pattern_Tools\ProcessedData; you must have write permission to this folder
<u>Output Geodatabase Name</u>: the output file geodatabase (must end with .gdb)
<u>Output Name</u>: Prefix for output raster and table names.
<u>Window Size</u>: moving window size of source input raster; added to output names as a suffix

3. Depending on the extent of the AOA feature class, the tool may take several minutes to run. Processing status will display in ArcMap, either as a popup or as a message in the geoprocessing background bar. The full tool summary is found in the ArcMap → Geoprocessing → Results popup, including error messages.
4. The clipped density raster, the grouped density raster, and the ungrouped and grouped AOA statistics statistics tables will be added automatically to the map. If single-part AOA polygons were used, only the rasters and statistics tables for the last feature will be added to the map. Other output rasters and tables can be added manually and symbolized as grouped density classes with *.lyr files in the ProcessedData subfolder.

5. See tables in the Interpretation Tips section for a description of attributes in the output rasters and statistics tables.
6. Running the tool again: open Geoprocessing → Results. Double-click on the PatternDensity_Metric tool name to open the tool dialog. Change parameters as needed. Change the output geodatabase name if you don't want your original output over-written.

Quality Control

Verify dataset outputs

1. Verify the expected rasters are created and that the AOA_NAME, CLASSNAME, TOTAL_AOA_AREA_SQKM, AOA_FEATURE_AREA_SQKM, TAREA_SQKM, AREA_SQKM, and PCT_AREA fields are present in AOA statistics table. If a multi-feature singlepart AOA polygon was used, there will be rasters and statistics tables for each AOA feature, named with the value of the AOA Field attribute. However, only outputs for the last feature processed will be added to the map automatically.
2. Verify that raster edges align correctly with each other and with the source raster. Use the Effects → Swipe tool to help verify this. Note that the NPScape layer files for pattern density (ProcessedData*.lyr) are used to standardize the raster symbology.
3. If outputs were generated for multiple window sizes (by re-running the tool), add those rasters to the map and zoom into an area and visually compare the outputs of the 7 cell window width raster with the other cell window width rasters. Check for alignment by swiping the top raster across the other rasters: the edges should. Note, rasters derived from grassland source rasters may not be contiguous for all areas of interest.
4. Look for areas of NODATA cells within the AOA. These cells are not included in statistics summaries, so care should be taken when interpreting outputs with NODATA areas.

Verify statistics output

1. Open each value attribute table and sort the PCT_AREA column in descending order. Look for outlying values (negative values, more than one value near 100, sum of values > 100).
2. By default, only the statistics table for the last feature is added to the map. Add the remaining statistics tables, if present, and sort each PCT_AREA column in descending order. Look for outlying values (negative values, more than one value near 100, sum of values > 100).
3. Select one record from each statistics table and double-check the PCT_AREA column values by re-calculating them by hand:

PCT_AREA = (AREA_SQKM / TAREA_SQKM) * 100

Interpretation Tips

Output raster and statistics table attributes:

Output density raster attributes:

VALUE	pattern class identifier
COUNT	number of cells in each pattern class
WINDOW_SIZE	Number of pixels on one edge; calculated from Window Size input parameter
CLASSNAME	Name of pattern class
AOA_Name	AOA name from AOA Identifier tool parameter concatenated with AOA Field value

Statistics table attributes:

CLASSNAME	Name of pattern class
WINDOW_SIZE	Number of pixels on one edge; calculated from Window Size input parameter
TOTAL_AOA_AREA_SQKM	Total area of the AOA in km^2, calculated from raster cells
AOA_FEATURE_AREA_SQKM	Total area of the AOA in km^2, calculated from polygon feature
TAREA_SQKM	Total class area in km^2, calculated from raster cells; (COUNT * cell size^2) / 1000000
AREA_SQKM	Class area in km^2, calculated from raster cells
PCT_AREA	Percent area of class, (AREA_SQKM/TAREA_SQKM) * 100
AOA_NAME	AOA name from AOA Identifier tool parameter concatenated with AOA Field value

Due to raster cell overlap outside the AOA polygon, the raster-derived total area value will be usually slightly larger than the polygon derived total area. In coastal or shoreline areas, the total AOA area values will be larger than the sum of TAREA_SQKM because source tool input rasters may have areas of NODATA values that begin a few kilometers off shore.

Frequently Asked Questions

Can/should I use a different spatial reference?

Any NPScape spatial output can be re-projected to a 'final' local spatial reference. For vector outputs, Repair Geometry should be run after re-projection. This approach should be noted in explanatory or interpretive documentation to avoid misleading the user; re-projection of an output dataset will have no effect on area attributes in the summary table generated by the NPScape script.

All NPScape tools generate area calculations from input data. If tool input data must be re-projected prior to running the tools, care should be taken to use a local spatial reference that distorts area minimally, such as an equal-area projection. For CONUS tool input datasets, NPScape uses USA Contiguous Albers Equal Area Conic USGS (NAD_83) as the spatial reference. Alaska-specific tool input datasets are in Alaska Albers Equal Area Conic (NAD_83) while Hawaii-specific datasets use UTM Zone 5N (NAD_83). UTM WGS84 Zone 55N is used for Saipan and Guam while UTN NAD83 Zone 2S is used for American Samoa.

Re-projecting vector input data:
NPScape tool input vector data can be re-projected prior to use as a tool input. The source dataset should be clipped to an extent larger than the intended area of analysis. Then, after clipping, Repair Geometry must be run to correct geometric errors. Finally, the clipped input can be re-projected to the local spatial reference, followed again with a Repair Geometry operation.

Re-projecting raster input data:
Re-projection to match a local spatial reference is not recommended for raster format NPScape tool input datasets. If re-projection is done, the source tool input raster should be clipped to an area of analysis rectangular extent first. Then, the Processing Extent → Snap Raster environment setting in ArcGIS should be populated with the source input tool raster. Warping will occur but should be less than it would be without the Snap Raster setting.

Alternatively, the AOA extent could be re-projected to the same spatial reference as the NPScape input raster followed by a repair geometry operation. Then, this polygon could be rasterized to a temporary raster dataset with a cell size matching the input raster, setting the snap raster to the input raster to minimize warping. Then, this temporary raster could be used to extract an area from the NPScape tool input raster. Finally, this extracted raster could be re-projected to the desired local spatial reference as described above.

I'm having trouble downloading the tool input dataset. Is there another way to get it?

Many tool input datasets are very large. Please contact the NPScape team to request a custom delivery and/or a custom clipped extent: mailto:NRSS_NRPC_NPScape@nps.gov

My outputs don't show up in my map. What can I do?

The tools use ArcGIS display layers to visualize the metric outputs. If you see a red **!** by the layer name in the map, the layer can't find the feature class or raster to which it is linked. The most common reason is that the Output Geodatabase Name parameter differed from what the tool script expected. Fix the problem by clicking the red **!** and navigating to the output geodatabase. Then, select the correct feature class or raster.

If a multi-feature singlepart AOA polygon was used, there will be an output raster or feature class and statistics table for each AOA feature, named with the value of the AOA Field attribute. However, only outputs for the last feature processed will be added to the map automatically. Add the remaining output rasters/feature classes and statistics tables. Use the *.lyr files in the ProcessedData subfolder to symbolize the features.

Literature Cited

Monahan, W. B., J. E. Gross, L. K. Svancara, and T. Philippi. 2012. A guide to interpreting NPScape data and analyses. Natural Resource Technical Report NPS/NRSS/NRTR—2012/578. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/App/Reference/Profile/2184927 (Accessed 20121130).

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Riitters, Kurt H. 2011. Spatial patterns of land cover in the United States: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-136. Asheville, NC: Department of Agriculture Forest Service, Southern Research Station. 64 p.

Riitters, K. H. 2005. Downscaling indicators of forest habitat structure from national assessments. Ecological Indicators 5:273-279.

Riitters, K. H., J. W. Coulston, and J. D. Wickham. 2003. Localizing national fragmentation statistics with forest type maps. Journal of Forestry 101:18-22.

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Riitters, K. H., J. D. Wickham, R. V. O'Neill, B. K. Jones, E. R. Smith, J. W. Coulston, T. G. Wade, and J. H. Smith. 2002. Fragmentation of continental United States forests. Ecosystems 5:815-822.

Wickham, J. D., K. H. Riitters, T. G. Wade, and J. W. Coulston. 2007. Temporal change in forest fragmentation at multiple scales. Landscape Ecology 22:481-489.

Wickham, J. D., K. H. Riitters, T. G. Wade, and C. Homer. 2008. Temporal change in fragmentation of continental US forests. Landscape Ecology 23:891-898.

Appendices

Appendix 1: Known issues

Data availability

Source NLCD and NALC-derived density tool input data are not available for off-shore parks (e.g. Dry Tortugas), Puerto Rico, the Virgin Islands, Hawaii, or the outlying Pacific Islands. Grassland source rasters may not be contiguous for all areas of interest

Data extent

Source NLCD-derived or NALC-derived raster data extend a few kilometers off the coasts and lakeshores of North America. Therefore, coastal AOAs may not include seamless coverage of the source data. In these areas, the AOA_FEATURE_AREA_SQKM attribute may be greater than the TAREA_SQKM value.

Appendix 2: Lookup and reclassification tables

Comparative Landscape Sizes for Pattern Density Analyses
(*shaded rows indicate NLCD-derived outputs*)

	NLCD			NALC		
Window Size (pixels per edge)	Pixel Size (m)	Area (hA)	Area (acres)	Pixel Size (m)	Area (hA)	Area (acres)
5	30	2.25	5.56	250	156.25	386.10
7	30	4.41	10.90	250	306.25	756.76
9	30	7.29	18.01	250	506.25	1250.97
11	30	10.89	26.91	250	756.25	1868.73
13	30	15.21	37.58	250	1056.25	2610.05
15	30	20.25	50.04	250	1406.25	3474.92
21	30	39.69	98.08	250	2756.25	6810.84
27	30	65.61	162.13	250	4556.25	11258.74
33	30	98.01	242.19	250	6806.25	16818.61
39	30	136.89	338.26	250	9506.25	23490.46
45	30	182.25	450.35	250	12656.25	31274.27
51		N/A	N/A	250	16256.25	40170.07
57		N/A	N/A	250	20306.25	50177.84
69		N/A	N/A	250	29756.25	73529.29
81	30	590.49	1459.13	250	41006.25	101328.65
243	30	5314.41	13132.19	250	369056.25	911957.85
729	30	47829.69	118189.74	250	3321506.25	8207620.67

Density Category and Grouped Category Reclassification Table

Byte Value Range	Category Value	Category Classname	Grouped Density Class Value	Grouped Density Class Classname
0	0	Missing		
1	1	No focal landcover	1	None
2 - 12	2	>0% to <5%	2	Rare
13 - 25	3	5% to <10%		
26 - 38	4	10% to <15%	3	Patchy
39 - 50	5	15% to < 20%		
51 - 63	6	20% to <25%		
64 - 76	7	25% to <30%		
77 - 88	8	30% to <35%		
89 - 101	9	35% to <40%		
102 - 114	10	40% to <45%	4	Transitional
115 - 127	11	45% to <50%		
128 - 139	12	50% to <55%		
140 - 152	13	55% to <60%		
153 - 165	14	60% to <65%	5	Dominant
166 - 177	15	65% to <70%		
178 - 190	16	70% to <75%		
191 - 203	17	75% to <80%		
204 - 215	18	80% to <85%		
216 - 228	19	85% to <90%		
229 - 241	20	90% to <95%	6	Interior
242 - 254	21	95% to <100%		
255	22	100%	7	Intact

Appendix 3: Using custom AOAs and/or local input data

Custom AOAs

The AOA feature class should include a text attribute with a name value for the AOA feature(s). This text attribute should not contain '/' or other special characters. The feature class can contain single or multi-part polygons. If single-part polygons are used, an output raster and statistics table will be produced for each feature, named with the attribute value selected in the AOA_Field parameter.

Local input data

Density tool input can be generated from land cover sources other than NLCD2006 and/or cover types other than forest and grassland. Follow the Processing steps – Creating Custom Tool Input Rasters instructions in Appendix 5 to produce custom density tool input rasters.

Appendix 4: Tool scripts

See Scripts subfolder for Python scripts used by the metric tool(s).

Appendix 5: Tool input and metric data processing details

Source data

Information in this appendix was excerpted from details provided by Kurt Riitters (KR) on 12 June 2009 (original email edited by John Gross). In this appendix, “NLCD” always refers to the 2001 NLCD land cover dataset. These notes are included because they also generally inform the processing and interpretation of NLCD 2006 and NALC density metrics. For more up-to-date information, see Riitters, 2011.

Comparability with NLCD

Generally, the goal was to have a pattern value for every pixel that was not null on the NLCD map. That was accomplished during the processing. But, when I (KR) put things together by State later on, I clipped everything to the detailed State boundaries in the ESRI data/maps collection, using a 30-m pixelated version of those detailed state boundaries. So you will not find pattern values for places like extraterritorial ocean, even if those places were included in the computations of the indices.

The projections are the same as the NLCD.

Everything should be overlay-able pixel-by-pixel with the original NLCD (2001). In some instances there may be a 1/2 pixel (or less) offset from NLCD which should not affect intersections with NLCD. There should not be any slivers between states when you recombine the grids for several states.

The ability to intersect with the original NLCD 2001 is really important, because some of the pattern measures will likely be summarized by original land-cover, and error will occur if the intersection of original and ‘derived’ measures is not accurate.

For example the 'area-density' (fden and gden, for forest and grassland density, respectively) maps show non-null pattern values for all pixels in a State, whether or not a given pixel is the focal class land cover or not. In other words, one can have a 'forest density' context even if one is not forest oneself. The decision to intersect or not depends on if you want to summarize forest (or grass) density in the vicinity of an arbitrary location in a park, or only in the vicinity of the focal class in the park. The former is more descriptive of landscapes, the latter is more descriptive of focal class patterns. I typically intersect with focal class land cover to make inferences about focal class pattern. The maps are not intersected in this way, to preserve options for other types of summaries, for example forest density in the vicinity of urban pixels, etc. This same consideration also applies to the 'landscape pattern type' (aka 'mosaic') maps.

This consideration does not apply to the 'morphology' (aka 'mspa') maps, for which the patterns are only shown for the focal class pixels (and the non-focal class pixels are set to the MSPA class 'background', see Vogt 2008).

Legend / Pixel values on the "area density" maps

The values 0-22 appear on the maps/attribute tables. The table below is the translation to "Px" (forest area density, grass area density). The ‘Recoded Class’ is the pixel ‘density class’ value in the attribute table (0-22), and the fourth column is the definition of each density class. Min and max values are the bin ranges.

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Conversion of raw density values to classes for forest and grassland density:

Min Val	Max Val	Recoded Class	Definition of recoded class
0	0	0	true missing (window contains no valid land cover pixels)
1	1	1	exactly zero (window contains land cover, but none of the focal class land cover)
2	12	2	0<Px<5
13	25	3	5<=Px<10 at least 5 but less than 10
26	38	4	10<=Px<15

Min Val	Max Val	Recoded Class	Definition of recoded class
39	50	5	15<=Px<20
51	63	6	20<=Px<25
64	76	7	25<=Px<30
77	88	8	30<=Px<35
89	101	9	35<=Px<40
102	114	10	40<=Px<45
115	127	11	45<=Px<50
128	139	12	50<=Px<55
140	152	13	55<=Px<60
153	165	14	60<=Px<65
166	177	15	65<=Px<70
178	190	16	70<=Px<75
191	203	17	75<=Px<80
204	215	18	80<=Px<85
216	228	19	85<=Px<90
229	241	20	90<=Px<95 at least 90 but less than 95
242	254	21	95<=Px<100 at least 95 but less than 100
255	255	22	exactly 100%

The densities are first calculated as real numbers in the range from 0.0 to 1.0, and then converted to 8-bit integers by:

MapValue = (RealValue * 254) + 1

MapValue = 0 is reserved for 'true' missing.

This conversion results in loss of precision, as does a small window (like 7x7 which only has 49 possible values). If the window is partly missing, the calculations are based on whatever is there, and there is no minimum number of pixels required to calculate a value for a particular window.

<u>Processing steps – Creating Custom Tool Input Rasters</u>
The following steps were used to process NLCD 2006 land cover into density outputs for all window sizes (Riitters 2011). <u>*As an example, shrub land cover from the 2006 National Land Cover Dataset (NLCD2006) is used as input to generate density rasters for shrub land using, ArcGIS v10. If other land cover density is needed (e.g. forest, grassland, etc), the extraction mask class(es) should be changed appropriately.*</u>

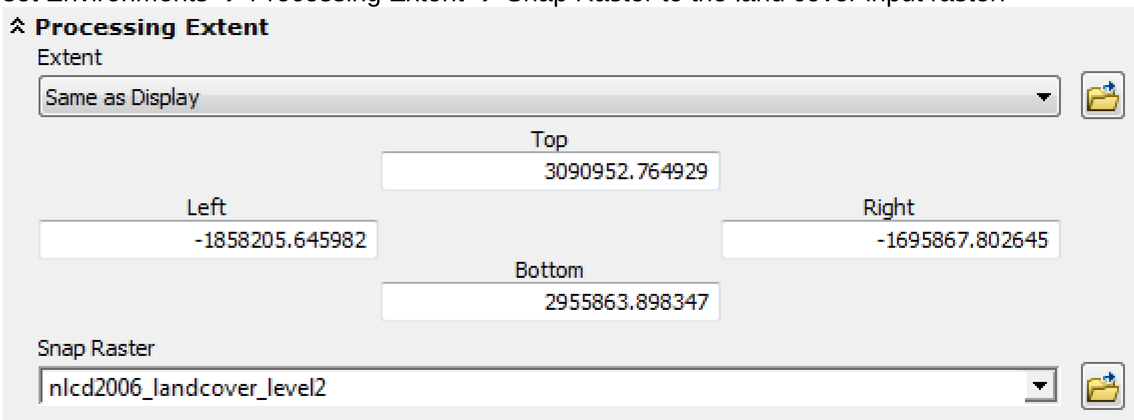
The processing steps include generating an extraction mask for the land cover thematic class of interest (e.g., shrub land) and extracting these pixels from the source land cover dataset. Then, the extracted raster is reclassified to produce an indicator raster for use in density processing.

<u>Cover Type Extraction and Indicator Raster Creation</u>

<u>Determine cover type of interest, extract and reclassify pixels</u>

Determine the cover type of interest and its corresponding pixel value(s). An 8-bit, GeoTIFF format indicator raster with two thematic classes should be produced: Value == 2 for target cover type pixels and Value == 1 for non-target cover type pixels.

1. Load the input land cover source raster into ArcMap. Zoom to the area of analysis. Open the Spatial Analyst → Conditional → Con *tool.*
2. *VERY IMPORTANT*: Set Environments → Processing Extent → Extent to 'Same as Display' and set Environments → Processing Extent → Snap Raster to the land cover input raster:

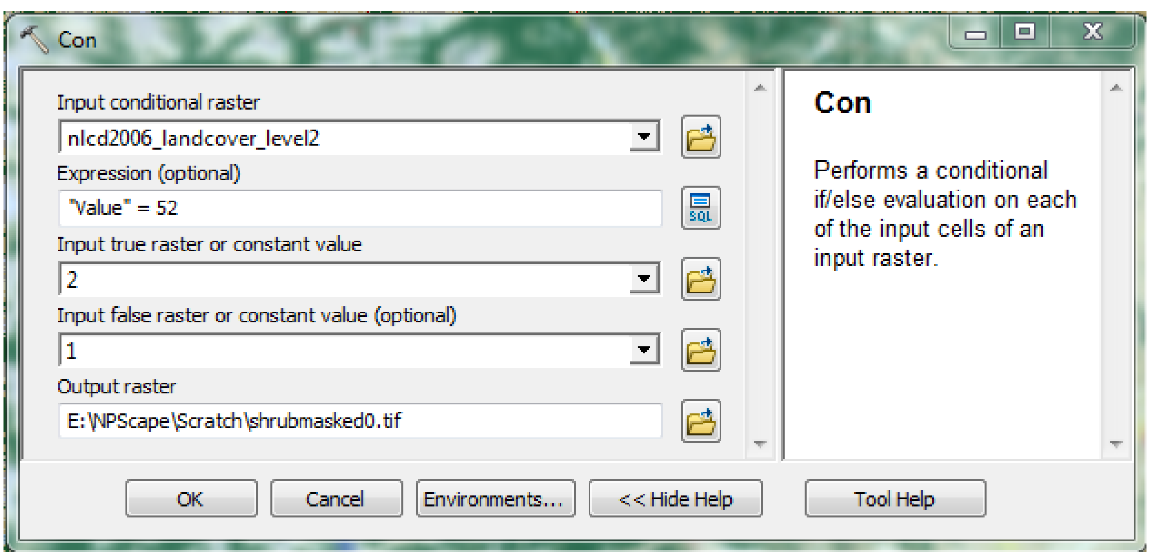


3. Create the interim indicator raster using the Spatial Analyst → Conditional → Con tool to extract pixels for the cover type. The Con logic finds the target pixels and generates an interim output raster with those pixels assigned a value equal to 2. All non-target pixels are assigned a value equal to 1. Depending on the size of the area of analysis, this operation may take several hours to complete.

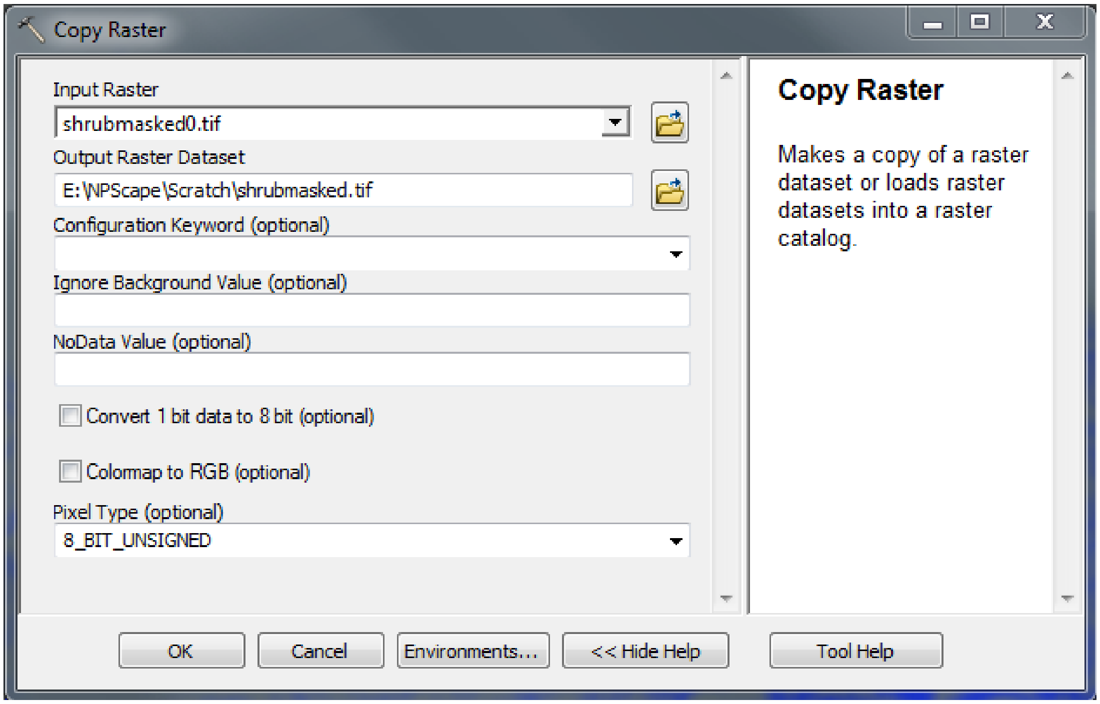
   Example shrub land syntax (python):

   ```
   outCon = Con((Raster(inputRaster) == 52) ,2, 1)
   ```

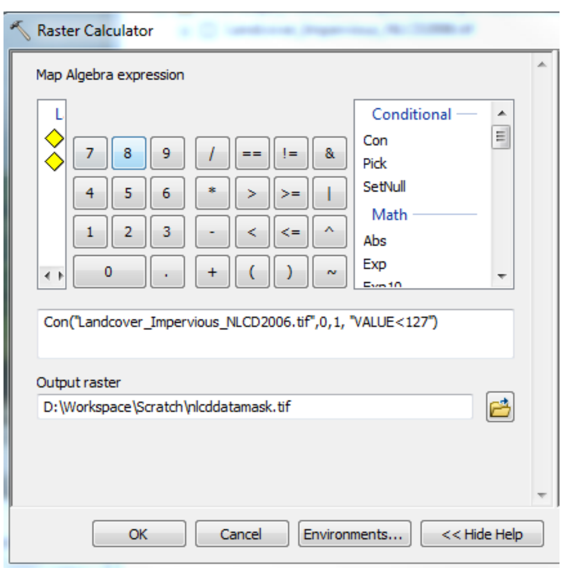
   Example tool settings for shrub land (NLCD source):



4. Run Data Management → Raster → Raster Properties → Build Raster Attribute Table with the overwrite option selected on the interim raster.
5. If the interim raster is anything other than 8-bit unsigned, use Data Management → Raster → Raster Dataset → CopyRaster to create the 8-bit unsigned indicator raster. Click on Environments. Select Processing Extent → Snap Raster and set its value to the extracted raster. Select Raster Storage → Compression and set it to 'NONE'.
   Populate the options as shown to create the 8-bit GeoTIFF indicator raster:



6. Run Data Management → Raster → Raster Properties → Build Raster Attribute Table with the overwrite option selected on the 8-bit indicator raster.
7. Finally, run Data Management → Raster → Raster Properties → Build Pyramids on the indicator raster.
8. To generate a mask for use in modifying density and morphology outputs, use the NLCD 2006 impervious surface raster and re-classify it into a mask of NLCD 'data' areas (0) vs nodata (1) using Spatial Analyst Tools → Map Algebra → Raster Calculator: Con("Landcover_NLCD2006.tif",0,1, "VALUE<127")



Calculate Density Values

The ArcGIS Focal Statistics tool and Conditional tool (Con) are used to generate density rasters for each moving window size. See Appendix 2 for window size details.

Three types of density values are calculated: raw density percentages (Pf), scaled byte values (Sf), and categorized scaled densities. These values are generated using a combination of focal (neighborhood) sums and counts.

$$Pfy = \frac{\text{adjusted focal sum for cover type x}}{\text{focal count for cover type x}} \qquad \text{where y = window size}$$

For each focal landscape area (i.e. moving window), a focal count of candidate pixels is generated from the indicator raster. This value accounts for the proportional occurrence of target cover type pixels within the landscape area. In other words, it adjusts for NoData areas and minimizes edge effects from the target cover type. The adjusted focal sum is calculated from the binary cover type raster.

$$Sfy = Int((Pfy * 254) + 1) \qquad \text{where y = window size}$$

The scaled byte values for landscape area y are calculated by adjusting the raw density values (Pf) to a 1-255 scale. This does result in a loss of precision, but this was deemed acceptable given the relative coarseness of the source landcover data.

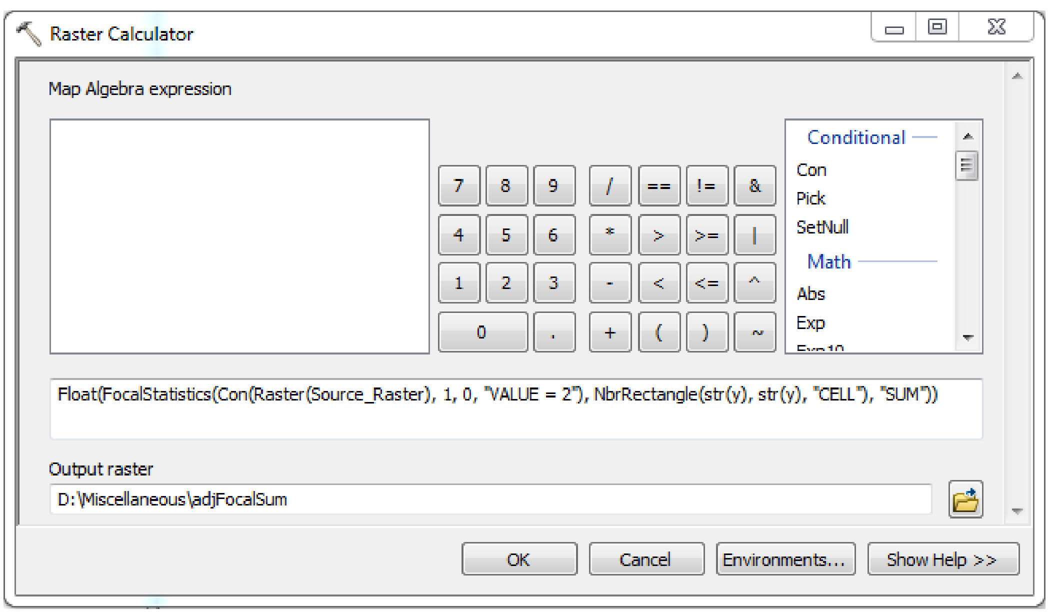
The categorized scaled densities are generated by reclassifying the scaled byte values into grouped density classes. See Appendix 2 for reclassification details.

Using Raster Calculator to generate Pf, Sf, and categorized scaled density values

Note: Source_Raster is the cover type indicator raster discussed above.

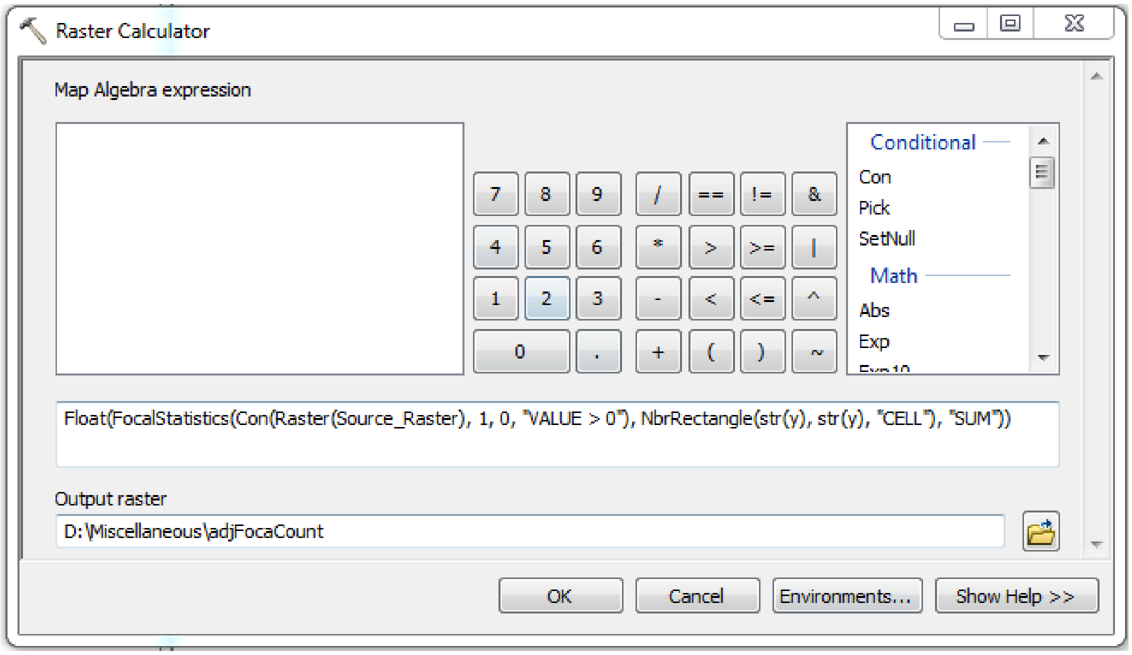
Adjusted focal sum for cover type x and window size y:

```
Float(FocalStatistics(Con(Raster(Source_Raster), 1, 0, "VALUE = 2"),
NbrRectangle(str(y), str(y), "CELL"), "SUM"))
```



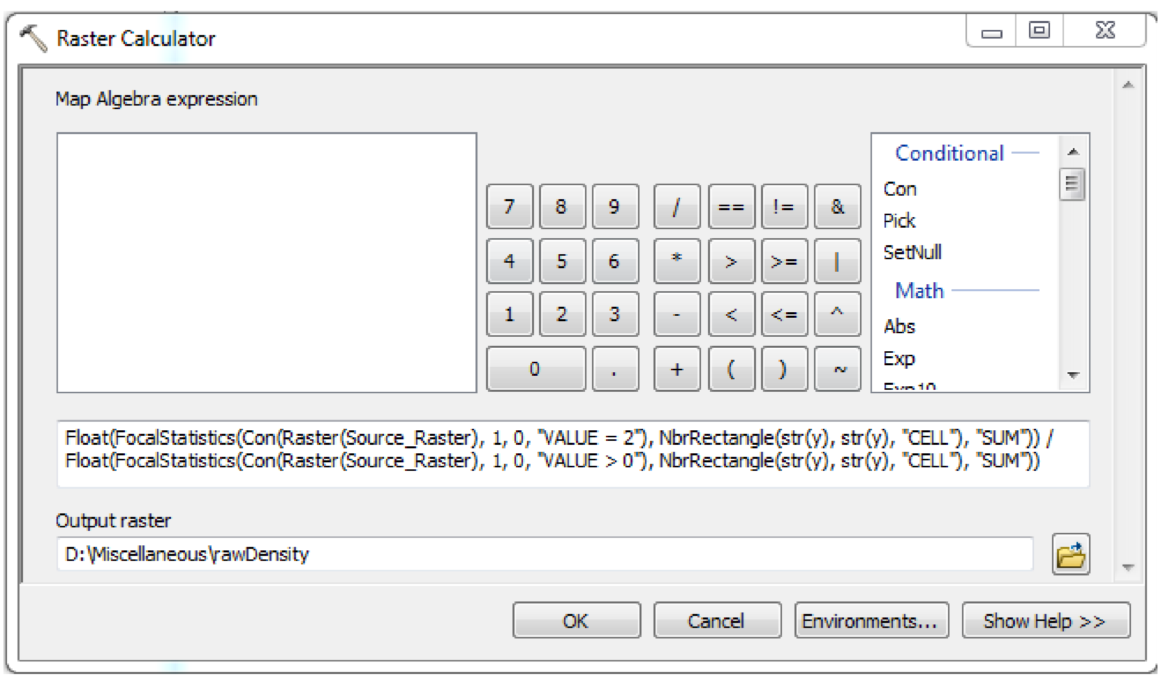
Focal count for cover type x and window size y:

```
Float(FocalStatistics(Con(Raster(Source_Raster), 1, 0, "VALUE > 0"),
NbrRectangle(str(y), str(y), "CELL"), "SUM"))
```



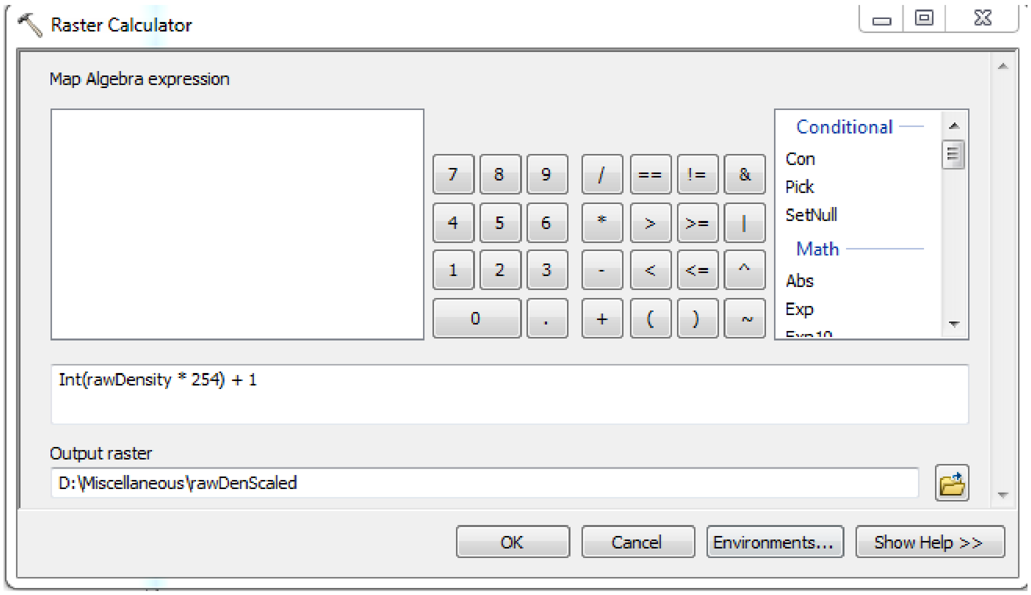
Combining two steps above to produce raw density percentage for cover type x and window size y (Pfx):

```
Float(FocalStatistics(Con(Raster(Source_Raster), 1, 0, "VALUE = 2"),
NbrRectangle(str(y), str(y), "CELL"), "SUM")) /
Float(FocalStatistics(Con(Raster(Source_Raster), 1, 0, "VALUE > 0"),
NbrRectangle(str(y), str(y), "CELL"), "SUM"))
```



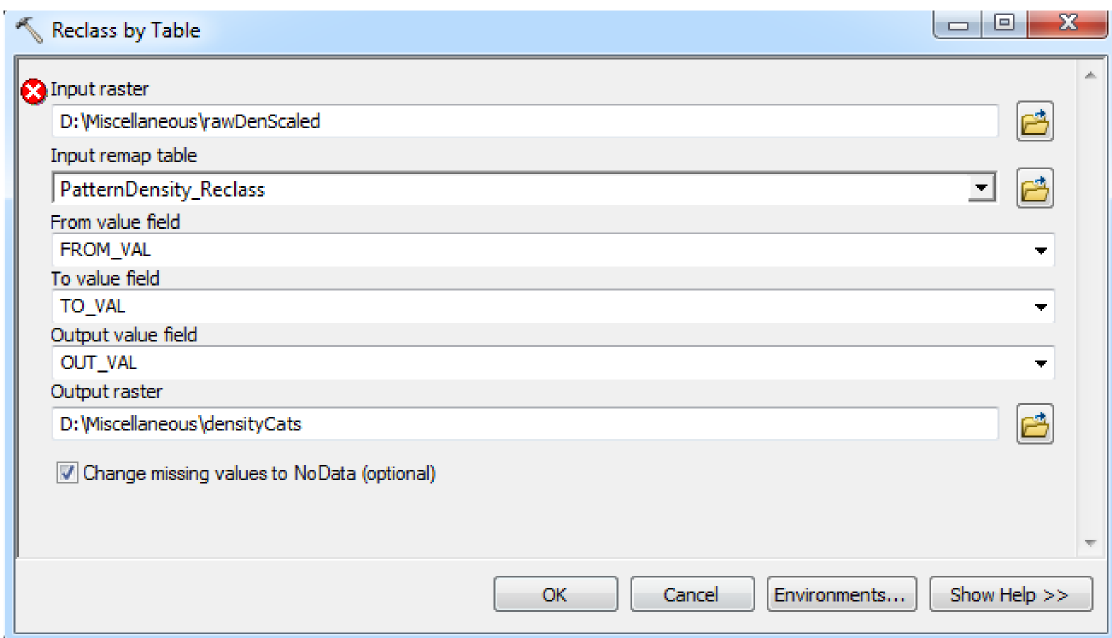
Scaled byte values for cover type x and window size y (Sfx):

```
Int(Pfx raster * 254) + 1
```



Categorized scaled density for cover type x and window size y:

```
ReclassByTable(Sfx raster, Reclass_Table, "FROM_VAL", "TO_VAL", "OUT_VAL", "NODATA")
```



See the Density Category and Grouped Category Reclassification Table in Appendix 2 for re-classification values.