

PALMS Standard Operation Procedure

Ecosystem type change and fragmentation: From pre Euro-American settlement to present day

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Introduction

Habitat destruction and fragmentation are leading causes of loss of biodiversity and ecosystem function globally (Sala 2000). Fragmentation involves both loss of habitat and change in spatial configuration towards smaller, less connected patches (Urban et al Bioscience 1984). It is particularly loss of habitat area that has the largest negative effect on biodiversity (Fahig paper). National parks are undergoing loss of habitat both in their boundaries and in the surrounding ecosystems they are contained within, largely due to land use change and intensification (Hansen and DeFries 2007).

It is likely that land use affects specific habitat or ecosystem types in different ways. As land use is a non-randomly distributed occurrence on the landscape, so are ecosystem types. As such, the overlay of land use and ecosystem type through time is expected to be nonrandom with patterns of change distinct to each ecosystem type.

The following standard operating procedure (SOP) from the Park Analysis of Landscapes and Monitoring Support (PALMS, see Estimating Protected-Area Centered Ecosystems, Appendix A for a complete description), project uses the protected-area centered ecosystem (PACE) as an organizing unit for analysis and reporting to inform management decision-makers of change in ecosystem type area and fragmentation through time. The goal is to delineate areas which are currently impacted by land use and report the change in undeveloped ecosystem type area on private and public lands since the Pre-Columbian era. This SOP also reports some basic fragmentation statistics for each ecosystem type through time as a way to examine how patch sizes and patch connectivity have changed in the presence of contemporary human land uses.

It is expected that land use impacts will differ by ecosystem type and that the pattern of these impacts through time will help managers identify which ecosystem types have been most impacted to date and which are most at risk of being impacted by future development. This kind of information can be used to prioritize future conservation efforts and to focus research and monitoring attention on particular areas of the PACE.

LIMITATIONS

All analyses herein require that a protected-area centered ecosystem (PACE) boundary has been generated for the park in question. See PALMS SOP Estimating Protected-area Centered Ecosystems included in this PALMS deliverables package for methods to generate a PACE boundary (Piekielek et al. 2010).

The ecosystem types used in this analysis are based on National Vegetation Classification System (NVCS) ecological systems that were modeled by the LANDFIRE project 2008 based on biophysical setting and presumed historic disturbance regime. The modeled systems are meant to represent the state of vegetation communities prior to European settlement. As such, they may not represent actual vegetation assemblages as they currently exist on the ground today. In some cases assemblages of species were modeled to have existed under historic conditions that are not observed today. In other cases vegetation communities that are observed or considered of importance today were not modeled to exist under historic conditions. The following analysis aggregates modeled ecological systems into ecosystem types of interest to the user.

As there are no methods to distinguish what natural communities existed prior to land use conversion, the methods presented in this SOP provides the most defensible and consistent way to quantify the effects of land use change on specific ecosystem types of interest to each park within their respective PACE area. In areas where ecological systems are largely biophysically limited the modeled data may closely match present day vegetation maps whereas in other areas they may not. In areas where vegetation communities are either already dramatically altered from historic land use, or where vegetation communities are not biophysically controlled the modeled ecological systems used in the following analysis do not likely match the distribution of present day vegetation.

The results of this SOP present area change and fragmentation for each ecosystem type through time. These results imply a complete loss of ecological function in ecosystem types that have experienced or are within a buffer distance of present day development. This is not likely to be the case.

Despite all of the limitations of these methods their results will be informative when compared across ecosystem types and examined for trends through time, as opposed to rigorous quantifications of area lost to development.

PERSONNEL

The following standard operating procedure (SOP) is an exercise in spatial analyses using geographical information systems (GIS) software. In addition to GIS skills, the user should also have substantial knowledge of vegetation communities and the nomenclature and classification structure used by the National Vegetation Classification System (NVCS).

SOFTWARE, KNOWLEDGE AND SKILLS

The following set of instructions was written for use with ESRI's ArcGIS (v9.2), although should be achievable with prior or forthcoming versions of ArcGIS or similar software. You will need the full suite of ArcGIS desktop tools including ArcCatalog and ArcToolbox, including the spatial analyst extension. A few steps also require ArcINFO Workstation and FRAGSTATs, although there are other ways to achieve the same results for these steps using other ArcGIS software packages. A skilled GIS user will likely recognize a variety of methods that could be employed in this SOP to achieve the same end result. More than a cookbook set of instructions, this SOP presents an approach to using existing datasets and software tools to examine ecosystem type change through time.

The practitioner implementing this SOP should be an experienced and knowledgeable GIS user familiar with spatial datasets, projections, basic data management and have access to a host of base cartographic data layers for each park such as boundary files, digital elevation models, roads, towns, National Land cover data (NLCD), and others. The following instructions do not cover basic skills that are assumed of the user already such as knowledge of how to search for, download and import spatial data into a GIS from internet sources, chose a projection in which to work, reprojecting data into a common projection, datum transformations and project management in ArcGIS. As a reminder, always carefully choose a projection in which to work and reproject data from different sources into that common projection using the appropriate datum transformations. Careful project management is vital to producing high-quality results from any GIS exercise.

ArcGIS tools in each step of the following instructions are invoked without specific reference to their location in ArcToolbox or ArcGIS toolbars. An experienced GIS user will likely be familiar with these tools and their use. However, if some steps are new to the user, a good way to locate tools is to use the "Search" function in ArcToolbox. The names of most tools in the document that follows are quoted so that the user can type these names into the ArcToolbox search function. The user will become familiar with the location and use of a variety of tools by the end of this SOP. The ArcGIS Desktop help menu, ArcGIS Desktop online help, and www.esri.com "knowledgebase" are also useful places to find helpful and more detailed information than is provided in this document.

This document has been written so that any confident GIS user should be able to complete the following steps. Implementation of this SOP should not be limited to GIS professionals alone unless they possess all relevant knowledge and expertise.

DATA REQUIRED

Some datasets used in the following analyzes are provided within this SOP package from the PALMS project. LANDFIRE data used in these analyses will need to be downloaded from the LANDFIRE program, see SOP1 "Estimating Park-Centered Ecosystems" page 10 for information on how to access LANDFIRE data.

Although there is no plan to update any of the included datasets, there are numerous programs which will likely generate similar datasets in the future and which could be used in update analyses. It is incumbent upon the user to locate, download and incorporate any data updates into future analyses. The following is a brief description of datasets included with this SOP:

1. CUS_UPPT_100 – this layer was generated by Theobald (2005) by combining a number of datasets to classify land ownership in the contiguous U.S. as one of four classes: private; private protected; public; Indian tribal. This layer is provided as part of the deliverables package with the PALMS SOP Estimating Protected-Area Centered Ecosystems package.
2. Hd_2000 – modeled housing density produced by Theobald (2005) at the 100 meter scale for the contiguous US for year 2000. This layer is provided as part of the PALMS SOP Analyzing Protected-area Centered Ecosystems deliverables package.
3. NPS Vegetation mapping program map for error checking if desired.

Identify ecosystem types of interest

The following steps use National Vegetation Classification System (NVCS) ecological systems and aggregations of these systems to represent ecosystem types of interest to the user. The steps are flexible in scale to accommodate ecosystem types at several levels of organization represented in LANDFIRE datasets and based on the NVCS.

Potential Issues

- ✓ There are cases where the LANDFIRE biophysical setting (bps) layer has modeled an ecological system that does not exist on the contemporary landscape (i.e. does not exist in the LANDFIRE existing vegetation type (evt) layer)
- ✓ There are cases where ecological systems observed on the present day landscape were not modeled to have existed historically by the LANDFIRE bps layer. This is especially true of disturbed and invasive species assemblages
- ✓ The LANDFIRE bps layer models historical ecosystem types with an unknown accuracy
- ✓ Ecological systems are not part of the National Vegetation Classification System (NVCS) hierarchy, but rather a particular vegetation association or alliance can be present in as many ecological systems as it occurs in unique ecological settings on the landscape.
- ✓ The ecological systems classification used by LANDFIRE is not a perfect mate to NVCS ecological systems classification, but rather LANDFIRE has combined NVCS ecological systems in places. The NatureServe Explorer is a useful reference for exploring NVCS and LANDFIRE vegetation classifications: <http://www.natureserve.org/explorer/>

Data

This analysis requires a GIS layer for both the park boundary and PACE boundary. See SOP1 Estimating Park-Centered Ecosystems (Piekielek et al. 2010) from the PALMS deliverables package for methods to delineate a PACE boundary for the park of interest.

The following analyses also require the biophysical setting layer (bps) and the existing vegetation type layer (evt) from the LANDFIRE program. Instructions on how to download LANDFIRE data are presented in more detail on page 11 of PALMS SOP Estimating Protected-area Centered Ecosystems (Piekielek et al. 2010).

Instructions

The LANDFIRE bps layer uses a similar classification scheme as the LANDFIRE evt layer if the user is familiar with these data from implementation of PALMS SOP Estimating Protected-area Centered Ecosystems (Piekielek et al. 2010). Evt vegetation community codes are stored natively in the raster layer's attribute table 'VALUE' column, while bps codes are not. Bps layer VALUES are merely codes used to link the spatial raster information to tables that contain ecological systems information. Bps codes which reference specific ecological systems are stored in a 'BPS_CODE' column. A .dbf table included in this SOP deliverable package contains most of the bps codes for the country, although at the time of this writing all codes were not yet available.

Evt codes for vegetation communities are four digit codes in the 2000s while bps codes are five digit codes in the 1000s with a one digit suffix. For example, evt code 2055 and bps code 10550 both represent 'Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest' ecological system and the additional '0' at the end of the bps

code signifies that this ecological system was not subdivided into additional systems by bps modeling. An example of an ecological system which was subdivided by bps modeling is as follows:

Evt 2080 represents 'Inter-Mountain Basins Big Sagebrush Shrubland', but for bps mapping this system was split into two units, being BPS_CODE 10801 – 'Intermountain Basins Big Sagebrush'; and BPS_CODE 10802 'Inter-Mountain Basins Big Sagebrush-Wyoming Big Sagebrush'.

In most cases the user will be aggregating multiple ecological systems into one ecosystem type of interest, in which case the above presented distinctions made by bps modeling between existing ecological systems will not be of importance. The user will select both bps systems (along with potentially others), and aggregate them into one ecosystem type of interest.

The following steps enable to user to select which LANDFIRE bps ecological systems they wish to represent ecosystem types of interest in their park:

1. Add the LANDFIRE bps and evt layers, as well as the park's boundary layer and the park's PACE layer to an ArcGIS project.
2. Use the 'Extract by mask' tool to subset the bps layer to the park's PACE boundary.
3. Use the 'JOIN' tool to join the bps.dbf table included in this SOP deliverable package to the newly extracted PACE bps raster file.

Note that in cases where the bps.dbf table does not have the BPS_CODES of interest the user will have to download these data from the LANDFIRE program directly.

The user now has a variety of options on how to choose which bps ecological systems to use for the following analysis and should reference the bps descriptions document for the LANDFIRE zone from which their data come by downloading the .pdf file from the following location:

http://www.landfire.gov/national_veg_models_op2.php

Use the 'Find' function for .pdf files to navigate the above document and search for individual bps types.

- a. Chose from the joined bps table of ecological system types and knowledge of park ecology. It may be helpful to reference the evt layer attribute table which presents the evt classes at several levels of organization. The user should also reference their NPS park vegetation map some of which include crosswalks of vegetation community association and alliances to ecological systems. Keep in mind that not all evt types will have a corresponding bps type. Or;
- b. Use the bps classes which comprise the largest proportion of either the park or PACE, or;
- c. another method chosen by the user

The following steps are presented for the user who wishes to choose bps classes directly from the bps table to represent a single ecosystem type. If the user is only choosing a small number of bps classes for each ecosystem type it may be easier to do a raster reclass so that the bps classes of interest contain new values of 1 and those not of interest contain new values of 'NoData'. If the user is choosing many bps classes to represent each ecosystem type a reclass table can become quite large and the following steps can be easier so long as the user keeps track of which bps ecological systems were aggregated to represent each ecosystem type:

4. Add a short integer field to the bps raster attribute table called 'LOOKUP'.
5. Select the bps classes from the bps attribute table using the mouse and holding the 'Control' key to select multiple classes.
6. In the raster attribute table hit the 'Selected' button to isolate only the bps classes which you selected in the prior step.
7. Left click on the head of the LOOKUP field which was added, and click the 'Field Calculator' button.
8. Make the LOOKUP value of the selected bps classes equal to 1 and press 'OK'.

9. Under the attribute table's 'Options' menu click 'Switch Selection' and make sure that all unselected bps classes are equal to 0.
10. Use the 'LOOKUP' ArcToolbox tool on the bps LOOKUP field to create a new raster layer of 1s which are pixels of interest and 0s for pixels which are not of interest.
 - a. Note that the LOOKUP tool will fail if the user does not both clear the selected features and remove any table joins first. As such, the user may choose to create separate "LOOKUP" fields for each ecosystem type and only have to JOIN the bps table once.

The user may chose to create a single raster layer of ecosystem types at this point for display, reference and smoothing, but will also have to create separate files for each ecosystem type in order to produce later analyses.

11. Add the raster layer of 1s and 0s as your first ecosystem type layer of interest; see Figure 1 for an example of what this looks like for the Douglas fir ecosystem type in the Yellowstone National Park PACE.
12. Repeat the above steps for as many ecosystem types as the user wants to analyze and add these layers to your ArcGIS project window.
13. The user may chose to create a final ecosystem type class of all other natural vegetation not captured by an existing ecosystem type layer. This would be all other bps classes except for: '11', '12', and '31'

The user may chose to perform steps at this point to "smooth" the data in order to normalize pixilation and irregular boundaries at levels of detail not warranted by the bps layer or the following analyses. These steps require that the user combine all ecosystem type layers into one raster, smooth the data and then separate each type out again into its own layer in order to perform the following analyses within the steps provided below. There may be other ways to perform these analyses however the author found the following steps to be most efficient.

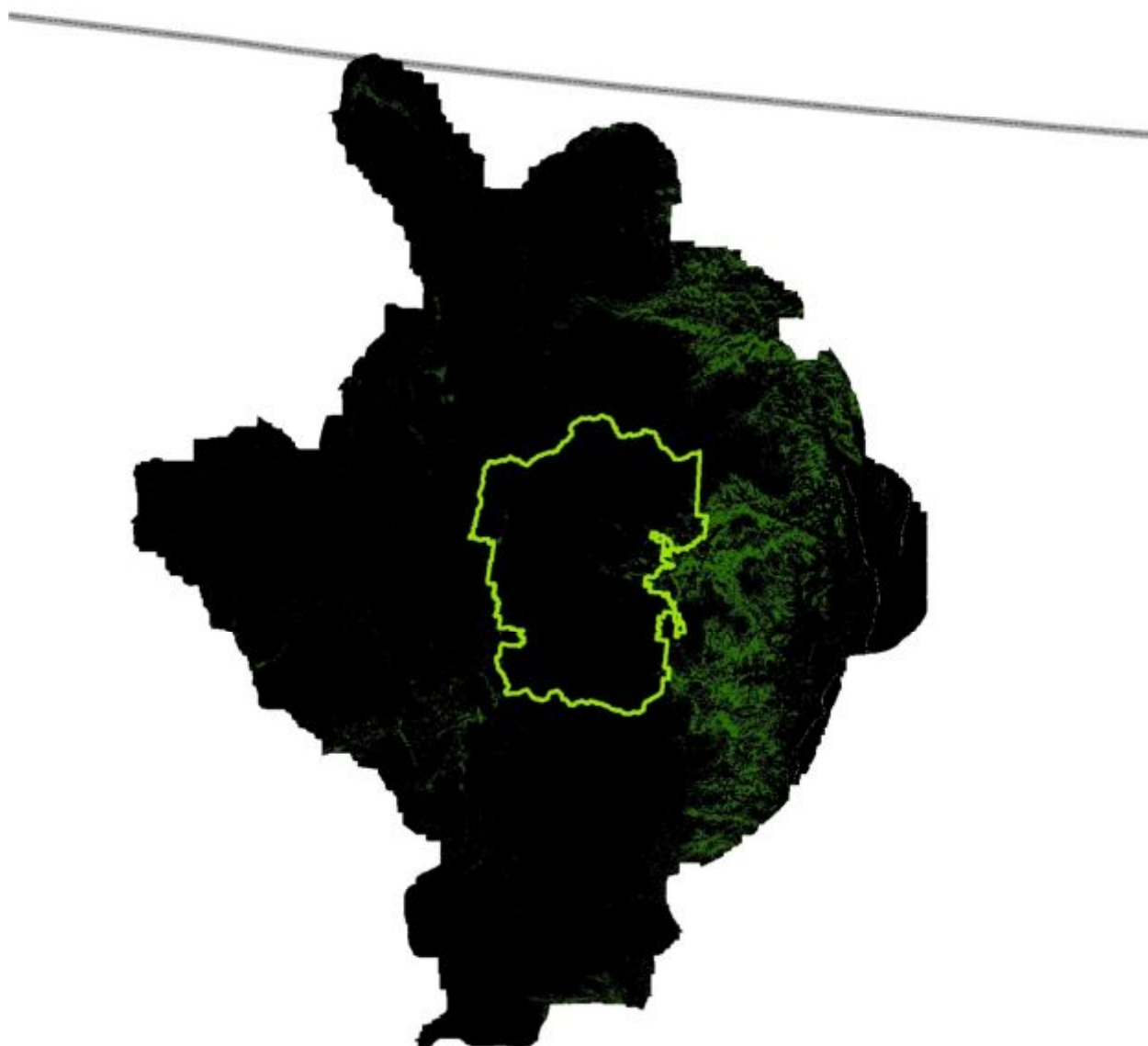


Figure 1.

Douglas fir ecosystem type of Rocky Mountain National Park's PACE

Wrap-up

- Compare the resulting ecosystem type raster of interest to other data layers to make sure it represents what the user was hoping to capture. Remember that as a modeled biophysical data product it may not match existing vegetation maps very closely.

Identify developed areas

The following steps use data products produced by national programs as well as buffer distances to generate developed areas within park PACEs representative of conditions circa year 2000. This layer will be used in the next steps to report ecosystem type area impacted and fragmented by land use from pre-Columbian times to the present day.

Potential Issues

- ✓ Little is known about the distance limits of ecological impacts by land use activity. The decision to use buffers or not is at the discretion of the user. If using buffers, the results of this analysis can be reported as percentage of ecosystem type within given distances of developed areas as opposed to percentage of ecosystem type lost to development if the user prefers.
- ✓ If the user chooses not to buffer roads in creating the developed layer they should be aware that in rasterizing these roads at a coarse pixel resolution these linear features will not bisect ecosystem type patches for analysis in Fragstats. More comments on this topic are provided in the text below.
- ✓ The LANDFIRE program's bps layer is meant to represent vegetation communities that may have been present on the landscape during the pre_Columbian era based on biophysical factors and an estimate of past disturbance regimes. As a modeled data product with no information with which to assess its accuracy, results from the following analysis is limited in its applicability to today's real-world conditions.
- ✓ The user may identify ecosystem types at any scale of organization. However, the LANDFIRE bps layer was created at the scale of ecological systems in the absence of human disturbance. As such, cross-walking the bps layer to the scale of interest can be an arduous and sometimes confusing task with opportunity to introduce error.
- ✓ The land cover and housing density data used in this analysis is already almost 10 years out of date and therefore does not likely represent a current land use scenario.
- ✓ The housing density data used in this analysis is a modeled data product by D. Theobald. It uses US census information in combination with spatial data on infrastructure and other factors to distribute housing into 100 meter pixels.

Data

US Census TIGER roads from: <http://www2.census.gov/cgi-bin/shapefiles2009/national-files>

Agricultural lands from the National Landcover Dataset (NLCD) from the USGS National Map:
<http://nationalmap.gov/viewers.html>

Housing density data from the year 2000 'hd_2000' layer provided with the PALMS SOP Analyzing Protected-area Centered Ecosystems deliverable package

Instructions

Roads

1. Use the 'Merge' tool to combine TIGER road files from multiple counties into a single file.
2. Use the 'Select by attribute' tool to select only the primary and secondary roads identified in the MTFFC attribute field as: R1011, R1051, R1052, S1100, S1200, S1400, S1630, S1730, S1740.
3. Clip this layer to the park's PACE boundary.
4. Use the 'Select by attribute' tool again to select only the interstate highways identified in the MTFFC attribute field as: R1011, R1051, R1052, S1100, S1200, S1630.

5. 'Export' the selected features to a new file and 'Buffer' this layer by 15 meters to represent the two-dimensional area of interstate highways (TIGER files contain only centerlines).
6. 'Select by attributes' only the primary roads identified in the MTFFC attribute field as: S1400, S1730, S1740.
7. 'Export' the selected features to a new file and 'Buffer' this layer by 7.5 meters to represent the two-dimensional area of primary roads.
8. 'Select by attributes' only the secondary roads identified in the MTFFC attribute field as: S1400, S1730, S1740.
9. 'Export' the selected features to a new file and 'Buffer' this layer by 5 meters.

Agriculture

10. Add NLCD data to the ArcGIS project
11. Use the 'Extract by attribute' tool to create a new raster file of NLCD classes which represents lands classified as agricultural: these are Anderson classes 81 (pasture/hay) and 82 (cultivated crops). Figure 2 shows a screen-capture of this step for Rocky Mountain National Park.

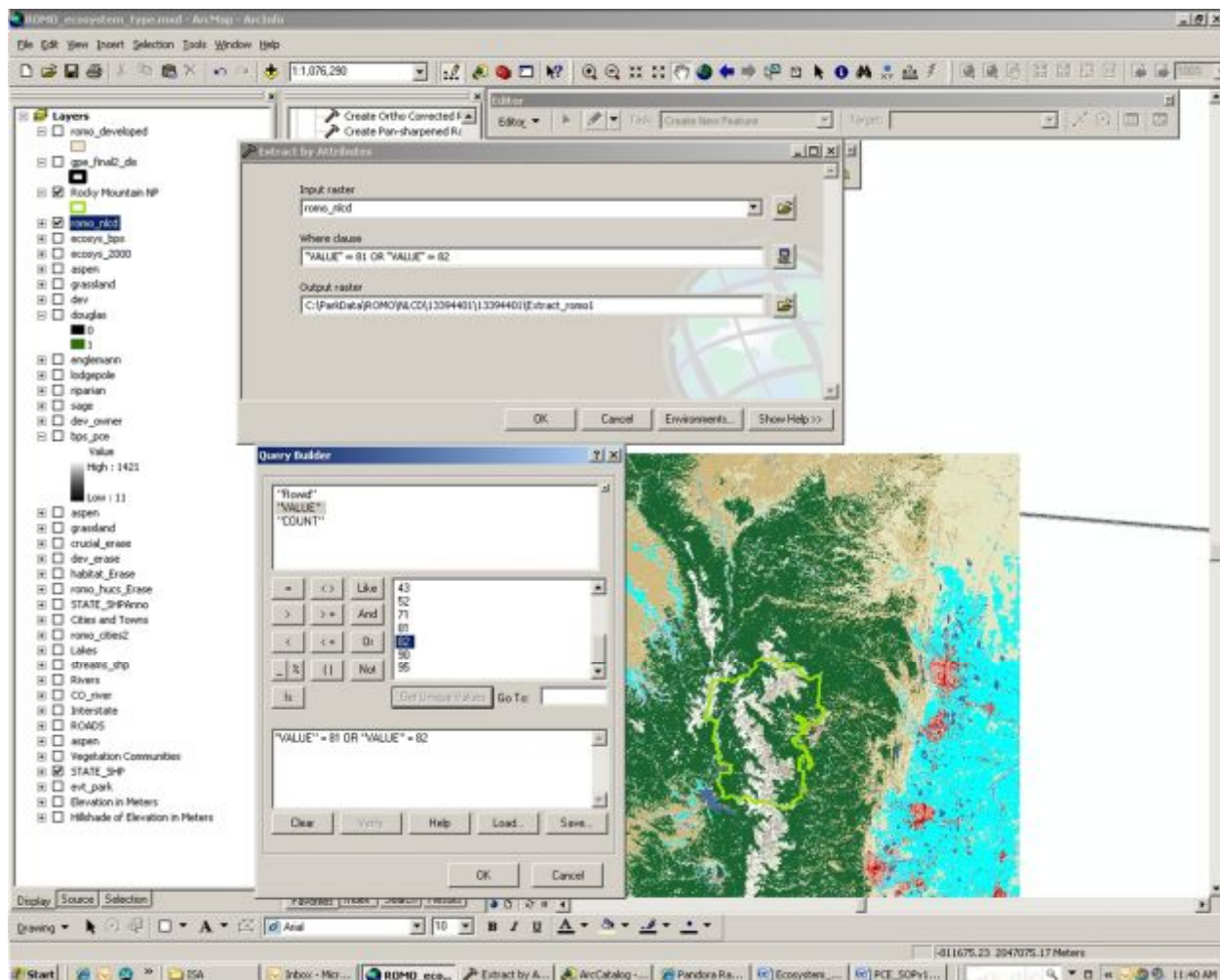


Figure 2. Extracting agricultural lands from NLCD using Extract by raster attribute

12. Use the 'Raster to polygon' tool to convert the above file to a shapefile.

13. The user may wish to either create a new attribute field, or use an existing field for which all features have the same value to 'Dissolve' all of the features into one feature to make the next step easier.

Housing density

14. Add the "hd_2000" raster file included in this SOP deliverable package to the ArcGIS project window.
15. Use the 'Extract by mask' tool to subset this layer to only the park's PACE boundary.
16. Use the 'Extract by attribute' tool to extract only developed housing density classes, being: 2 (rural), 3 (exurban), 4 (suburban/urban), 5 (commercial/industrial).
17. Use the 'Raster to polygon' tool to convert the above file to a shapefile.

Merge developed layers

18. Use the 'Merge' tool to combine the buffered primary and secondary roads layers with the agricultural lands and developed housing lands layers.
19. Use the 'Clip' tool and PACE boundary to eliminate any developed buffers in the new merged file that extend beyond the park's PACE boundary.
20. The user may choose to 'Dissolve' this layer again to simplify future analysis steps.

The user should inspect the resulting layer and road features especially to ensure that roads remain contiguous features as represented by this developed raster if they want the results of Fragstats to reflect the propensity for roads to bisect ecosystem type patches.

The user now has a polygon shapefile that represents a conservative best guess of areas within the park's PACE that are affected by human land use to be used in the next step's analysis.

Wrap-up

- Check the resulting developed layer for accuracy

Quantify ecosystem type area impacted through time

The following steps analyze area of ecosystem type that falls within given buffers of existing developed areas. In so doing it presents the pattern of land use change impacts by ecosystem type and through time.

Potential Issues

- ✓ None known

Data

A land ownership layer “cus_uppt_100” included with the PALMS SOP Analyzing Protected-area Centered Ecosystems deliverable package.

Instructions

The user may use the ArcToolbox model titled “area change” within the “Ecotype change” toolbox delivered with this SOP package and presented in figure 3, or follow the steps below.

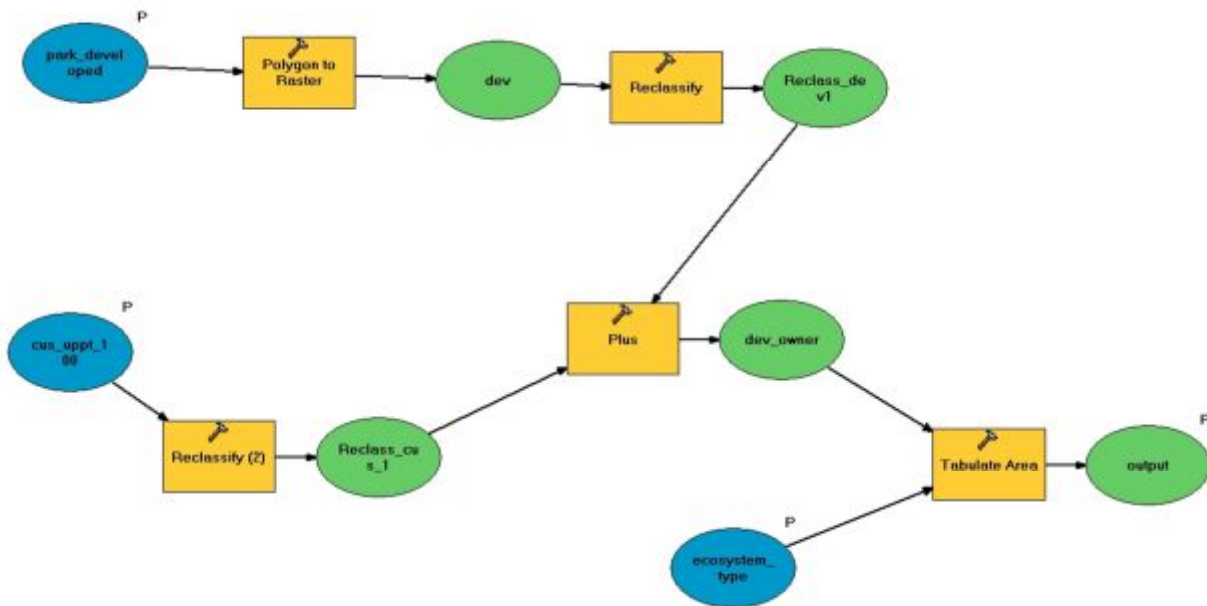


Figure 3. ArcToolbox model to calculate ecosystem type area change from pre-Columbian to present day

Note that the user can employ a similar reclassification scheme as is presented below and skip to the next section “Fragmentation” to produce statistics on area impacted by development using the FragStats software package. See the note on step 10 in the following section.

1. Using the merged developed area from the prior section “Identify developed areas”, convert it to a raster file using the ‘Polygon to Raster’ tool and based on the ‘Id’ field.
2. Use the ‘Reclassify’ tool to create a new raster file with VALUE = 10 in developed areas and “NoData” where there is no development.
3. Reclassify the “cus_uppt_100” layer to a public versus private raster layer using the reclass table below so that private lands are classified as ‘1’ and public lands are classified as ‘2’:

OLD VALUE	NEW VALUE
1	1
2	1
3	2
4	2

Table 1. Reclass table for land ownership

4. Use the ‘Plus’ tool to sum the developed raster and the public versus private raster so that the user ends up with a raster with the following relationships:
 - i. Class 1 = private undeveloped lands
 - ii. Class 2 = public undeveloped lands
 - iii. Class 11 = private developed lands
 - iv. Class 12 = public developed lands
5. Use the ‘Tabulate Area’ tool as depicted in figure 4 with the raster layer created in step 4 as the zone data and the ecosystem type layer created in the “Identify ecosystem type” section of this SOP as the other data set. Leave the “processing cell size” option to 100m and the tool will automatically resample the two rasters to a common 100m pixel resolution prior to tabulating areas.

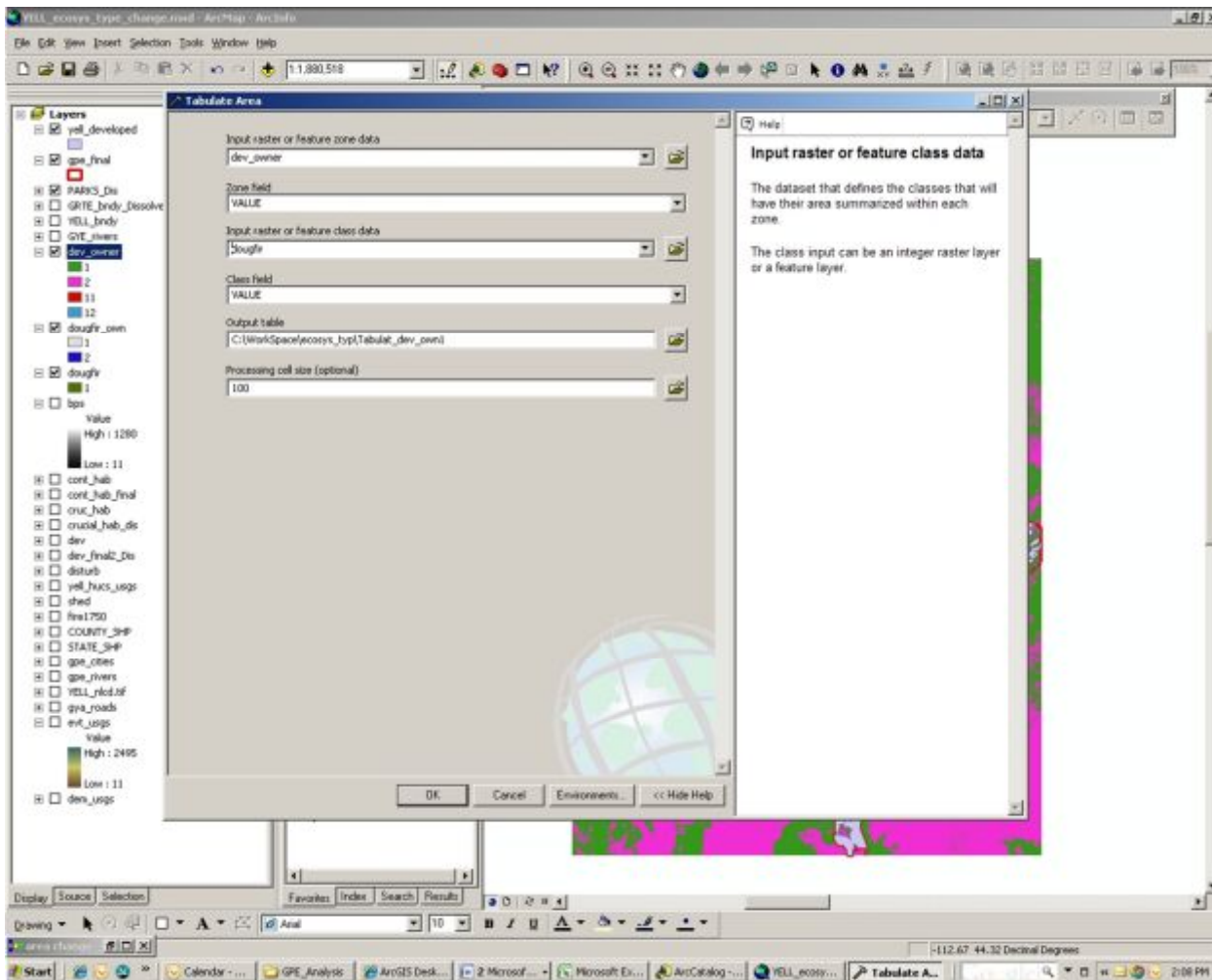


Figure 4. Using the tabulate area tool

6. Output from the above tool will be in table form with an area associated with each of the four ownership and developed classes assigned in step 4. Keep in mind that to calculate the total area of the ecosystem type of interest on private lands for example the user must add the area of VALUE = 1, row 1 to the area of VALUE = 11, row 3 since one represents area on private developed lands and the other on private undeveloped lands. The excel spreadsheet titled "Ecosystem_type_change.xlsx" in this SOP's deliverable package gives an example of how to organize this information and calculate the percentage of total PACE landscape in each ecosystem type for the two time-periods.

Wrap-up

- Compare results across ecosystem types and to other sources of information that may be available

Fragmentation

The previous steps identified the proportion of the park's PACE landscape that was comprised of each ecosystem type from pre-European settlement times to the present day. Just as change in area of each ecosystem type is significant, how that area is distributed across the landscape is also of ecological importance (Fahrig 2003, Urban 1987). The use of fragmentation statistics are a well-developed and recognized method of quantifying landscape composition and configuration (Neel et al. 1995). The following analysis methods use fragmentation statistics to represent how ecosystem type configuration has changed within the PACE landscape through time.

Potential Issues

- ✓ Fragmentation statistics are very sensitive to the quality and resolution of the input data
- ✓ Choosing between using a 4-cell versus an 8-cell analysis window rule can dramatically change results, but is a necessary choice to make

Data

Output layers from previous sections of this SOP document

The documentation for the FragStats software as well as the metrics used in this analysis are useful for interpreting results from this section:

http://www.umass.edu/landeco/research/fragstats/documents/fragstats_documents.html

Instructions

The ArcToolbox model "Fragmentation" depicted in figure 5 and included in this SOP deliverable package can be used, or the user may chose to follow the steps below:

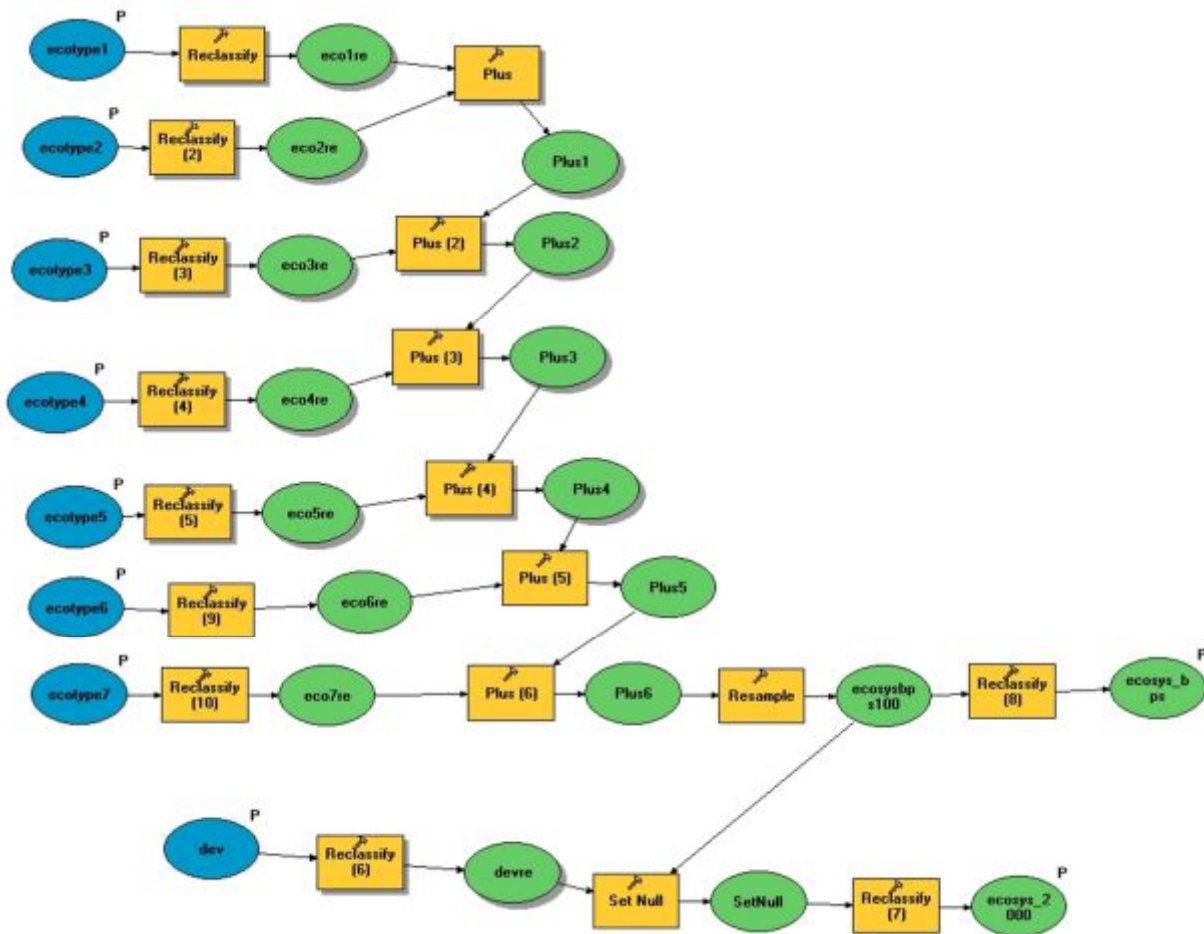


Figure 5. ArcToolbox model for the creation of ecosystem type rasters to be used in fragmentation analysis

The following steps prepare a raster layer for input to the Fragstats software package to calculate fragmentation statistics by ecosystem type through time.

1. Reclassify each ecosystem type raster layer so that the VALUE field for ecosystem type equals 1 through the number of types the user has identified, and for other areas of the PACE VALUE = 0, instead of NoData. The user can follow the reclass table below:

Note that to make copying and pasting of results easier it is helpful to organize the ecosystem type codes in the same way that the user's excel spreadsheet with results is organized so that if 'douglas fir' is the ecosystem type which appears first in the excel spreadsheet it should receive a VALUE of 1 etc. FragStats results can then be sorted, copied and pasted directly into a master results spreadsheet.

Old value	New value
1	1 (or 2, 3, 4...)
NoData	0

Table 2. Ecosystem type reclass table for fragmentation

Note that the above 'New Value' column should only contain one unique number but this reclassification step is repeated for each ecosystem type of interest, each of which will receive a different 'New Value' code.

2. Use the 'PLUS' tool to add all of the reclassified ecosystem type rasters together. The resulting layer should cover the entire park PACE area and each should have a unique VALUE equal up to the number of ecosystem types of interest, as well as a VALUE = 0 where there is no ecosystem type.
3. 'Reclassify' this raster so that areas without an ecosystem type of interest (i.e. where VALUE = 0), are reclassified as '999' so that the background value is readable by FragStats software which requires a positive integer background value. The user may chose any value that they wish, however '999' is the default background value used by FragStats.
4. Use the 'Resample' tool and the nearest neighbor method to resample the 30 meter resolution raster from the preceding step to match the 100 meter resolution of the developed layer to be created next. The result of the raster resample will be the layer which depicts modeled pre-Colombian ecosystem type conditions.
5. Use the developed raster layer that results from step 1, section "Quantifying ecosystem type area impacted through time" and 'Reclassify' this layer so that developed areas have a VALUE = 1 and all other areas have VALUE = 0.
6. Use the 'Set Null' tool with the reclassified developed raster from the prior step as the input conditional raster and the raster ecosystem type layer from step 3 above as the input false conditional raster and the SQL expression "VALUE" = 0. This step is depicted in figure 3 below.

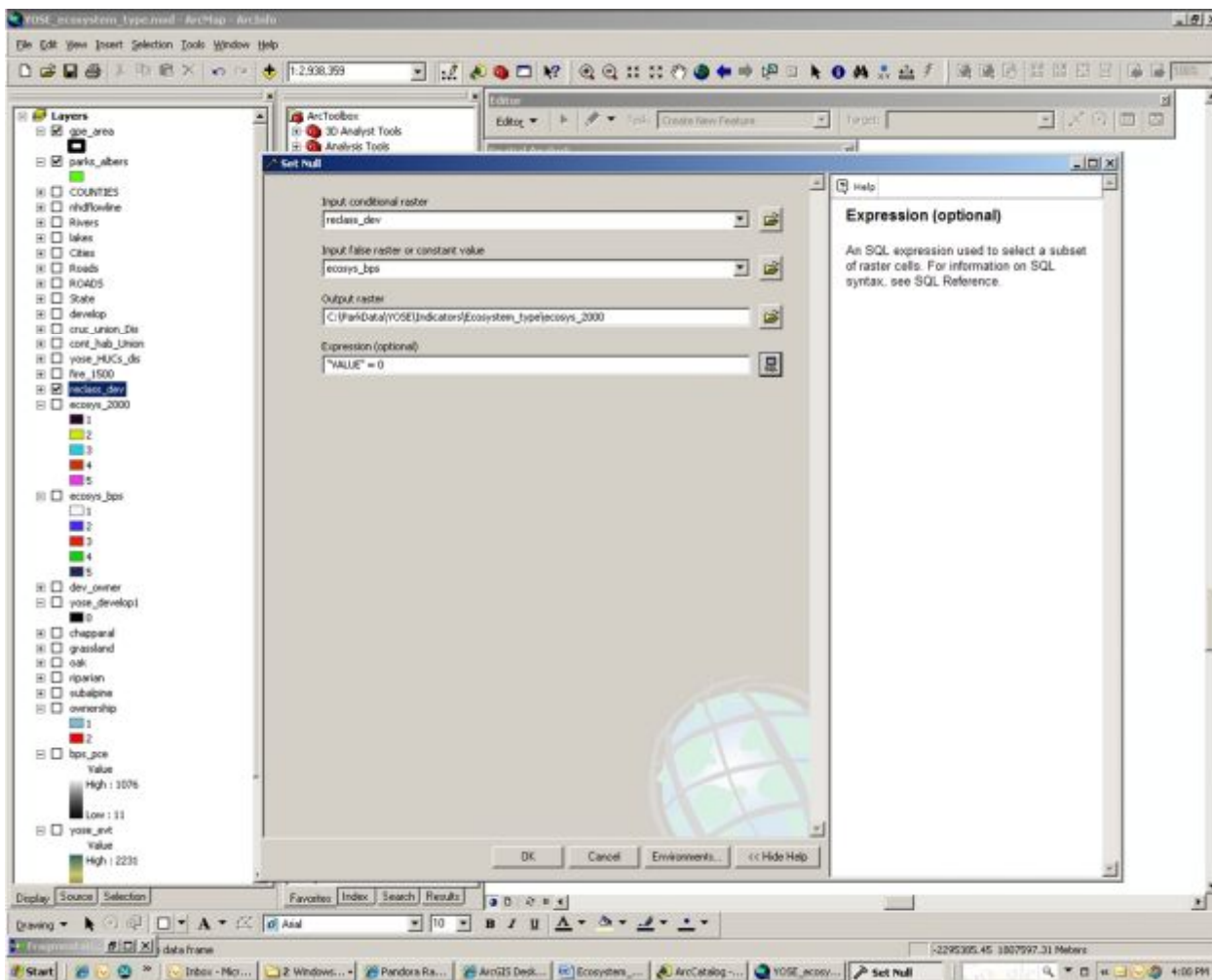


Figure 6. Using the Set Null tool to calculate an ecosystem type layer minus developed areas

7. 'Reclassify' the raster from step 5 so that NoData = 999 to match FragStats requirements for background values.

The raster layer resulting from step 6 above should depict each ecosystem type of interest as a different VALUE and have 999 everywhere else. This is the layer which depicts roughly present day ecosystem type conditions for the park's PACE. It will serve as input to FragStats software for further analysis.

The user may choose to Resample the above two ecosystem type layers to a more coarse spatial resolution (500 meters for example), to reduce processing time in FragStats. This should only be necessary for especially large areas of interest or a high number of ecosystem types of interest (greater than 12 for example). However, always keep in mind the consequences of resampling and the resampling method chosen as both can have a profound effect on the resulting fragmentation statistics. Fragmentation statistics are highly sensitive to the resolution of the data used.

8. Open the Fragstats software and under the 'Fragstats' menu click on the 'Set Run Parameters' option.
9. Under 'Input Data Type' click on the 'Arc Grid' radio button, then the 'Grid name' button and navigate to your raster file from step 3 above. Input a Output File name and location. Finally, under the 'Output Statistics' options click the 'Class Metrics' box and press 'OK'. Figure 4 depicts the Run Parameters options box as it should appear for the user.

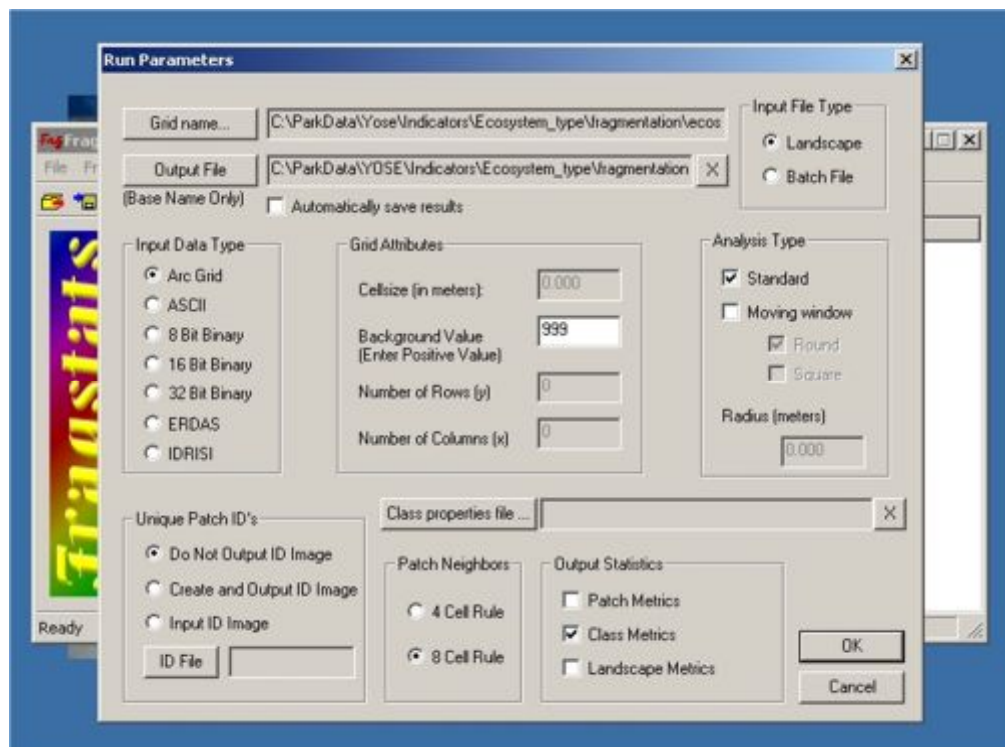


Figure 7. Fragstats Run Parameters options box

10. Back at the main FragStats window, under the 'Fragstats' menu click on the 'Select Class Metrics' option.
11. The first tab will be 'Area/Density/Edge'. Under 'Distribution Statistics' and the first row 'Patch Area (AREA_?)' click the 'Mean Area' and 'Coefficient of Variation (CV)' boxes to return mean patch area and coefficient of variation of patch area for each ecosystem type.

Note if the user is tabulating change in area affected by development from the preceding section using FragStats they should have reclassified so that there is a 'private' and 'public' class for each ecosystem type and should select the 'Total Area' button in the 'Area/Density/Edge' tab referenced above. The user will then have to sum the private and public numbers accordingly to get total area in each ecosystem time across the two time-periods.

12. Under the 'Isolation/Proximity' tab click the 'Euclidean Nearest Neighbor' 'Mean (MN)' to return a mean distance from one patch of a given ecosystem type to the next patch of the same ecosystem type. Click 'OK'.
13. Back at the main FragStats window the user can either push the green running man 'Execute' button, or under the 'Fragstats' menu select 'Execute'.

Note that for larger parks or more ecosystem type classes FragStats may run for some time and appear unresponsive. When it's finishing running the following prompt depicted in figure 8 will appear.

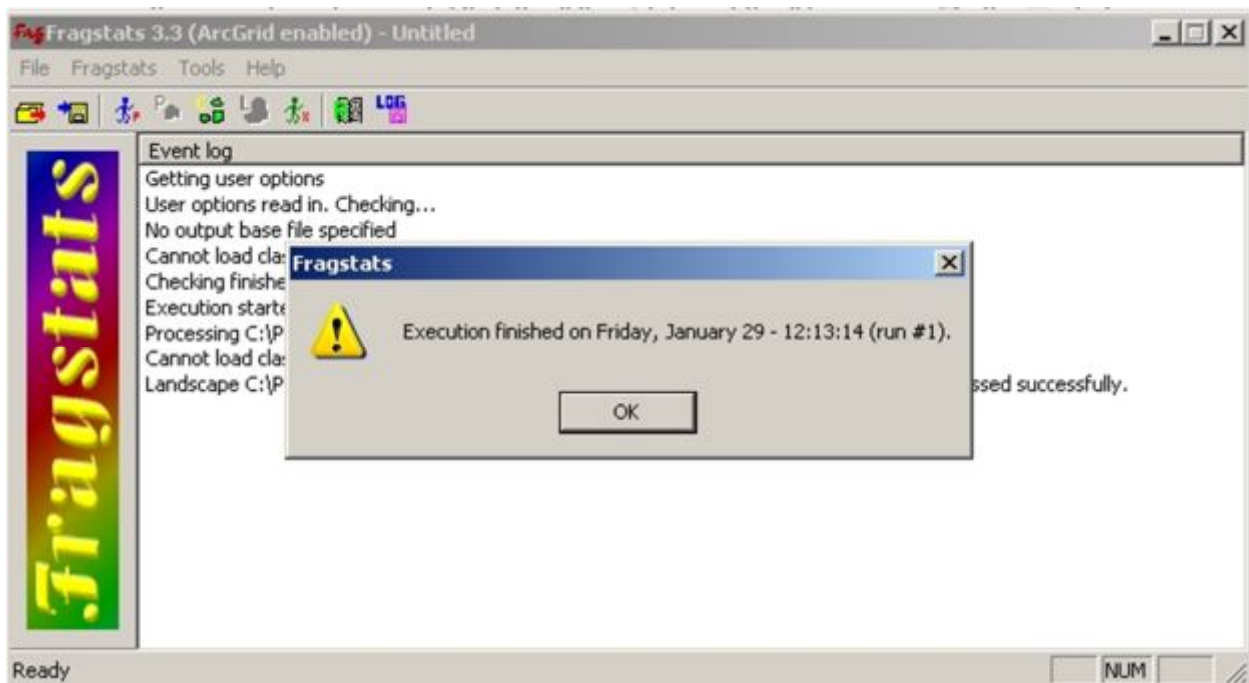


Figure 8. Fragstats completion prompt

14. Click 'OK' in the Execution finished window and then on the browse results button  or select browse results under the 'Tools' menu. The results window will pop-up with three tabs across the bottom left for the metrics which the user chose to report. Click the 'Class' tab and the 'Save run as' button and chose a location to save these results.
15. Results from this exercise will be saved in two files with extensions '.adj', and '.class'. Open Microsoft Excel, go to 'Open file', navigate to the FragStats results files, make sure that 'Files of Type' is set to 'All Files' and click on the results file of extension '.class'.
16. The Excel Text Import Wizard will appear as shown in figure 9. Select 'Delimited', press next, make sure that comma Delimiter is the only option checked and click finish.

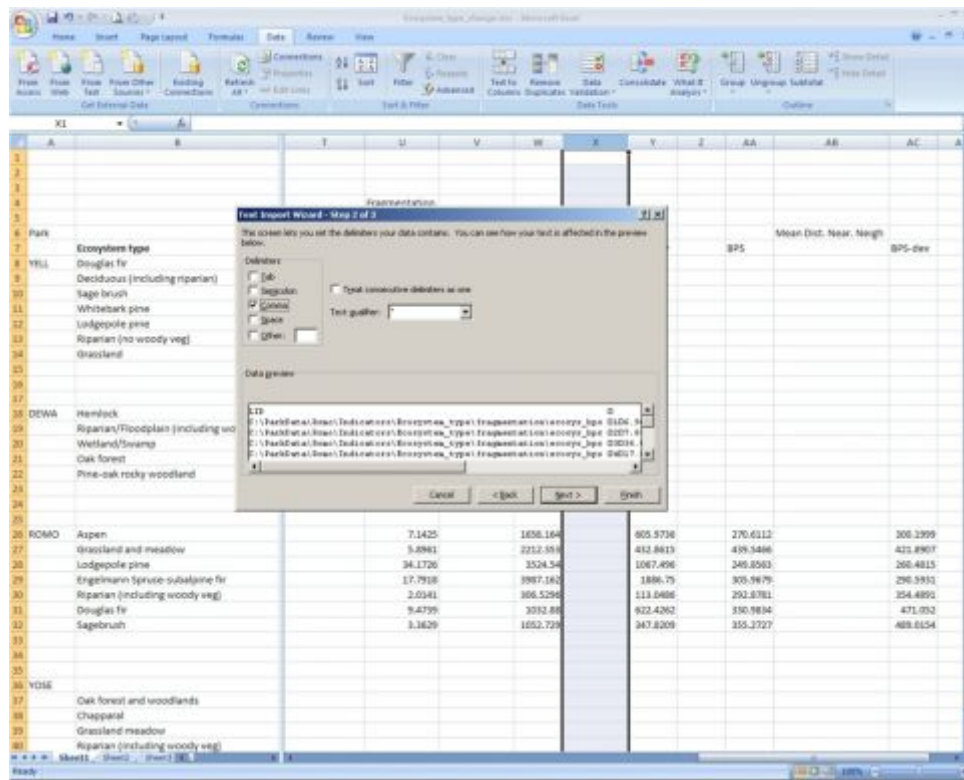


Figure 9. The MS Excel text import wizard

17. The FragStats results will open in Excel with the 'Type' field referring to each ecosystem type class with the numbers assigned by the reclassification undertaken in step 1 above and the fragmentation statistics under each named header. The user can now sort data in Excel and copy and paste the results into a central Excel spreadsheet of results similar to the one presented as an example with this SOP deliverable package titled "Ecosystem_type_change.xlsx".

Comparing the LANDFIRE bps layer to NPS Vegetation Maps

Biophysical settings predict the presence of certain ecosystem types on a historical landscape with unknown accuracy. In theory, natural vegetation communities should occur on today's landscape only within the bounds of their identified biophysical settings so long as disturbance regimes have not changed substantially. This assumption is perhaps most relevant to park interiors. Since most parks have NPS derived vegetation community maps of known accuracy there is an opportunity to compare the spatial location of LANDFIRE bps ecosystem types with those of NPS vegetation maps of known accuracy.

Potential Issues

- ✓ Some NPS vegetation maps have cross-walked association or alliance level information mapped by the NPS vegetation mapping program to ecological systems used by the LANDFIRE program
- ✓ Cross-walking NPS vegetation mapping products to LANDFIRE bps layers can be an arduous and error-prone task if undertaken by the user
- ✓ Given that the LANDFIRE bps layer was generated under a hypothetical 'mean' historical disturbance regime there should be no expectation of perfect overlap with current vegetation community data. Rather, consistent spatial patterning and some level of overlap should validate that indeed the LANDFIRE bps layer is capturing the spatial variation of ecosystem types at a level of detail suitable for the above analyses

Data

Output layers from previous sections of this SOP document

Instructions

1. 'Add' the park's NPS vegetation map to a new ArcMap project window.
2. To prepare a layer to clip bps layers, 'Add a field' to the vegetation map's attribute table and use the 'Field Calculator' to make all rows = 1.
3. 'Dissolve' the vegetation map layer by this new field so that you have only the outermost bounding polygon of the original vegetation map layer.
4. 'Add' the ecosystem type grids that were created in Identify Ecosystem Types of Interest section above.
5. Use 'Extract by Mask' tool with each ecosystem type grid and the vegetation map bounding polygon as the clipping area, so that the grids are sub-setted to only the area for which there is NPS vegetation data.
6. Use the 'Select by Attribute' function on the original NPS vegetation map to select mapped vegetation communities that the user wishes to represent each ecosystem type of interest using published cross-walks or other information to do so.
7. Use the 'Data export' function to export only the selected polygons from above to a new polygon layer and chose 'Add new layer' when prompted.
8. Use the 'Polygon to Raster' tool to convert the above layer to an Arc grid file of 30 meter resolution and for which each cell has a VALUE = 1. The user may use the field that they created in step 2 for this last purpose. This step is represented in Figure10 below.

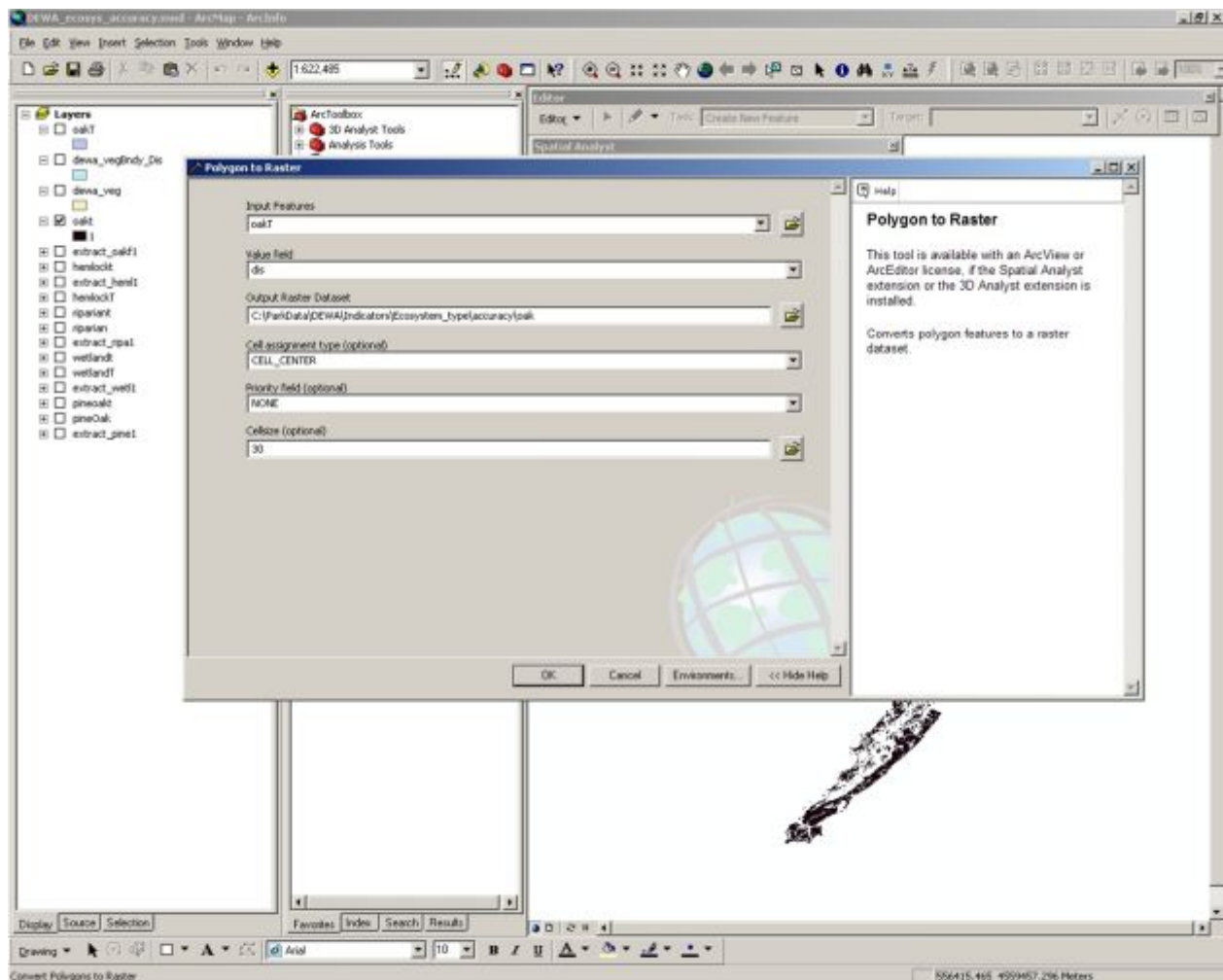


Figure 10. Converting NPS vegetation map polygons to ecosystem type rasters

9. 'Add' the newly created raster to the project window.
10. Use the 'Zonal Statistics as Table' tool with the bps ecosystem type raster as the Input zone data and the NPS vegetation map derived ecosystem type grid as the value raster.
11. Open the generated zonal statistics table where COUNT for VALUE 0 represents the number of cells where the NPS vegetation map data showed the ecosystem type of interest is present but the bps ecosystem type layer has not mapped this ecosystem type (i.e. disagreement); and where COUNT for VALUE = 1 represents the number of cells where there is agreement between the two data layers. This is depicted in figure 11 below.

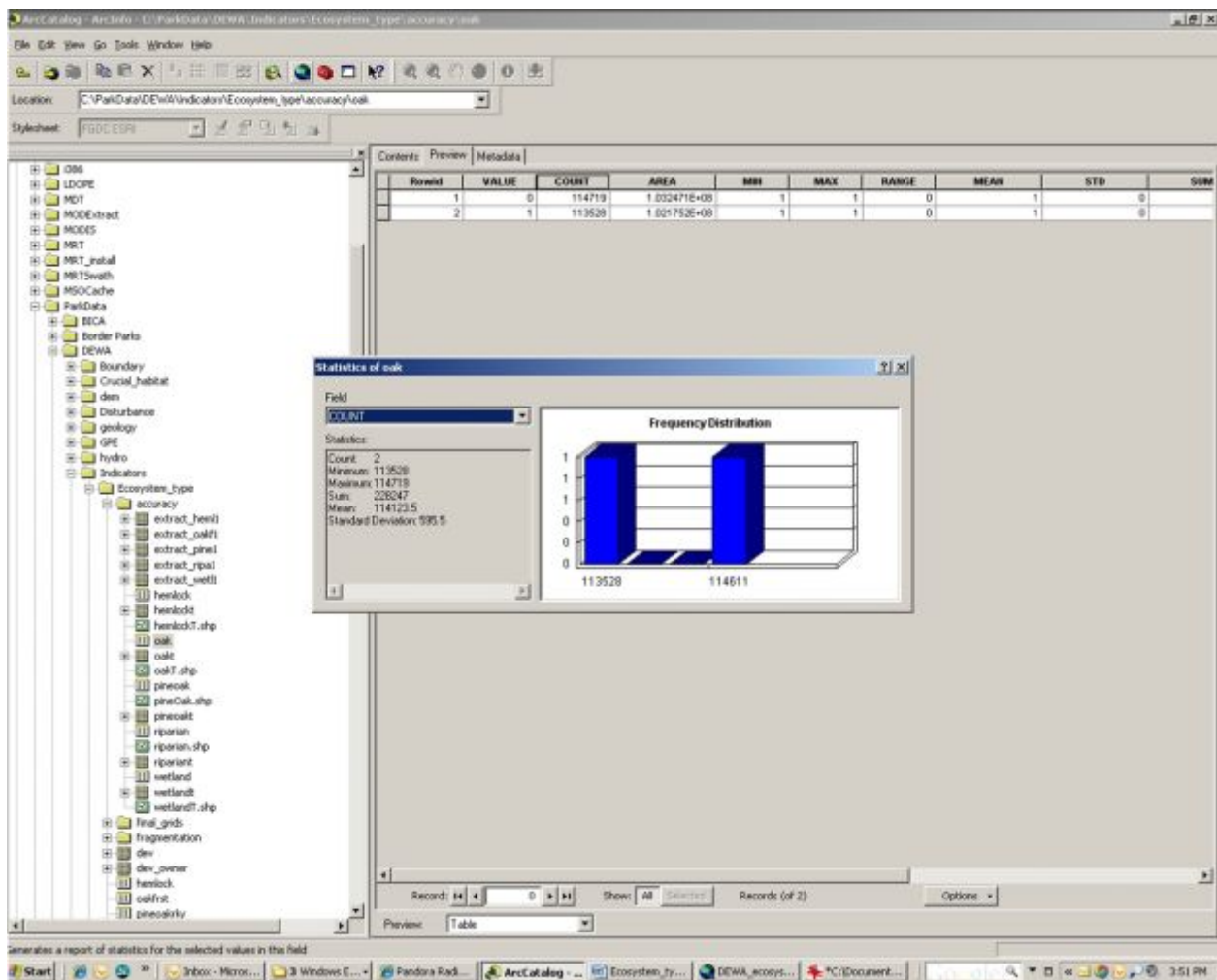


Figure 11. Examining the agreement between ecosystem type data layers

There is no way to test the accuracy of LANDFIRE bps layers, however the above steps give the user a sense of for which ecosystem types of interest the approach presented in this SOP may work well and for which ecosystem types of interest this approach may not work well. In our experience there is a very large range of agreement between these two data layers (1 – 80%), and roughly 40% agreement seems to be average.

Additional Analyses

The approach presented in this SOP can be modified and repeated by the user with different data layers and for different time periods. For example, if the user has historic data to represent ecosystem types of interest within the PACE they can quantify actual ecosystem type area lost to land use change through time; this analysis would likely exclude the buffer distances presented here. As the layers used in this analysis to represent development are updated, this SOP can also be repeated to track change through time. The results of these analyses can be examined for trends by ecosystem type and/or used in other analyses.

Literature cited

- Annual Review of Ecology, Evolution, and Systematics
Vol. 34: 487-515 (Volume publication date November 2003)
(doi:10.1146/annurev.ecolsys.34.011802.132419)
- Urban, D.L., Robert V. O'Neill and Herman H. Shugart, Jr. *Bioscience* Vol. 37, No. 2 (Feb., 1987), pp. 119-127.
- Fahrig, Lenore. 2003. EFFECTS OF HABITAT FRAGMENTATION ON BIODIVERSITY.
- Hansen, A.J. and R. DeFries. 2007. Ecological mechanisms linking protected areas to surrounding lands. *Ecological Applications* 17(4), 974-988.
- Neel, MC; McGarigal, K; Cushman, SA. 2004. Behavior of class-level landscape metrics across gradients of class aggregation and area. *LANDSCAPE ECOLOGY* 19 (4):435-455.
- Sala, Osvaldo E., F. Stuart Chapin, III, Juan J. Armesto, Eric Berlow, Janine Bloomfield, Rodolfo Dirzo, Elisabeth Huber-Sanwald, Laura F. Huenneke, Robert B. Jackson, Ann Kinzig, Rik Leemans, David M. Lodge, Harold A. Mooney, Martín Oesterheld, N. LeRoy Poff, Martin T. Sykes, Brian H. Walker, Marilyn Walker, and Diana H. Wall. 2010. Global Biodiversity Scenarios for the Year 2100. *Science* **287** (5459), 1770.
Ottawa-Carleton Institute.
- Piekielek, N.B., C. Davis and A. Hansen 2010. PALMS Standard Operating Procedure – Estimating Protected-area Centered Ecosystems. Inventory and Monitoring Program, Natural Resource Program Center, National Park Service, Fort Collins, CO.

Appendix 1. Extent of fragmentation of ecosystem types in and around US National Parks - a draft manuscript January 2011.

Introduction

Protected area (PA) managers face numerous challenges to preserving the ecological condition and biodiversity in PAs. Principle among them is that PAs represent only subsets of larger ecosystems (GAO 1994, Machlis and Field 2000, Carrol et al. 2004, Hansen and DeFries 2007). Processes, organisms, material and energy routinely pass back and forth across PA boundaries that were sometimes drawn for reasons other than biodiversity conservation (Pressey 1994). Human activity in areas surrounding PAs can affect the condition of PAs by changing the ecological condition of surrounding lands and interrupting ecological flows between PAs and adjacent portions of the ecosystem. Indeed, habitat destruction and fragmentation are the leading causes of loss of biodiversity and ecosystem function globally and many PAs are experiencing loss of biodiversity at the hands of human activity on surrounding lands (Sala 2000, Newmark 1985, 1987, 1995, 1996, Parks and Harcourt 2002). A number of researchers have documented recent rates of land use change around U.S. National Parks (“parks”) that exceed national averages (Wade and Theobald 2009, Radeloff et al. 2010). In response to these and other national trends, the U.S. National Park Service (NPS) established a program to monitor the ecological condition and trends in condition, of US parks and surrounding areas, called the NPS Inventory and Monitoring Program (I&M) (Fancy et al. 2009). The I&M program organized 270+ U.S. parks into 32 ecoregional Networks where routine monitoring is performed. In the early stages of this program, over 1000 scientists and park managers across the country identified and prioritized indicators of ecological condition to monitor (Gross 2010). From this process, “landscape dynamics” was identified as a high priority indicator to measure. Landscape dynamics refers to change in natural land cover types and human land use.

A key challenge for the NPS I&M Program is now to quantify landscape dynamics in ways that are relevant to impacts on biodiversity. Such information is needed by park managers who are trying to anticipate and plan strategies to mitigate the detrimental impacts of land use change on biodiversity in and around their parks. Ideally, species specific data and spatially explicit population models would be used to interpret how land use change is influencing key species. However, such datasets and models are not presently widely available. A long recognized alternative to species-specific (termed fine-filter) approaches is a coarse-filter approach where habitat types and vegetation communities rather than species are the units of analysis (Hunter 1988). Many organisms and ecological processes are associated with particular habitat types. Thus, quantifying change in habitat types, which is easier to measure, is informative about change in species, which is more difficult to measure (McGarigal et al 2002).

The goal of this paper is to develop and apply a method for monitoring change in the aerial extent and spatial configuration due to land use of coarse-scale units of natural habitat in and around a subset of US parks. We drew on the biophysical setting (bps) data layer of the LANDFIRE Program (USFS 2010) to represent habitat types of interest. This dataset was developed as a science-based, nationally consistent layer of ecosystem reference conditions based on historical ranges of natural variation (Keane et al. 2002, 2009, USFS 2010). The layer is based on present day relationships between ecosystem types and biophysical conditions. These relationships are used to model the distribution of ecosystem types under presumed pre-EuroAmerican settlement conditions. We overlay present day human land use on modeled historical ecosystem type distributions in and around US National Parks to quantify the extent of fragmentation of ecosystem types to the present day. The objectives of the study are to:

1. Quantify change in the aerial extent and spatial configuration of key natural ecosystem types due to land use intensification.
2. Assess the accuracy of modeled historical ecosystem types by comparing them with present-day maps of known accuracy in reference portions of the landscape.
3. Use the results to identify the ecosystem types that have been most fragmented by land use and therefore are high priorities for further research and management.

We demonstrate the approach at four pilot study areas containing US parks. The results provide an approximation of loss of key habitats that can be used to both infer finer scale impacts and inform and prioritize future research and management.

Methods

Study Sites

This study focuses on four sites containing seven USNPS parks and surrounding lands that have strong ecological connections to the parks themselves. Parks were selected as part of a larger study based on availability of datasets and principal investigators' familiarity with the areas (Gross et al. 2010). Determining the area of analysis on surrounding lands was done according to the methods of Hansen et al. (2010). According to these methods the areas of analysis are referred to as "protected-area centered ecosystems", or PACES. PACES represent the portions of surrounding ecosystems which are most strongly coupled to park biodiversity. To define PACE boundaries the spatial extent of several criteria were mapped including: watershed and airshed boundaries; disturbance events; crucial habitat areas; contiguous habitat based on species-area relationships; and areas of human edge effects (see Hansen et al. 2010, appendix 1 for methods details). A union of all criteria was used as the final PACE and area of analysis for the current research project. Figure 1 shows each PACE boundary

and the parks that lie therein. All analysis that follow were performed across the entire PACE area including within park boundaries.

Historical reference conditions

The collaborative multi-agency LANDFIRE program (USFS 2010) has published a suite of nationally consistent, scientifically based data layers for use in land management and research. The bps layer represents International Ecological Classification Standard (ITESC) terrestrial ecological systems and their spatial location at 30 meter spatial resolution which may have been present on the landscape prior to European settlement (NatureServe 2009, Comer et al. 2003, FRCC 2010). This modeled representation of pre-European settlement condition was chosen by the current project in contrast to empirical observations of historical conditions or other layers of potential vegetation, for the following reasons:

- i. While many parks have used satellite imagery and aerial photography to document recent land use and cover change, this timeframe does not serve as an adequate reference, nor does it often match well, dates of park establishment especially in western parks (Varanka 2005, Wang 2009).
- ii. The LANDFIRE bps layer models different successional stages of potential vegetation communities under assumed natural disturbance regimes, thereby making an important improvement on layers of potential vegetation which typically only model “climax” communities.

The LANDFIRE bps layer was developed based on the relationship between current vegetation communities and their biophysical environments, transition probabilities associated with different types of disturbance identified by local experts, and modeled historical ranges of variation in disturbance return intervals and intensities (FRCC 2010, Keane et al. 2002). It was created as a layer of reference conditions to assess departure by present day vegetation communities from historical conditions as determined by disturbance and its recent exclusion by human activity. The bps layer can be interpreted as the central tendency of vegetation communities at distinct locations on the landscape under a static climate envelope in the several hundred years preceding European settlement. For a complete description of modeling methods see FRCC 2010. Across landscapes and through time, generalizations of the LANDFIRE bps used in this analysis as “ecosystem types” are thought to be representative of the coarse-scale habitats within which species evolved prior to European settlement.

We worked with park managers to identify the six to eight ecosystem types in and around their parks for use in this analysis. Ecosystem types were chosen based on their present prevalence on the landscape and importance to supporting wildlife and other biodiversity. We also created an ecosystem type which captured “all other natural vegetation”. Ecosystem types were not identified at the thematic level of

ITESC ecological systems so a crosswalk was created whereby multiple LANDFIRE bps ecological systems made up each ecosystem type. Appendix A shows the complete crosswalk map used for this purpose. Overall, 112 ecological systems were reclassified to 26 ecosystem types. This thematic generalization was warranted given the scale of analysis and was thought to improve the accuracy of results. Layers of ecosystem types were clipped to each PACE area and used to represent the historical reference conditions against which present day conditions were compared.

Developed Areas

The study identified human dominated, intensively managed, or areas under permanent human infrastructure as being developed for human use. This included primary and secondary roads, areas under intensive agricultural management, commercial and industrial areas and areas where residential housing densities were above one home per 80 acres of land. Table 1 shows the data sources used for each class of development. Data from each class were spatially combined into a single layer using ArcGIS 9.2 (ESRI 2009) and represents conditions for the time-period 2000-2009. The only pre-processing of these data included the addition of a buffer to the roads layer as it natively came in only one dimension. Roads were buffered with an approximation of actual road footprint width based on road class.

Overlay analysis

Developed areas were overlaid on and used to erode historical ecosystem types in ArcGIS 9.2 to create present day conditions. In present day conditions it is assumed that ecosystem type areas which have become intensively human developed are functionally lost to the ecosystem.

Ecosystem type composition and pattern analysis

Area lost to present day by ecosystem type was quantified in a before and after framework where percent change from reference conditions was the metric of interest. In addition to total loss of area, proportions lost on public versus private lands was also tabulated as an indicator of where on the landscape development had occurred and the difficulties involved in conserving threatened ecosystem types for the future. Ranges of area lost across ecosystem types for each PACE was also calculated to indicate the degree to which some ecosystem types had preferentially been the subject of human activity. A large range would indicate non-random spatial arrangement of human land use and a small range would indicate a more random pattern. Landscape pattern metrics and their change from historical conditions to present day, including mean patch area, coefficient of variation in mean patch area, Euclidean distance to nearest neighbor (ENN) of same patch class and coefficient of variation of ENN were also quantified using FragStats 3.3 software (McGarigal et al. 2002). All of these results are presented in Table 2 as percentage change from historical reference conditions.

Agreement of Ecosystem Types with Data of known Accuracy

Satisfactory ways to validate, assess accuracy or quantify confidence in modeled historical conditions don't presently exist (Keane 2009). However, there remains a need to carefully examine maps of ecosystem types used in this analysis to assess the confidence that we can place in study results. One approach is to compare the location of modeled ecosystem types with present day maps of known accuracy in locations where we would expect the greatest agreement. This approach qualitatively assesses the accuracy of modeled historical conditions and determines if the present analysis is equally appropriate for all ecosystem types. The justification for exploring agreement only within US NPS boundaries comes from the following reasoning. If US parks have been successful in preserving disturbance and other ecosystem processes in a semi-natural state to the present day then we should expect at least moderate levels of agreement between modeled historical conditions and present day landscape conditions *within park boundaries*. If moderate levels of agreement exist, we can qualitatively place higher confidence in the methods used to generate reference conditions. If on the other hand, at least moderate agreement is not discovered, then we are left to conclude one of the following propositions:

- i. The methods used in this study do not adequately capture the relationship between biophysical conditions and present day ecosystem types; or
- ii. Present day parks have not done an adequate job of preserving disturbance and ecosystem process sufficient to support vegetation conditions that persisted in the past; or
- iii. There are spatial or thematic issues of scale that obscure the true relationship between reference and present day conditions.

The NPS in partnership with the US Geological Survey (USGS) has undertaken an intensive, field based vegetation community mapping project which is ongoing to the present day (NPS 2010). Maps of present day ecosystem types derived from NPS maps were compared to maps of historical reference conditions using published crosswalks. We should not expect perfect agreement between the two layers because NPS vegetation maps are not of 100% accuracy and the LANDFIRE bps layer from which reference conditions were derived, represents only a hypothetical snapshot in time, or central tendency, of historical vegetation conditions. Vegetation communities are dynamic in nature and what is present at the plot or pixel level on today's landscape should not be expected to correspond perfectly to what was there at any known or hypothetical point in the past. Moderate levels of agreement between the two layers should increase our confidence that maps of ecosystem types used in this analysis do a reasonable job of representing unknowable historical conditions within parks. If this is true within park boundaries, by extension, it should also be true in the surrounding landscape.

Agreement was explored for Delaware Water Gap National Recreation Area, Upper Delaware Scenic and Recreational River, and Rocky Mountain National Park where NPS vegetation mapping had been

completed and for which there were published crosswalks (Bureau of Reclamation 2005, Largay and Sneddon 2009). Agreement was also explored as a function of sample size to explain some of the variation in agreement between ecosystem types.

Results

Agreement analysis

The results of comparisons of maps of ecosystem types used in this study and maps of ecosystem types of known accuracy are presented in Table 4. Mean agreement presented in the last row of Table 4 can be loosely interpreted as “map accuracy”. Agreement ranged from a low of 4% for riparian areas of the Rocky Mountain PACE to a high of 66% for the Douglas-fir ecosystem type also in the Rocky Mountain PACE. On average, agreement in the Rocky Mountain PACE was 51% and for the Delaware Water Gap PACE 52% while reported map accuracies for NPS vegetation maps were 49% for Rocky Mountain and 50% for Delaware Water Gap.

Change in Ecosystem type Area

No ecosystem type in either the Yellowstone or Yosemite PACEs lost more than 25% of its reference area suggesting that these regions have been well-protected from human development. Potential exceptions to being well-protected in the Yellowstone PACE are grasslands and sagebrush which typically occur in valley bottoms and toeslope areas that have been the documented subject of low-density residential development for some time (Gude et al. 2006). The sagebrush ecosystem type lost 19% of its reference area and grasslands 6%. Also, the ecosystem type encompassing “all other natural vegetation” lost 17% of its area in the Yellowstone PACE. In the Yosemite PACE possible exceptions to being well-protected are the Oak forest and woodlands type which lost 14% of its reference area and the Chaparral type which lost 8%. These two ecosystem types occur principally at lower elevations on the west slope of the Sierra Mountains approaching the central valley (Figure 4). Like valley and toeslope areas of the Yellowstone PACE, this biophysical zone has also been the focus of low to medium density residential development. Finally, riparian areas of the Yosemite PACE have been eroded by development on private lands where they have lost 54% of their reference area. On average, Yellowstone PACE ecosystem types lost 2% of their area on public lands, 32% on private lands and 8% overall. Yosemite PACE ecosystem types lost 2% of their area on public lands, 37% on private lands and 11% of their total reference area.

Results for the Rocky Mountain PACE varied dramatically between public and private lands with some ecosystem types losing almost all of their area on private lands. This included the grassland meadow type of which there is only 14% remaining on private lands, although 65% remaining in total. Also suffering in the Rocky Mountain PACE were areas of “all other natural vegetation”. This type lost 68%

of its area on private lands and 40% overall. On average, Rocky Mountain PACE ecosystem types lost 53% of their area on private lands, 3% on public lands and 22% of their area overall.

No ecosystem type in the Delaware Water Gap PACE retained more than half of its reference area and most lost more than 60%. Of particular note are areas of Hemlock forest which lost 74% of its reference area, the most of any type in the Delaware Water Gap PACE. The Oak forest ecosystem type experienced the next greatest loss at 29% of its reference area followed by Pine-oak rocky woodlands which have only 12% of their area remaining on private lands and 35% overall. On average Delaware Water Gap PACE ecosystem types lost 80% of their reference area on private lands, 10% on public lands and 66% overall.

Loss of ecosystem type reference area varied across PACEs, within PACEs by ecosystem type and between private versus public lands. In general, public lands across the study area have been well-protected with an average loss of only 4%. Maps of loss show that road development has accounted for the majority of losses on public lands. Losses on private lands averaged 50% across the study area and appear to be highly aggregated in space. Percentage losses also varied across PACE areas. The Yellowstone PACE experienced the smallest losses followed by the Yosemite PACE area, Rocky Mountain PACE and the Delaware Water Gap PACE suffered by far the greatest losses. Finally, there were differences in the range of total losses. The Delaware Water Gap PACE had the smallest range of total losses at 15%, followed by the Yellowstone PACE at 17%, the Yosemite PACE at 24% and the Rocky Mountain PACE at 40%.

Change in ecosystem type pattern

For some ecosystem types in this analysis very small losses in total area resulted in disproportionately large changes in the configuration of that ecosystem type on the landscape. The Douglas-fir type in the Yellowstone PACE area for example, lost only 2% of its historical reference area, but suffered a 40% decline in mean patch size. It also experienced a decrease in the coefficient of variation of mean patch size of 41% and a decrease in the Euclidean distance to the next nearest patch of Douglas-fir of 29% (Table 3). This suggests that the largest patches of Douglas-fir have been bisected or fragmented by human development, functionally creating multiple distinct patches where historically there was only one large patch. Similar results were produced for grassland and Sagebrush ecosystem types in the Yellowstone PACE area. Areas of “all other natural vegetation” had their pattern affected the least, followed by Whitebark pine in the Yellowstone PACE. Across all ecosystem types in the Yellowstone PACE mean patch size decreased an average of 34%, variation in patch size decreased 25%, distance to nearest neighbor decreased 29% and variation in distance to nearest neighbor increased by 14%. Although the Yellowstone PACE area has suffered very small losses in total area to human land use, some of those losses have produced large changes in the configuration of natural landscapes.

The change in ecosystem type pattern for the Yosemite PACE area was similar to that of the Yellowstone PACE area. Oak forest and woodlands, Chaparral, Giant sequoia and the “all other natural vegetation” ecosystem type had their mean patch size halved or more despite losing an average of only 13% of their historical area. Mean distance to the next nearest neighbor patch of the same ecosystem type increased the most for riparian areas, growing by 41%. As in the Yellowstone PACE, areas of Whitebark pine had their pattern affected the least. On average mean patch size decreased by 44%, variation in patch size decreased by 38%, mean distance to the next nearest neighbor of the same type decreased by 36% and variation in distance to nearest neighbor grew by 19%.

The pattern of ecosystem types in the Rocky Mountain PACE area is not as impacted as would be expected based on total losses of area. The most impacted ecosystem type in terms of pattern change for Rocky Mountain appears to still be in better condition than the average ecosystem type in the Yosemite or Yellowstone PACE areas. Mean patch area for Aspen and Engelmann spruce-Subalpine fir grew, presumably as a result of losses of small patches from the landscape (fewer total patches in present day conditions), and preservation of the remaining patches intact. Mean distance to the next nearest neighbor of the same ecosystem type grew the most for the “all other natural vegetation” ecosystem type. On average, mean patch size shrank by 7%, variation in patch size shrank by 50%, distance to nearest neighbor grew by 11% and variation in distance to nearest neighbor grew by 19%.

The configuration of ecosystem types in the Delaware Water Gap PACE area has been greatly impacted. On average mean patch size has decreased by 81%, variation in patch size has increased by 11%, distance to the next nearest neighbor decreased by 11% and variation in distance to next nearest neighbor increased by 33%. The small increase in patch size variation is likely due to the preservation of a few large patches on the landscape, but otherwise high degrees of patch fragmentation by human land uses. The pattern of the Hemlock forest ecosystem type appears to be the most impacted by human development whereas the wetland/swamp ecosystem type is the least impacted.

Across all PACE areas in the study, mean patch size decreased by 41%, variation in patch size decreased by 26%, distance to nearest neighbor decreased by 26% and variation in distance to nearest neighbor increased by 19%. These results indicate that landscapes around US parks are becoming fragmented by human activity. The largest patches of natural habitat are being split up, there are generally more smaller patches of habitat on the landscape and aside from cases where one patch was split into two, patches are generally further apart.

Discussion

There is both moderate known accuracy of NPS vegetation maps and agreement between these maps and ecosystem types used in this study. Some of the variation can be explained by sample size.

Results presented in Figure 6 suggest that sample size explains about 58% of the variation in agreement with most ecosystem types covering larger areas having higher agreement than those covering smaller areas. This result is consistent with an interpretation of ecosystem types as a central tendency. Types which are mapped across a large number of pixels should approach a theoretical maximum agreement with actual present day conditions. We conclude that for ecosystem types with low agreement, large sample sizes and moderate to high reported NPS class accuracies, results of the present analysis should be viewed with skepticism. These include for the Rocky Mountain PACE, riparian and perhaps grassland meadow ecosystem types. For Delaware Water Gap, although the wetland swamp ecosystem type was not mapped over large areas, the high class accuracy reported by the NPS maps and exceptionally low agreement with maps of ecosystem type may bring these results into question as well. Though not conclusive, results from agreement analysis are consistent with the notion that maps of historical condition match well the present day location of ecosystem types within three US parks. By extension, there appears to be support for the use of these maps as reasonable reference conditions in areas surrounding parks. In one respect, a biophysical, central-tendency approach to identifying the spatial location of ecosystem types should be robust to the dynamic nature of ecosystems at the right spatial and temporal scales in ways that empirical observations of present day or recent historical land cover change are not. However, if there is no way to determine across which spatial and temporal scales these models “work”, then their utility for conservation planning remains questionable. Given persistent and substantial inaccuracies of NPS vegetation maps the true agreement between ecosystem types and present day conditions remains unknown. Further exploration of the reliability of maps of historical reference conditions is warranted as methods and data improve.

The present study proposes methods to monitor the ecological condition of ecosystems containing US parks. By repeating the present analysis as input data layers are updated, park managers could track which ecosystem types are being most affected by land use change both outside and within park boundaries. By doing so hereafter should be high priorities for conservation and management action. By examining the overlap and pattern of ecosystem types and land use together, the present methods are also likely to refine understanding of how land use impacts ecosystems and focus future research and monitoring efforts.

Many of the results presented in this study are explained by spatially coherent patterns of ecological phenomenon and human activity. For example, the Whitebark pine ecosystem type was one of the least impacted in both the Yellowstone and Yosemite PACEs. Whitebark pine (*Pinus albicaulis*) thrives in high elevation, often harsh environments which are in general on public lands or not suitable for human use. Another example comes from configuration metrics for the Rocky Mountain PACE which were relatively unchanged. This is due to the concentration of land use in a few specific biophysical

settings, to the east of Rocky Mountain National Park towards the Rocky Mountain foothills and to the immediate southwest of the park (Figure 2). Further evidence of highly aggregated land use in the Rocky Mountain PACE is that it had the largest range of proportional losses, followed by the Yosemite PACE. Human land use is a spatially non-random process often organized around the same dimensions of landscapes that are ecological systems (Seabloom et al. 2002, Hansen et al. 2005, Leu et al. 2008).

In order to apply the results of this study in a local conservation context it is important to understand two things. First is to understand the biophysical setting of the park relative to its surroundings and how species are distributed across these landscapes. Second is to understand the relationship between biophysical setting and where people choose to develop land for human use. Each relationship is the result of human decision-making in distinct ecological, socio-cultural, political and historical contexts and they have had and will continue to have profound implications for the preservation of protected areas and maintenance of biodiversity at the scale of park ecosystems. There is an evolving field of research which can form a basis of understanding with which to interpret the results of the present study.

Scott et al. (2001) in a study of the coterminous U.S. found that the existing network of protected lands occur most frequently at higher elevations and in areas of lower soil productivity and hence lower species diversity according to species-energy theory (Wright 1983). The authors contrast this with observations that the greatest number of species are found at lower elevations that are often under private ownership. Seabloom et al. (2002) demonstrated with a modeling study how the concentration of human development in low-elevation, coastal areas of California overlaps with areas of highest vascular plant species diversity. They found that predictions of extinctions based only on species-area relationships grossly underestimated extinction predictions which also take into account the aggregated spatial pattern of diversity and habitat loss. The co-location of California's plant diversity with areas under greatest threat by human land use means that likely future extinction rates will be far greater than would have been expected under spatially random patterns of species diversity and human land use. Leu et al. (2008) used human footprint analysis across 11 western U.S. states to demonstrate that human activity is concentrated on highly biologically productive, low-elevation valley bottoms of greatest biological diversity. They emphasize that intense human land uses are not restricted to urban areas and their surroundings, but that high human footprint scores were also associated with agricultural lands and secondary roads in areas of lower human population and housing densities. Oneill et al. (2009) set out to explicitly test whether the global network of protected areas has been created on low-productivity lands relative to more highly productive urbanized areas. They found that in almost all regions of the world humans have settled the most productive and biologically diverse areas and chosen to protect areas of only average biological productivity and diversity. The authors point out

that their analysis was based on an approach to model potential biological productivity which may overestimate the productivity of protected areas which could increase the actual contrast in productivity between global parks and urbanized areas. Finally, even though the conclusions of Oneill et al. offer some tempered optimism at the global scale that parks do not represent areas of lowest productivity, the authors point out that the contrast in productivity is most stark in western portions of North America. Indeed, as has been suggested by Pressey (1994) and others for quite some time, the US system of National Parks was designed in an ad hoc manor based principally on considerations other than efficiency of biodiversity conservation. In summary, there is a large body of evidence put forth by the research community that suggests the following:

- Species abundance and diversity are concentrated in moderate to highly productive biophysical zones associated with low-elevation, higher temperatures, deep soils and rivers valleys.
- Parks and protected areas are primarily located in biologically less productive areas associated with high-elevation, lower temperatures, shallow soils and limited summer precipitation.
- Human activity and species abundance and diversity largely overlap.
- A major conservation challenge for land managers is working to protect aspects of local and regional biodiversity which are not represented, or cannot be exclusively supported by the existing network of parks and protected areas in the coterminous U.S.

The dimensions of human systems that determine the specific locations of land use are not static. Huston (2005) detailed three phases of land use development beginning with an agricultural phase. During the agricultural phase human land use is most closely tied to the biological productivity of the land with human activity concentrating in areas of greatest biological productivity. During a second industrial phase human land use begins to transition away from historical agricultural centers and instead clusters around transportation networks. Finally, a third phase is characterized by electronic communication and information transfer and frees human populations from locating near either agricultural centers or existing transportation networks. Each stage of development threatens different portions of the landscape and hence different ecosystem types. Many park managers understand well which phase of development the communities and economies surrounding their parks are in through personal experience and through the mapping of socio-economic indicators or other similar activities (Greb et al. 2008). The present study quantifies which ecosystem types have been impacted to the present day. By using a qualitative understanding of local communities and economies, park managers may be able to anticipate which ecosystem types are likely to be at risk to future development. As monitoring of both human land use and ecosystem type fragmentation continues, park managers will likely develop an understanding of the spatial relationships between them sufficient to inform local conservation planning and guide future research and monitoring.

In addition to contributions to monitoring and research, the results of this study could also be used in application to local conservation efforts. For example, Yosemite and Rocky Mountain typify the classic western park that suffers from a productivity bias towards private lands. The low-elevation ecosystem types that occur around these parks have suffered large percentage losses in area as well as large increases in fragmentation to present. Populations of many species associated with these habitats are already ailing and park managers recognize a need to protect these habitats outside of parks. Because funds to protect new lands are always limited this process needs to be carefully planned and prioritized. As rural portions of the western U.S. move from Huston's second stage of development towards the final stage we expect development pressure on some of the most productive portions of the landscape to lessen, principally through agricultural abandonment. This will provide opportunities to preserve large tracts of land that are of high quality for supporting biodiversity and that support ecosystem types which are not well-represented within park boundaries. In order to prioritize these efforts the present project answers two important questions. First, which ecosystem types have been most impacted by human development and should be the highest priorities for conservation action? And second, what kind of habitat would a restored property likely support over the long-term given its biophysical setting and historical disturbance regime? Knowing the answers to these two questions will allow those working in the local conservation community to target specific properties which if they become available would be the highest priorities for conservation and restoration in the ecosystems surrounding parks like Yosemite and Rocky Mountain.

In some eastern parks like Delaware Water Gap where many ecosystem types have experienced almost total losses on private lands, it may be that there is not enough habitat remaining to preserve biodiversity into the future. Development in the Delaware Water Gap PACE has been operating in Huston's (Huston 2005) final stage of development for some time and the spatial pattern of impacts approaches random as indicated by the smallest range of percentage losses in the study. The present analysis (along with the work of others), may direct park managers to refocus some of their conservation attention from their individual park and PACE to the region as has already been suggested. In a 2009 study, Goetz et al. identified core forested habitat areas in the northeastern U.S. and their connectivity to one another using graph theory analysis. Habitat in Delaware Water Gap was identified as a core area along with potential corridors to connect this area to other large core areas to the east (north central Pennsylvania), and northwest (Catskill mountains of New York state). In combination with the work of Goetz et al., Delaware Water Gap managers could use the present analysis to identify key areas of hemlock or oak forest (as highest priorities), that if protected would increase connectivity of local habitat to regional core habitats. They could also guide interested researchers and monitoring programs towards questions related to corridor ecology?

In and around parks like Yellowstone that remain little impacted by human development, park managers may use the information presented by this study as quantifications or justifications for intuitions that they already held. For instance, it is well accepted that sagebrush and grassland habitat surrounding Yellowstone has been under threat from development for some time. However, it was not previously known to park managers what percentage of sagebrush habitat had been lost or impacted to date (Oliff personal communication). Knowing that roughly one third of sagebrush habitat on private lands in this ecosystem has been lost will likely focus the conservation problem or stimulate additional projects. Yellowstone park managers may also take note of large changes in the pattern of medium elevation Douglas fir habitat despite only a small loss of area. This ecosystem type has not previously received attention as being under threat from land use change, however if the current trend of large impacts despite few losses continues it could signal a conservation problem for the Yellowstone ecosystem.

Some of the above discussion suggests that NPS managers should work towards protecting specific ecosystem types outside of their park boundaries based on the extent of fragmentation by human land use and yet there remain serious questions about how to accomplish this task. The answer to these questions is very likely specific to the contexts in which land use change is taking place and at a finer scale, the specific motivations of individuals involved (Brown et al. 2008). There already exist useful tools for park managers, ecologists and land use planners to work towards ameliorating some of the ecological impacts of human development. These tools range from software and textbooks to regulatory and incentive-based approaches, some of which have a long history of use and some of which are just now gaining in popularity (Botequilha 2006, Lindenmayer et al. 2007, Benedict et al. 2006, Theobald et al. 2005, Pejchar et al. 2006, Milder 2007). One approach suggests involving ecologists directly in local land use planning efforts and is advocated by Theobald et al. (2005). In fact, this suggestion has already been acted upon in the Delaware Water Gap PACE where park staff is involved in a number of planning and land use scenario building research efforts in cooperation with local land use planning offices (Morlock 2010 *personal communication*).

Through projects like the one presented here, the research and monitoring communities are beginning to provide local scale information to park managers on land use change and expected impacts to ecosystem integrity and biodiversity. Armed with this information and understanding parks can become more involved in local conservation, restoration and land use planning efforts to help better preserve the ecosystems which they strive to protect.

Conclusion

US NPS managers, like PA managers around the globe, face a variety of challenges to preserving the biodiversity which reside in their parks. Chief among those challenges is to anticipate the impacts to biodiversity that land use intensification around their borders will have and to develop conservation strategies to minimize those impacts. In the absence of ideal sets of data and models, the present study presents methods and results which demonstrate a first-pass approach to developing management relevant information for four pilot study areas. The areas in this study represent a cross-section of the landscape contexts in which U.S. parks presently exist in the coterminous U.S. As such, they demonstrate the various contemporary conservation challenges with which parks are currently faced. In some cases these challenges center around spatially non-random and highly aggregated human development such as in the Yosemite and Rocky Mountain PACEs, in others they involve substantial losses of habitat area such as in the Delaware Water Gap PACE, and in still others like Yellowstone there are challenges principally related to maintaining ecosystem integrity in its current (or better), condition and planning for the future. Best strategies for each situation will need to be locally developed. It is likely in all cases that future conservation efforts will have to be piecemeal and employ hybrid approaches where additional lands are added to reserve networks in the most efficient and informed manner possible. Long-term monitoring strategies like the one proposed in the present study will play a key role in this process. There are also likely to be opportunities to work towards mitigation of the impacts to biodiversity caused by “inevitable” human development. Crucial to these efforts will be the involvement of ecologists and park managers in local land use planning. This study provides recommendations for monitoring methods and contributes to an understanding of the spatial organization and relationship between natural land covers and human land use. The results of this study will help to guide future monitoring, research and management around US parks to better protect our nation’s biodiversity heritage.

Literature Cited:

1. Benedict, MA and ET McMahon. 2006. Green Infrastructure: Linking landscapes and communities. Island Press. Washington, D.C.
2. Brooks et al. 1999. Time Lag between Deforestation and Bird Extinction in Tropical Forest Fragments.
3. Bureau of Reclamation. 2005. Rocky Mountain National Park, Colorado 2001-2005 Vegetation Classification and Mapping. Technical Memorandum 8260-05-02. Remote Sensing and GIS Group, Technical Service Center. Denver, CO.
4. Carroll, C, Noss, RF, Paquet, PC and N.H. Schumaker. 2004. Extinction debt of protected areas in developing landscapes. *Conservation Biology*. 18(4):1110-1120.
5. Comer, P., D. Faber-Langendoen, R. Evans, S. Gawler, C. Josse, G. Kittel, S. Menard, M. Pyne, M. Reid, K. Schulz, K. Snow, and J. Teague. 2003. Ecological systems of the United States: A working classification of U.S. terrestrial systems. NatureServe, Arlington, VA.
6. Environmental Systems Research Institute (ESRI). ArcMap software version 9.2. Copyright 1999-2006.
7. Fancy, S. G., J. E. Gross, and S. L. Carter. 2009. Monitoring the condition of natural resources in US national parks. *Environmental Monitoring and Assessment* 151:161-174.
8. FRCC 2010. Fire Regime Condition Class: Interagency Fire Regime Condition Class (FRCC) Guidebook Version 3.0. National Interagency Fuels, Fire, &Vegetation Technology Transfer (NIFTT).
9. GAO (General Accounting Office). 1994. Activities outside of park borders have caused damage to resources and will likely cause more. GAO/RCED-94-95. U.S. Government Printing Office, Washington D.C.
10. Goetz, SJ, Jantz, P and CA Jantz. 2009. Connectivity of core habitat in the Northeastern United States:parks and protected areas in a landscape context. *Remote Sensing of Environment*. 113:1421-1429.
11. Gross, JE, AJ Hansen, SJ Goetz, DM Theobald, FM Melton, NB Piekielek and RR Nemani. 2010. Remote sensing for inventory and monitoring of the U.S. National Parks. In (Y. Wang editor) Remote sensing of protected lands. Taylor and Francis.
12. Hansen and Rotella. 2002. Biophysical Factors, Land Use, and Species Viability in and around Nature Reserves.
13. Hansen, A, Davis, C, Piekielek, N, Gross, J, Theobald, D, Goetz, S, Melton F and R Defries. 2010. Delineating the ecosystems containing protected areas for monitoring and management. *Bioscience*. (In review).
14. Huston, M. 2005. The three phases of land-use change: implications for biodiversity. *Ecological Applications* 15(6):1864-1878.
15. Keane, RE, Parsons and P. Hessburg. 2002. Estimating historical range and variation of landscape patch dynamics: Limitations of the simulation approach. *Ecological Modeling* 151 (2002), pp. 29–49.
16. Keane et al., 2009. The use of historical range and variability (HRV) in landscape management. *Forest Ecology and Management*. 258(11):1025-1037.
17. Largay, E and L Sneddon. 2009. A method for developing ecological systems maps from national vegetation classification association-level vegetation maps for eight National Parks in the Eastern Rivers and Mountains Network of the National Park Service. Technical Report NPS/NER/NRTR—2009/136. Northeast Region. Philadelphia, PA.
18. Leitao, AB, Miller, J, Ahern, J and K McGarigal. 2006. Measuring landscapes: A planner's handbook. Island Press. Washington, D.C.
19. Leopold A.S. Cain, S.A, Cottam, C.M., Gabrielson, I.N. and T.L. Kimball. 1963. Wildlife Management in the National Parks: The Leopold Report. National Park Service, Department of the Interior, Washington D.C.

20. Leu, M., Hanser, SE and ST Knick. 2008. The human footprint in the west: a large-scale analysis of anthropenic impacts. *Ecological Applications*. 18(5):1119-1139.
21. Lendenmayer, DB and RJ Hobbs (Eds.). 2007. Managing and designing landscapes for conservation. Blackwell Publishing. Malden, MA.
22. Machlis, GE and DR Field. 2000. National Parks and rural development: practice and policy in the United States. Island Press. Washington D.C.
23. McGarigal, K., SA Cushman, MC Neel, and E Ene. 2002. FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: <http://www.umass.edu/landeco/research/fragstats/fragstats.html>
24. McGarigal, K and SA Cushman. 2002. Comparative evaluation of experimental approaches to the study of habitat fragmentation effects. *Ecological Applications*. 12(2):335-345.
25. Milder, JC. 2007. A framework for understanding conservation development and its ecological implications. *Bioscience*. 57(9):757-768.
26. Miller, C.I. et al. 2007. Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications*. 17(8):2145-2151.
27. Morlock, L. 2010. *personal communication*.
28. NatureServe. 2009. International Ecological Classification Standard: Terrestrial Ecological Classifications. NatureServe Central Databases. Arlington, VA, U.S.A. Data current as of February 2009.
29. Norris, K and N Harper. 2004. Extinction processes in hot spots of avian biodiversity and the targeting of pre-emptive conservation action. *Proceedings: Biological Sciences*. 271(1535):123-130.
30. O'Neill, DW and DJ Abson. 2009. To settle or protect? A global analysis of net primary production in parks and urban areas. *Ecological Economics*. 69:319-327.
31. Perles, SJ, Podiesinski, GS, Eastman, E, Sneddon, LA and SC Gawler. 2007. Classification and mapping at Delaware Water Gap National Recreation Area. Technical Report NPS/NER/NRTR—2007/076. Northeast Region. Philadelphia, PA.
32. Perles, SJ, Podniesinski, GS, Furedi, MA, Eichelberger, BA, Feldman, A, Edinger, G, Eastman, E and LA Sneddon. 2008. Vegetation classification and mapping at Upper Delaware Scenic and Recreational River. Technical Report NPS/NER/NRTR—2008/133. Northeast Region. Philadelphia, PA.
33. Peterson, MN, Cheng, X and J Liu. 2008. Household location choices: implications for biodiversity conservation. *Conservation Biology*. 22(4):912-921.
34. Radeloff, VC, Stewart, SI, Hawbaker, TJ, Gimmi, U, Pidgeon, AM, Flather, CH, Hammer, RB and DP Helmers. 2010. Housing growth in and near United States protected areas limits their conservation value. *PNAS*. 107(2):940-945.
35. Rentch, J et al. 2008. Using dendrochronology to model hemlock wooly adelgid effects on eastern hemlock growth and vulnerability. *Biological Invasions*. 11(3): 551-563.
36. Sala, Osvaldo E., F. Stuart Chapin, III, Juan J. Armesto, Eric Berlow, Janine Bloomfield, Rodolfo Dirzo, Elisabeth Huber-Sanwald, Laura F. Huenneke, Robert B. Jackson, Ann Kinzig, Rik Leemans, David M. Lodge, Harold A. Mooney, Martin Oesterheld, N. LeRoy Poff, Martin T. Sykes, Brian H. Walker, Marilyn Walker, and Diana H. Wall. 2010. Global Biodiversity Scenarios for the Year 2100. *Science* 287 (5459), 1770.
37. Seabloom, EW, Dobson, AP and DM Stoms. 2002. Extinction rates under nonrandom patterns of habitat loss. *PNAS*. 99(17):11229-11234.
38. Scott, JM, Davis, FW, Mcghee, RG, Wright, RG, Groves, C and J Estes. 2001. Nature reserves: do they capture the full range of America's biological diversity? *Ecological Applications*. 11(4):999-1007.

39. Spring, DA, Cacho, O, MacNally, R and R Sabbadin. 2007. Pre-emptive conservation versus “fire-fighting”: A decision theoretic approach. *Biological Conservation*. 136:531-540.
40. Theobald, D.M. 2001. Land use dynamics beyond the American urban fringe. *Geographical Review* 91(3):544-564.
41. Theobald, D.M. 2003. Targeting conservation action through assessment of protection and exurban threats. *Conservation Biology* 17(6):1624-1637.
42. Theobald, D.M. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. *Ecology and Society* 10(1): 32. [online] URL: <http://www.ecologyandsociety.org/vol10/iss1/art32/>.
43. Theobald, DM, Spies, T, Kline, J, Maxwell, B, Hobbs, NT and VH Dale. 2005. Ecological support for rural land-use planning. *Ecological Applications*. 15(6):1906-1914.
44. Newmark, W. D. 1985. Legal and biotic boundaries of Western North American national parks: a problem of congruence. *Biological Conservation* 33:197–208.
45. Newmark, W. D. 1987. A land-bridge island perspective on mammalian extinctions in western North America parks. *Nature* 325:430–432.
46. Newmark, W. D. 1995. Extinction of mammal populations in western North American national parks. *Conservation Biology* 9:512–526.
47. Newmark, W. D. 1996. Insularization of Tanzanian parks and the local extinction of large mammals. *Conservation Biology* 10:1549–1556.
48. NPS. 2010. website: <http://science.nature.nps.gov/im/inventory/veg/index.cfm>
49. NPS.2. 2010. Sage-Grouse Resource Brief. www.greaterYellowstoneonescience.org
50. NPS.3. 2010. Pronghorn Fact Sheet. www.greaterYellowstoneonescience.org
51. Parks, S. A., and A. H. Harcourt. 2002. Reserve size, local human density, and mammalian extinctions in the U.S. protected areas. *Conservation Biology* 16:800–808.
52. Sala, D, Stevens, J and K Schulz. 2005. Rocky Mountain National Park, Colorado 2001-2005 Vegetation classification and mapping. Technical Memorandum 8260-05-02. Remote Sensing and GIS Group Technical Service Center, Bureau of Reclamation. Denver, CO.
53. USFS. 2010. Website. www.landfire.gov
54. Varanka, D. 2005. Twentieth-Century Land Surface Changes in the Delaware Water Gap. http://mcmcweb.er.usgs.gov/de_river_basin/
55. Wade, AA and DM Theobald. 2009. Residential development encroachment on U.S. protected areas. *Conservation Biology*. 24(1):151-161.
56. Wang, Y., B.R. Mitchell, J. Nugranad-Marzilli, G. Bonyne, Y. Zhou, G. Shriver, 2009. Remote sensing of land-cover change and landscape context of the National Parks: A case study of the Northeast Temperate Network, *Remote Sensing of Environment*. 113: 1453-1461.
57. Wright, DH. 1983. Species-energy theory: an extension of species-area theory. *Oikos*. 41:496-506.

Table 1. Data sources and resolution

	Data Source	Spatial Resolution
Developed Area		
Transportation corridors (Primary, secondary and private roads, railroads)	TIGER lines file; US Census Bureau http://www2.census.gov/cgi-bin/shapefiles2009/national-files	Approximation of actual footprints
Agricultural	National Land Cover Dataset 2001 http://nationalmap.gov/viewers.html	30 meter
Commercial and industrial	National housing density database from SERGoM model (Theobald 2001, 2003, 2005; EPA 2009)	30 meter
Residential housing	National housing density database from SERGoM model (Theobald 2001, 2003, 2005)	30 meter
	(SERGoM = Spatially Explicit Regional Growth Model)	

Table 2. Area losses by PACE and ecosystem type

PACE	Ecosystem type	Private lands % Remaining	Public lands % Remaining	Total % Remaining
Yellowstone				
	Douglas-fir	79	99	98
	Deciduous	64	98	93
	Sagebrush	66	97	81
	Whitebark pine	75	100	99
	Riparian	78	100	96
	Grassland	53	97	94
	Other natural vegetation	59	97	83
	mean	68	98	92
Yosemite				
	Oak forest and woodlands	58	97	76
	Chapparal	78	100	82
	Grassland meadow	77	100	99
	Riparian	44	96	76
	Subalpine forest	45	98	91
	Whitebark pine	62	100	100
	Giant Sequoia	69	97	93
	Other natural vegetation	73	98	97
	mean	63	98	89
Rocky Mountain				
	Aspen	65	100	88
	Douglas-fir	40	100	74
	Englmann spruce-subalpine fir	65 14	100 95	100 65

	Grassland meadow	55	98	91
	Lodgepole pine	51	95	77
	Riparian	54	95	70
	Shrubland	32	97	60
	Other natural vegetation	47	97	78
	mean			
Delaware Water Gap		20	86	26
	Hemlock	21	82	32
	Riparian	27	95	41
	Wetland/swamp	14	90	29
	Oak forest	12	90	35
	Pine-oak rocky woodland	28	97	41
	Other natural vegetation	20	90	34
	mean			
Study Mean		50	96	73

Table 3. Change in ecosystem type pattern metrics

PACE		Change in mean patch size %	Change in mean patch size coefficient of variation %	Change in mean Euclidean distance to nearest neighbor %	Change in Euclidean distance to nearest neighbor coefficient of variation %
Yellowstone					
	Douglas-fir	-40	-41	-29	14
	Deciduous	-30	-31	-28	21
	Sagebrush	-75	-37	-59	42
	Whitebark pine	-14	-9	-14	7
	Riparian	-25	-8	-25	14
	Grassland	-44	-28	-41	34
	Other natural vegetation	-9	5	-12	1
	mean	-34	-25	-33	22
Yosemite					
	Oak forest and woodlands	-81	-78	-58	14
	Chapparal	-50	-73	-40	29
	Grassland meadow	-8	5	-11	5
	Riparian	-46	-41	-41	41
	Subalpine forest	-37	4	-32	22
	Whitebark pine	-5	-6	-3	1
	Giant Sequoia	-65	-49	-54	33
	Other natural vegetation	-57	-64	-52	28
	mean	-44	-38	-36	22
Rocky Mountain					
	Aspen	10	-38	8	6
	Douglas-fir	-3	-78	12	7
	Englmann spruce-subalpine	6	-19	4	-5

	fir	-25	-84	5	3
	Grassland meadow	-1	-55	6	-27
	Lodgepole pine	-19	-40	13	2
	Riparian	-14	-62	11	2
	Shrubland	-11	-26	26	-2
	Other natural vegetation	-7	-50	11	-2
	mean				
Delaware Water Gap		-94	-66	-42	9
	Hemlock	-81	-1	-45	49
	Riparian	-60	28	-34	47
	Wetland/swamp	-92	-46	-49	10
	Oak forest	-66	75	-35	42
	Pine-oak rocky woodland	-91	76	-61	40
	Other natural vegetation	-81	11	-44	33
	mean				
Study Mean		-41	-26	-26	19

Table 4. Agreement between present day maps of known accuracy and modeled reference conditions

PACE	Ecosystem type	# pixels Mapped by LANDFIRE	# pixels Mapped by NPS/USGS	% Agreement (ecol. Systems level)	NPS Class Accuracy	Total NPS Map Accuracy (association level)
Rocky Mountain						49
	Aspen	206,606	51,792	33	39	
	Douglas-fir	173,288	341,225	66	33	
	Englmann spruce-subalpine fir	509,801	507,832	64	61	
	Grassland meadow	106,084	212,069	21	54	
	Lodgepole pine	398,769	319,092	51	51	
	Riparian	89,044	47,825	4	48	
	Shrubland	32,860	40,520	12	64	
	mean			51	50	
Delaware Water Gap						50
	Hemlock	201,108	184,895	50	46	
	Riparian	43,882	14,970	39	NA	
	Wetland/swamp	5,371	842	13	62	
	Oak forest	241,491	216,701	55	49	
	Pine-oak rocky woodland	60,315	4,616	33	70	
	mean			52	57	
Mean				51.5	54	50

Figure Legends

Figure 1. Parks, study areas and abbreviations.

Figure 2. Historical versus present day ecosystem type conditions for Rocky Mountain NP PACE Area

Figure 3. Historical versus present day ecosystem type conditions for Delaware Water GAP NRA and Upper Delaware SRR PACE Area

Figure 4. Historical versus present day ecosystem type conditions for Yosemite and Sequoia-Kings Canyon NP PACE area

Figure 5. Historical versus present day ecosystem type conditions for Yellowstone and Grand Teton NP PACE Area

Figure 6. Correspondence as a function of sample size

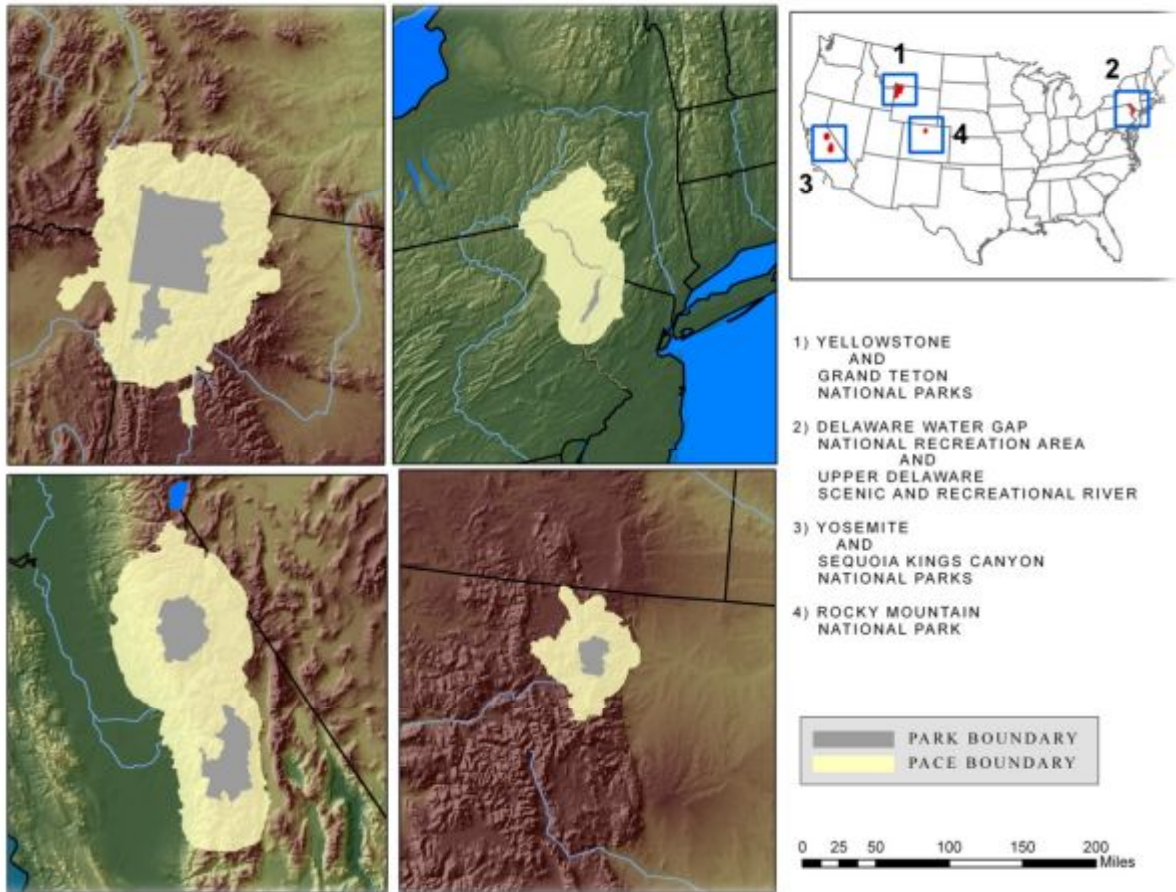


Figure 1.

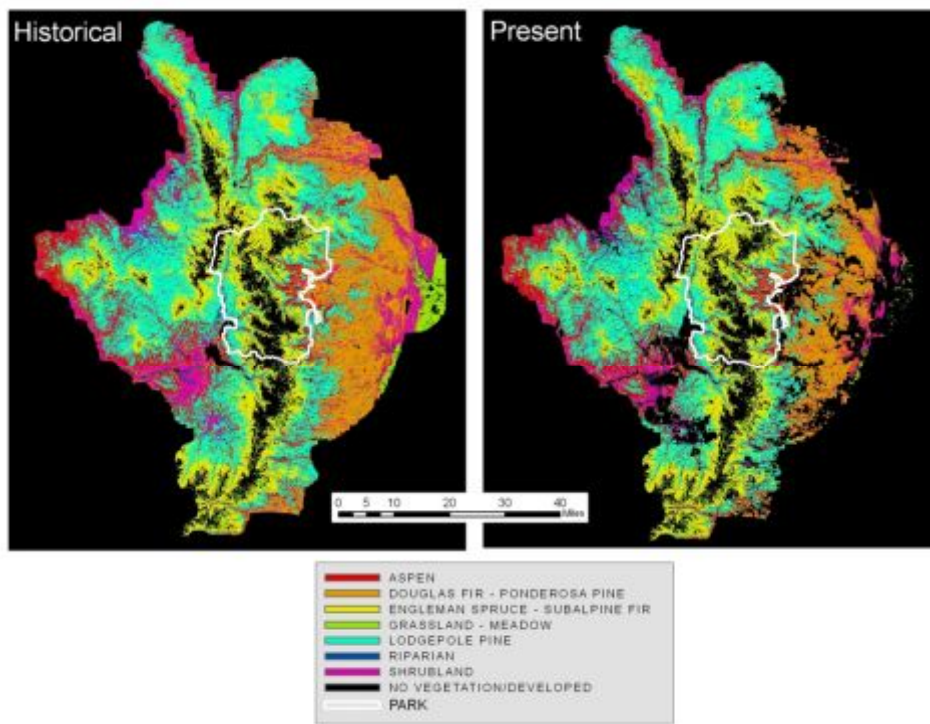


Figure 2.

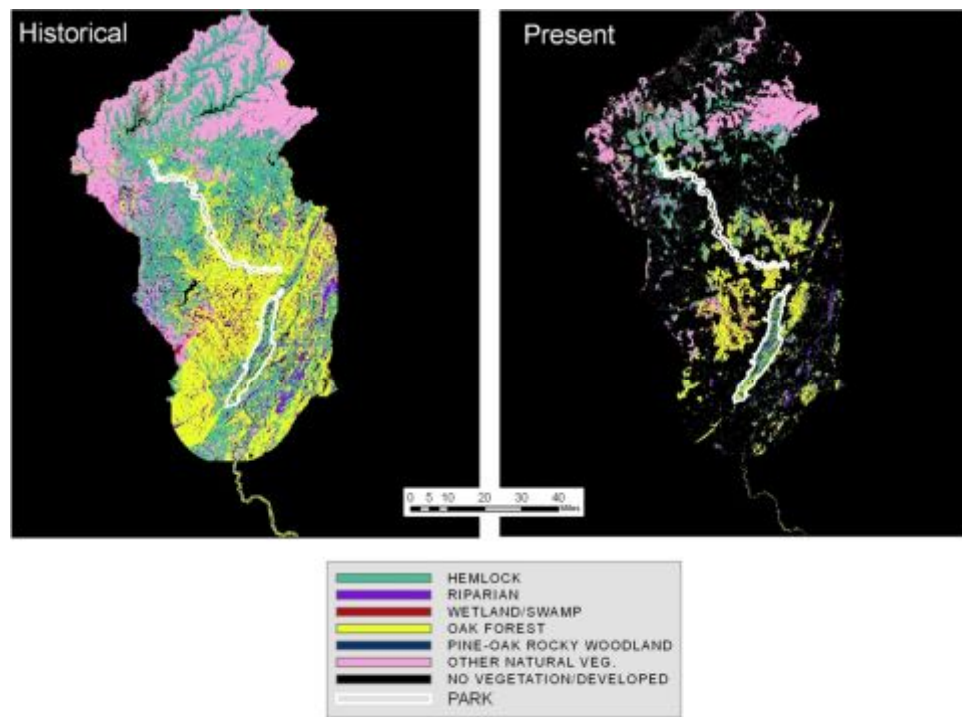


Figure 3.

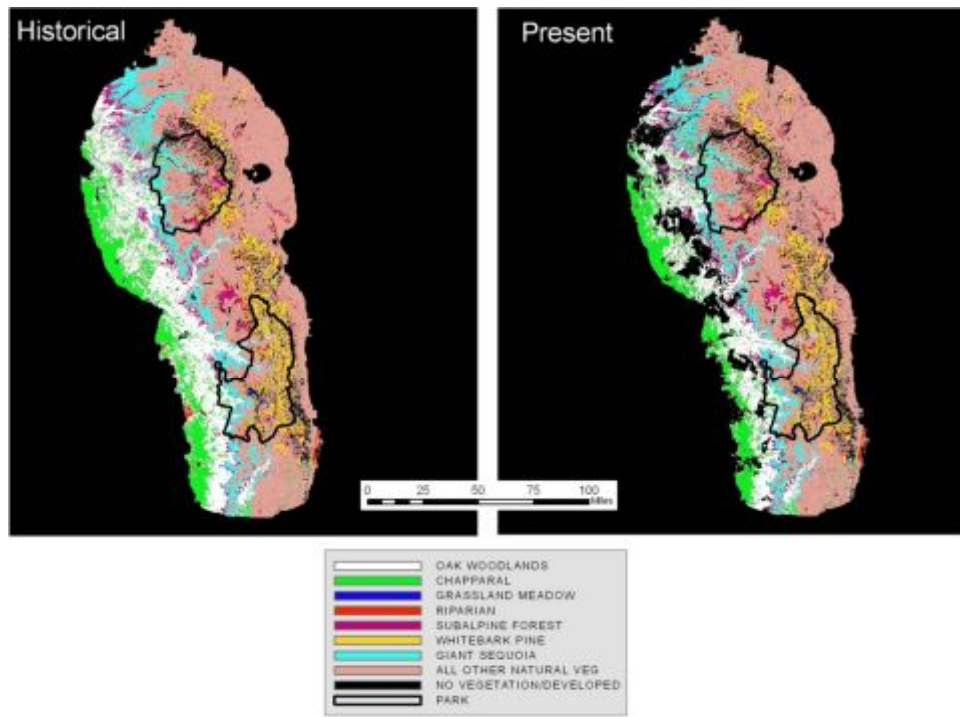


Figure 4.

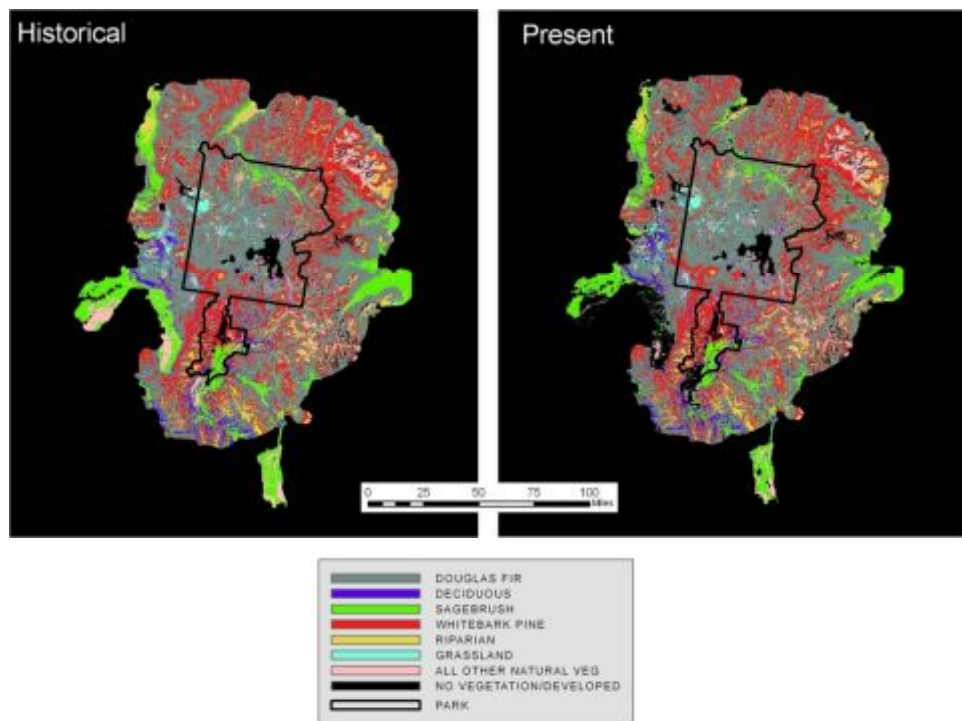


Figure 5.

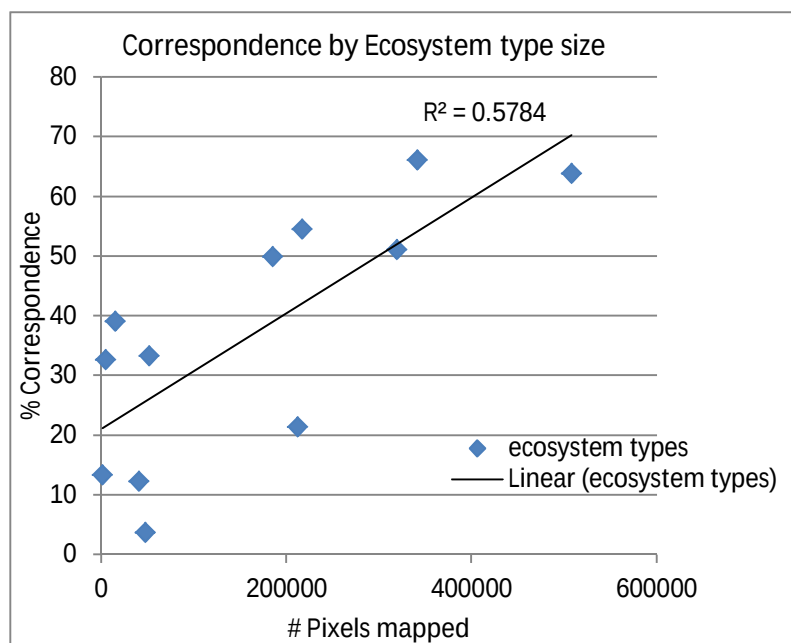


Figure 6.

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Appendix A. Crosswalk of LANDFIRE bps ecological systems to ecosystem types

PACE	LANDFIRE Ecological Systems		LANDFIRE Ecological Systems	
	Ecosystem type	Unique ID	Names	
Yellowstone	Douglas-fir	CES306.805	Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest	
		CES306.823	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	
		CES306.828	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	
		CES306.959	Middle Rocky Mountain Montane Douglas-Fir Forest and Woodland	
	Deciduous	CES306.813	Rocky Mountain Aspen Forest and Woodland	
		CES306.814	Rocky Mountain Bigtooth Maple Ravine Woodland	
		CES304.776	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	
		CES306.994	Northern Rocky Mountain Montane-Foothill Deciduous Shrubland	
		CES306.803	Northern Rocky Mountain Conifer Swamp	
	Sagebrush	CES304.783	Inter-Mountain Basins Mat Saltbush Shrubland	
		CES304.794	Wyoming Basins Dwarf Sagebrush Shrubland and Steppe	
		CES304.774	Great Basin Xeric Mixed Sagebrush Shrubland	
		CES304.777	Inter-mountain Basins Big Sagebrush Shrubland	
		CES303.662	Northwestern Great Plains Shrubland	
		CES304.080	Columbia Plateau Low Sagebrush Steppe	
		CES304.778	Inter-mountain Basins Big Sagebrush Steppe	
		CES304.785	Inter-Mountain Basins Montane Sagebrush Steppe	
		CES304.788	Inter-Mountain Basins Semi-Desert Shrub-Steppe	

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Whitebark pine	CES306.807	Northern Rocky Mountain Subalpine Woodland and Parkland
	CES306.830	Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland
Riparian	NA	Inter-Mountain Basins Montane Riparian Systems
	NA	Rocky Mountain Montane Riparian Systems
	NA	Rocky Mountain Subalpine/Upper Montane Riparian Systems
Grassland	CES304.083	Columbia Plateau Steppe and Grassland
	CES304.787	Inter-Mountain Basins Semi-Desert Grassland
	CES306.040	Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland
	CES306.806	Northern Rocky Mountain Subalpine-Upper Montane Grassland
	CES303.674	Northwestern Great Plains Mixedgrass Prairie
	CES306.811	Rocky Mountain Alpine Fell-field
	CES306.816	Rocky Mountain Alpine Turf
	CES306.829	Rocky Mountain Subalpine-Montane Mesic Meadow
	CES303.670	Western Great Plains Sand Prairie
Yosemite		
Oak forest and woodlands	CES206.920	Central and Southern California Mixed Evergreen Woodland
	CES206.909	Mediterranean California Mixed Oak Woodland
	CES206.923	Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland
		Rocky Mountain Gambel Oak-Mixed Montane Shrubland

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	CES306.818	California Lower Montane Blue Oak-Foothill Pine Woodland and Savanna
	CES206.937	
Chapparal	CES206.928	Mediterranean California Mesic Serpentine Woodland and Chaparral
	CES206.925	California Mesic Chaparral
	CES206.925	California Montan Woodland and Chaparral
	CES304.001	Great Basin Semi-Desert Chaparral
	CES302.741	Mogollon Chaparral
	CES206.931	Northern and Central California Dry-Mesic Chaparral
	CES302.757	Sonora-Mojave Semi-Desert Chaparral
Grassland meadow	CES206.900	Mediterranean California Alpine Fell-Field
	CES206.924	Sierra Nevada Alpine Dwarf-Shrubland
	CES304.787	Inter-Mountain Basins Semi-Desert Grassland
	CES206.939	Mediterranean California Alpine Dry Tundra
	CES206.940	Mediterranean California Subalpine Meadow
	CES204.100	North Pacific Montane Grassland
	CES206.946	California Central Valley Riparian Woodland and Shrubland
	CES304.780	Inter-Mountain Basins Greasewood Flat

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Riparian	NA	California Montane Riparian Systems
	NA	Inter-Mountain Basins Montane Riparian Systems
	NA	North American Warm Desert Riparian Systems
	NA	Rocky Mountain Montane Riparian Systems
	NA	Rocky Mountain Subalpine/Upper Montane Riparian Systems
Subalpine forest	CES206.916	Mediterranean California dry-Mesic Mixed Conifer Forest and Woodland
	CES206.911	Northern California Mesic Subalpine Woodland
	CES306.823	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland
	CES306.825	Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland
	CES306.819	Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland
	CES206.912	Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland
Whitebark pine	CES304.790	Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland
	CES206.913	Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland
Giant Sequoia		Mediterranean California Subalpine Woodland
	CES206.915	Mediterranean California Mesic Mixed Conifer Forest and Woodland

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Rocky Mountain	Aspen	CES304.776	Inter-Mountain Basins Aspen-Mixed Conifer Forest and woodland
		CES306.813	Rocky Mountain Aspen Forest and Woodland
Grassland meadow		CES306.810	Rocky Mountain Alpine Dwarf-Shrubland
		CES306.824	Southern Rocky Mountain Montane-Subalpine Grassland
		CES306.811	Rocky Mountain Alpine Fell-Field
		CES306.829	Rocky Mountain Subalpine-Montane Mesic Meadow
		CES306.816	Rocky Mountain Alpine Turf
		CES304.787	Inter-Mountain Basins Semi-Desert Grassland
		CES303.817	Western Great Plains Foothill and Piedmont Grassland
		CES303.672	Western Great Plains Shortgrass Prairie
			Rocky Mountain Lodgepole Pine Forest
Engelmann spruce-subalpine fir		CES306.828	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland; Rocky Mountain Subalpine Mesic- Wet Spruce-Fir Forest and Woodland
		CES306.830	
Riparian		NA	Rocky Mountain Subalpine/Upper Montane Riparian Systems
		NA	Rocky Mountain Montane Riparian System
Douglas fir-		CES306.823	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland
			Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland

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Delaware Water Gap	Ponderosa Pine	CES306.825	Southern Rocky Mountain Ponderosa Pine Woodland
		CES306.648	Southern Rocky Mountain Ponderosa Pine Savanna
		CES306.649	
	Shrubland	CES304.777	Inter-Mountain Basins Big Sagebrush Shrubland
		CES305.785	Inter-Mountain Basins Montane Sagebrush Steppe
		CES304.788	Inter-Mountain Basins Semi-Desert Shrub-Steppe
		CES304.794	Wyoming Basins Dwarf Sagebrush Shrubland and Steppe
		CES306.822	Rocky Mountain Lower Montane-Foothill Shrubland
		CES306.818	Rocky Mountain Gambel Oak-Mixed Montane Shrubland
	Hemlock	CES201.563; CES202.593	Laurential-Acadian Pine-Hemlock-Hardwood Forest
			Appalachian (Hemlock)-Northern Hardwood Forest
	Riparian	NA	Central Interior and Appalachian Riparian Systems
			Central Interior and Appalachian Floodplain Systems
			Laurentian-Acadian Floodplain Systems
			Gulf and Atlantic Coastal Plain Floodplain Systems
			Gulf and Atlantic Coastal Plain Small Stream Riparian Systems
	Wetland/swamp	NA	Boreal Acidic Peatland Systems
			Central Interior and Appalachian Swamp Systems

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	NA	Gulf and Atlantic Coastal Plain Swamp Systems
	NA	Laurentian-Acadian Alkaline Conifer-Hardwood Swamp
	NA	Gulf and Atlantic Coastal Plain tidal Marsh Systems
	NA	Laurentian-Acadian Shrub-Herbaceous Wetland Systems
	NA	North-Central Interior Wet Flatwoods
	NA	Laurentian-Acadian Swamp Systems
	NA	
Oak forest	CES202.600	Central Appalachian Dry Oak-Pine Forest
		Northeastern Interior Dry-Mesic Oak Forest
	CES202.592	Laurentian-Acadian Northern Pine-(Oak) Forest
	CES201.719	Northern Atlantic Coastal Plain Hardwood Forest
	CES203.475	Southern Peidmont Dry Oak-(Pine) Forest
	CES202.339	
Pine-oak rocky woodland		
	CES202.600	Central Appalachian Pine-Oak Rocky Woodland
Total Number of classes mapped	26 Ecosystem Types	FROM 112 Ecological Systems

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