Introducing the Global Ecological Land Units ArcGIS℠ Online Services

An Esri® White Paper
October 2015

380 New York Street
Redlands, California 92373-8100 USA

800 447 9778
info@esri.com

esri.com

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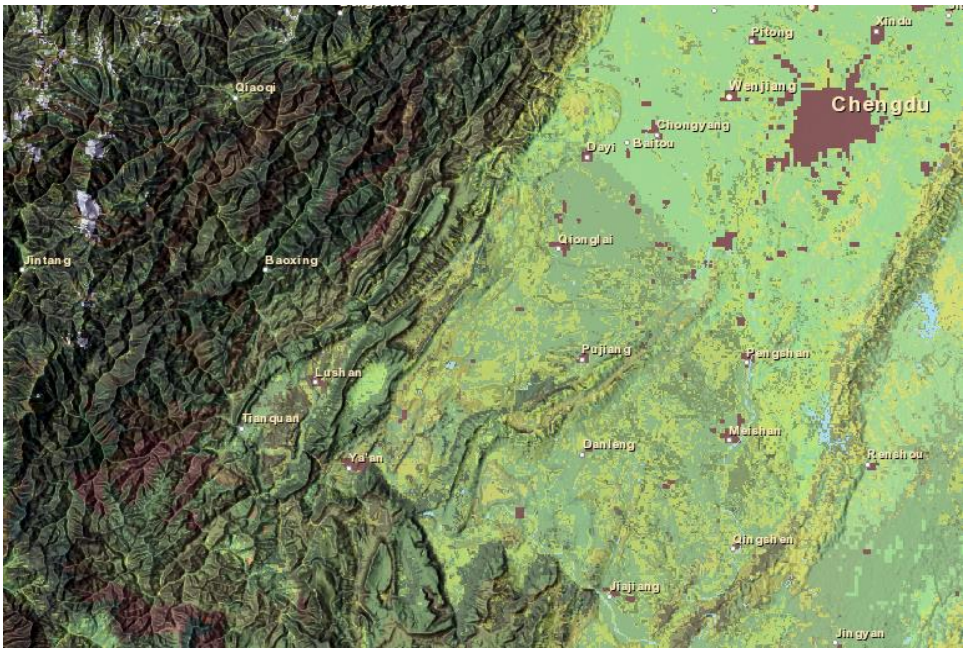
Introducing the Global Ecological Land Units ArcGIS Online Services

Introduction

In December 2014, Esri made the Global Ecological Land Units (ELU) map available to ArcGIS® software users for the first time. This map is a new way to see the natural world because it is a classification of fundamental ecological potential rather than a classification of existing ecosystems or vegetation. Dr. Roger Sayre, senior ecosystems scientist at the US Geological Survey (USGS) developed this new way to organize information about the earth's landscape ecology. Esri worked with the USGS and Dr. Sayre to produce the Global ELU map.

Figure 1
Excerpt of the Global Ecological Land Units Map Showing Southeast China



One of the challenges to producing this map was to depict the highly detailed data on climate, landform, rock type, and land cover in a meaningful way. There are almost 4,000 unique classes on the global map. Traditionally, we look at each of those topics using separate maps. Imagine those four maps, and try to blend pictures of them in your head. It is impossible because the information is too complex. Esri's chief cartographer, Charlie Frye, worked with Dr. Sayre and found a way to blend the four maps into one map using

ArcGIS software. A new publication from the American Association of Geographers, *A New Map of Global Ecological Land Units—An Ecophysiographic Stratification Approach*, describes how a large team of experts from USGS, Esri, and others from around the world collaborated to produce ecological land units.

For scientists and GIS professionals who may want to explore the data and undertake further analysis, Esri provides the source datasets as cloud-based ArcGIS services on its geospatial portal, ArcGIS.com. Esri also provides additional ecologically related layers that can be used in conjunction with the ecological land units to go even further into ecosystem assessment and analysis. A sample list of these layers is included below. Many other related data layers in the areas of earth science, ecology, and the human footprint can be found in ArcGIS.com.

Figure 2a
List of Global ELU and Related Services in ArcGIS.com Released in Fall 2014

ELU Services	Related Services
World Ecophysiographic Map 2014	World Biomass
World Bioclimates	World Population Estimated
World Landforms – MORAP Method 2014	World Elevation GMTED
World Lithology	World Slope GMTED
World Land Cover ESA 2009	World Distance to Surface Water
World Ecophysiographic Facets 2014	World Surface Water
World Ecophysiographic Land Units 2014	World Soils HWSD Bulk Density
World Ecophysiographic Diversity 2014	World Soils HWSD Chemistry
World Ecophysiographic Data Tables	World Soils HWSD Exchange Capacity
	World Soils HWSD General
	World Soils HWSD Hydric
	World Soils HWSD Texture
	World Precipitation Change 2050 Scenario 2.6
	World Precipitation Change 2050 Scenario 4.5
	World Precipitation Change 2050 Scenario 6.0
	World Precipitation Change 2050 Scenario 8.5
	World Temperature Change 2050 Scenario 2.6
	World Temperature Change 2050 Scenario 4.5
	World Temperature Change 2050 Scenario 6.0
	World Temperature Change 2050 Scenario 8.5

Figure 2b
List of New Services in ArcGIS.com Released in Summer 2015

ELU Services	Related Services
World Ecophysiographic Map 2015	World Local Relief
World Landforms – Improved Hammond Method	
World Land Cover ESA 2010	
World Ecophysiographic Facets 2015	
World Ecophysiographic Land Units 2015	
World Ecophysiographic Diversity 2015	

Most of these services are image services and cover the earth at a resolution of 250 m. ArcGIS image services support visualization and analysis, meaning these services may be the source for layers in ArcGIS℠ Online and in ArcGIS for Desktop. In ArcGIS for Desktop, they can be inputs for geoprocessing tools and models. In addition, the Bioclimates, Landforms, Lithology, Population Estimated, and Surface Water services

are available in a GIS-ready format for the first time. This collection is the newest and most detailed GIS-ready global data.

Global data is a special concept in this context. There are many datasets available for the above topics, but very few are global in scope, and fewer still that use consistent measurement methods and terminology everywhere. In addition, the team that selected these datasets analyzed them against other possibilities and made final choices based on value and applicability for ecological research.

The purpose of this white paper is to provide you with the information and references needed for successfully using these services. There are several reasons we chose to produce this white paper:

- ELUs, ArcGIS Image Services, ArcGIS Online, and several of the datasets in the collection are all new and unfamiliar to everyone.
- Most of the above resources are complex. The ELUs, for instance, are introduced in the above publication, which lays out a logical conceptual framework for what they are and how they fit within larger bodies of science and information about ecosystems.
- Because this conceptualization of ELUs is new, there is not yet a set of case studies demonstrating their value. The authors had many ideas for potential applications of ELU information and saw that as others learned about ELUs, more ideas were generated. ELUs are a powerful concept. We at Esri are asking experts in many fields to evaluate and try working with ELUs, share what they find, and help build communities of use.

When this collection is introduced to various audiences, some common questions are asked. The purpose of this white paper is to provide full and, where necessary, detailed responses to those questions. Each major section in this white paper corresponds to a common question.

Recommended Steps for learning about ELUs

Depending on whether you are a student, scientist, or leader, there is a path for you to learn about nature and the value of ecological land units.

There are multiple ways to learn more and access the map and the underlying data:

- Read the *ArcNews*™ article in the Winter 2014/2015 issue, which offers the fastest introduction to the broadest audience.
- Go to the Explore a Tapestry of World Ecosystems story map at esriurl.com/elu. This engages the broadest audience and allows them to find some common ground before digging deeper.
- Go to the Explore the Ecological Tapestry of the World app at esriurl.com/EcoTapestry. This app is for those who want to see the data. It shows the ELU map and provides the values from the more detailed supporting data when you click on the map.

- View the PowerPoint presentation from the Town Hall Reports by Roger Sayre (USGS) and Dawn Wright (Esri) at the ACES Conference in Washington, DC, on December 10, 2014.

- Read the Association of American Geographers (AAG) publication at www.aag.org/global_ecosystems. This paper is written as a technical characterization of the ELUs in a format typical of a peer-reviewed scientific journal but also written with a broader readership in mind.

- Get started using this content in ArcGIS (with an ArcGIS Online organizational subscription) at esriurl.com/landscape.

- The full dataset is available from the USGS as a TIFF file at http://rmgsc.cr.usgs.gov/outgoing/ecosystems/Global/. The full metadata is available at http://catalog.data.gov/harvest/object/8c3bf25a-1dcd-4db8-9716-57e5b05ba234/html/original.

About Server-Side Processing for Image Services to Support Analysis in ArcGIS Desktop

ArcGIS Image Services provide raster data for visualization and analysis. However, these two tasks often require different delivery methods to best support each task. Map projection is most often the foremost of these differences. The raster data behind each of the ELU services are stored on their respective servers with the best coordinate system for preserving the data for subsequent analysis. However, the image services are set, by default, to deliver these raster datasets as imagery using the Web Mercator (Auxiliary Sphere) projected coordinate system, which primarily supports visualization in online (browser) environments.

Web Mercator (Auxilliary Sphere) is one of the worst projected coordinate systems to use in geospatial analysis because of distance and area distortion (Web Mercator, like it's forebear Mercator, supports the idea of drawing straight lines on a 2D map that represent the shortest path between two points).

Another aspect of choosing the best coordinate system to store these raster datasets on their servers is the ability of image services to support server-side processing tasks, such as projecting, resampling, and snapping. The goal is to choose a coordinate system that is most flexible relative to common contexts for geospatial analysis, which are overlay-, area-, and distance-based analyses. Flexible means the ability to project raster datasets to the most appropriate projected coordinate systems for these analysis contexts with a minimum of data loss.

Choosing the Best Projected Coordinate System for Analysis of ELU Services

Based on recent studies at Esri and others, most of the ELU raster datasets are stored using WGS_1984 geographic coordinate system. This is because the minimum amount of data loss will occur when projecting to either World Equidistant Cylindrical (best global equidistant projected coordinate system), or Mollweide, Equal Area Cylindrical, or Goode's Interrupted Homolosine for Land (best equal-area projected coordinate systems). Esri's tested these scenarios using 30-meter, 150-meter, and 250-meter resolution rasters datasets, finding that settings for snap rasters always resulted in significant data loss, and resampling (bilinear vs. nearest neighbor) circumstantially caused data loss depending on whether the data were real numbers versus categories and whether the spatial distribution of the data were continuous or discreet. Thus, it is Esri's strong recommendation to consider this information, and test to develop the best methodology for your analysis.

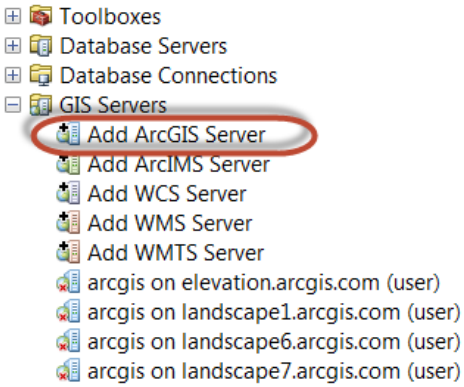
The only exception for the ELU services is Distance to Surface Water, which uses Equidistant Cylindrical because that projected coordinate system was used to derive the data from the surface water raster dataset, which was originally stored in WGS_1984.

Add ELU Image Services Desktop Apps using Server-side Projection

There is only one way to add the ELU image services to ArcGIS desktop that avoids using the Web Mercator Auxiliary Sphere projected coordinate system. This method requires a GIS Server connection and using the Make Image Server Layer geoprocessing tool with the appropriate Geoprocessing Environment settings.

Create a GIS Server Connection:

1. In ArcCatalog's tree view, scroll down to the GIS Servers node and expand it.
2. Double-click the Add ArcGIS Server item.



3. In the Add ArcGIS Server Wizard, the default setting is Use GIS Services, which is needed. Click Next.
4. In the Server URL section type: http://landscape7.arcgis.com/arcgis
5. If you are not signed into ArcGIS Desktop using a named user in an ArcGIS Online Organization, enter the credentials for your account in the Authentication section. Note you must have such an account to use these services. If you are not sure if you have the correct type of account, see Appendix A of this white paper.
6. Click Finish
7. Repeat Steps 2-6 using http://landscape6.arcgis.com/arcgis in step 4.
8. This will produce a new node in your GIS Servers section. Double-click the new node to browse the services.

Use the Make Image Server Layer tool to create an analysis-ready layer in ArcMap:

1. Open the Make Image Server Layer tool.
2. For the input Image Service, browse to the GIS Servers node, and from the landscape7 server, choose (for example), World_Landforms_Improved_Hammond_Method.ImageServer.
3. Optionally update the Output Image Server Layer's name
4. Click the Environments button at the bottom of the tool window.
5. In the Environment Settings window expand the Output Coordinates section.
6. Change the output Coordinate system setting to "As Specified Below".
7. Browse for the World Equidistant Cylindrical projected coordinate system.
8. Click OK in the Environment Settings window.
9. Click OK to run the Make Image Server Layer tool.
10. Check the resulting layer by opening its layer properties and switching to the Source tab, verify that the Spatial Reference property is World_Ecophysiographic_Diversity_2015.

Optionally the above steps for the Make Image Server Layer tool can include setting a Snap Raster in the Geoprocessing settings within the Processing Extent Settings. If using a Snap Raster, it should already use the same projected coordinate system use by the Output Coordinates Environment setting.

The layer that results from these steps is a temporary raster layer within ArcMap. This layer can be used as an input to geoprocessing tools, and behaves like a raster layer in that it can be symbolized and queried.

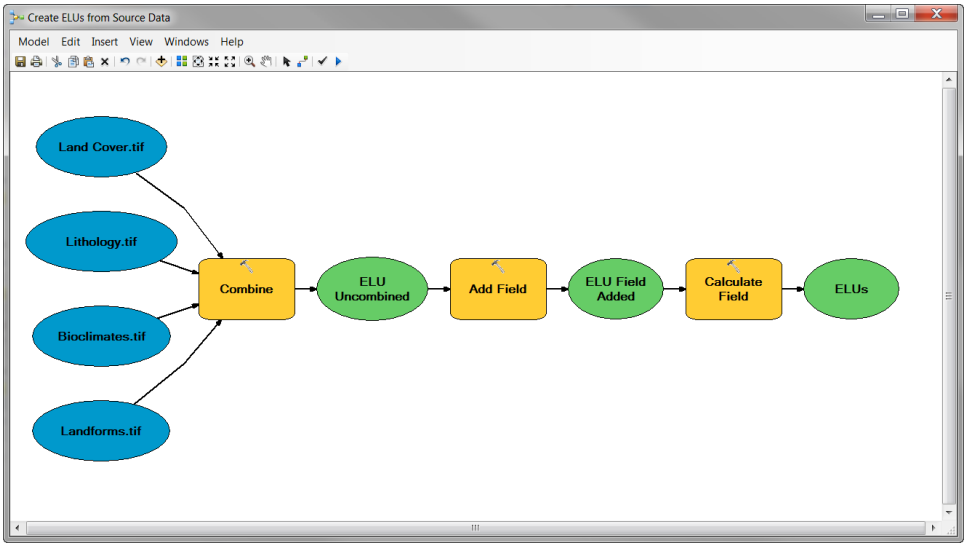
See Appendix B for additional tips and ideas to take full advantage of these image server layers.

Use Your data with the ELU Method

One of the primary objectives of this work is to share the method so that it can be adapted using any of the many datasets that may not be global but represent better data for a given state, region, or locale. This section contains the essential processing steps and guidance for successfully creating new ELUs with your data or by mixing some of your data with the ELU services.

Geoprocessing Steps

A relatively simple process produces ELUs.



The ELU field is a 254-character text field. It is calculated based on the name of each input component: Bioclimate + space + Landform + space + "on" + space + Lithology + space + "with" + space + Land Cover. This creates the basic form of an ELU description that is nearly always grammatically correct. This particular way of expressing the ELU characteristics is logical and inserts naturally into a sentence to produce a descriptive and conversational tone.

The input datasets are all stored using the TIFF format with LZW compression, as that is the recommended format for creating image services. Each raster is stored using the WGS_1984 geographic coordinate system (the mosaic dataset we used to create the image services uses Web Mercator, which allows for the most efficient performance

when combined with basemaps and other data to make web maps on ArcGIS Online). All input rasters are 8-bit unsigned thematic rasters with a NoData value of 0.

Data Management Challenges

There were two key data management challenges in constructing the ELUs: attribute consistency and management and managing NoData values around coastlines.

Attribute Management

It is important for each of the input raster datasets to have a raster attribute table and associated fields. Each input raster by default has an integer Value field, and we added two text fields (character length ranging from 32 to 128 as required) to store the descriptions of the classes that originated with the source datasets and the corresponding ELU descriptions. Below is an example of a Lithology raster attribute table.

Table

Lithology.tif

OID	Value	Count	Lithology	Litho_ELU
0	1	813458897	Unconsolidated Sediment	Unconsolidated Sediment
1	2	657743836	Siliciclastic Sedimentary Rock	Non-Carbonate Sedimentary Rock
2	3	22168284	Pyroclastics	Pyroclastics
3	4	661147801	Mixed Sedimentary Rock	Mixed Sedimentary Rock
4	5	287737218	Carbonate Sedimentary Rock	Carbonate Sedimentary Rock
5	6	8967739	Evaporite	Evaporites
6	7	38716730	Acid Volcanic	Acid Volcanics
7	8	70182295	Intermediate Volcanics	Non-Acidic Volcanics
8	9	145939834	Basic Volcanics	Non-Acidic Volcanics
9	10	239688239	Acid Plutonics	Acid Plutonics
10	11	15953043	Intermediate Plutonics	Non-Acidic Plutonics
11	12	37034364	Basic Plutonics	Non-Acidic Plutonics
12	13	508017615	Metamorphics	Metamorphic Rock
13	14	33193788	Water Bodies	Unconsolidated Sediment
14	15	1422447525	Ice and Glaciers	Non-defined
15	16	2595837	Non-defined	Non-defined

16 (0 out of 16 Selected)

Lithology.tif

NoData Values

The goal is to have the offshore areas or oceans as NoData. The problem is that each of the input datasets was created independently with a different coastline. With the landforms dataset as input, we produced a mask raster where land had a value of 1 and offshore a value of NoData by using the Local Statistics tool with the Maximum option. We initially treated all datasets as being NoData values by reclassifying them such that 0 (zero) was used for all areas without a valid category, and by successively applying the Local Statistics tool with each input raster, we found the full extent where any dataset had a valid value. The final step was to reclassify that output such that the 0s were converted to NoData and nonzero values were converted to 1.

Accuracy and Uncertainty Considerations

No global datasets are perfect given the nature of data capture, assumptions about the way interpolation methods work, and the fact that humans intervene to correct at least some of the data. Esri has developed a set of thematic data accuracy tools that will soon be part of the ArcGIS Spatial Analyst extension. The results were that 81.4 percent of the ELU classifications are correct, which is very good for classified thematic raster data. This assessment was performed using a sampling method that is statistically significant at 90 percent confidence with a +/- 5 percent margin of error.

We also, empirically, see that the datasets are generally a little more accurate in Europe and North America, with Southeast Asia and Oceana having lower levels of accuracy. The basis for this understanding is mainly due to the number of islands with no Lithology data and, therefore, a higher frequency of undefined land cells within the data within this region.

Integrating Your Data with the ELU Services to Create New ELUs

This process first starts with reconciling the terms used to describe the classes in the data you are supplying to ELU terminology. For instance in the United States, it is likely that scientists may want to resample and use National Land Cover Database (NLCD) data as a replacement for the land-cover component. Here is one possible way to map the NLCD classes:

NLCD #	NLCD Class	Suggested ELU Land-Cover Class
11	Open Water	Surface Water
12	Perennial Ice/Snow	Snow and Ice
21	Developed, Open Space	Artificial Surface or Urban Area
22	Developed, Low Intensity	Artificial Surface or Urban Area
23	Developed, Medium Intensity	Artificial Surface or Urban Area
24	Developed, High Intensity	Artificial Surface or Urban Area
31	Barren Land (Rock/Sand/Clay)	Bare Area
41	Deciduous Forest	Mostly Deciduous Forest
42	Evergreen Forest	Mostly Needleleaf/Evergreen Forest
43	Mixed Forest	Mostly Needleleaf/Evergreen Forest
51	Dwarf Scrub	Grassland, Scrub, or Shrub
52	Shrub/Scrub	Grassland, Scrub, or Shrub
71	Grassland/Herbaceous	Grassland, Scrub, or Shrub
72	Sedge/Herbaceous	Grassland, Scrub, or Shrub
73	Lichens	Sparse Vegetation
74	Moss	Sparse Vegetation
81	Pasture/Hay	Mostly Cropland
82	Cultivated Crops	Mostly Cropland
90	Woody Wetlands	Swampy or Often Flooded Vegetation
95	Emergent Herbaceous Wetlands	Swampy or Often Flooded Vegetation

ELUs have three explicitly collapsed classes: Surface Water, Snow and Ice, and Artificial Surface or Urban Area. These classes are not set up using the compound structure of bioclimate landform on lithology with land cover. These classes are ELUs without further qualification.

This mapping also clearly demonstrates that some compromises will be required. For instance, mapping Mixed Forest to Mostly Needleaf/Evergreen Forest is arbitrary, and such decisions should be made using consistently applied rules.

One frequently asked question is whether it is acceptable to add new ELUs or replace ELUs. While users are encouraged to create new ELU datasets for their own local applications using the concepts and processing methods presented above and taking advantage of their own local data, modifications to the original global ELU resource through addition of new ELUs or deletion of existing ELUs is discouraged. There are two primary reasons for this. First, one purpose of ELUs is to have a globally comparable set

of information rather than an information set that only functions for a given study area. Second, adding new ELUs adds to the complexity of communicating global concepts—which is already considerably complex. The current ELUs represent a tremendous effort to simplify how the method and the value of the information are communicated outside the science community.

Thus, while the ELU classes ought to remain immutable, the underlying classes for the equivalents to ecological facets (EFs) by design must change. The EFs are the level of information where we anticipate most analysis will be done. The perspective is that ELUs are the common ground everyone shares and can use as the basis for collaboration because they are comparable and broadly approachable.

Ideas for Using ELUs in Practice and Research

The organization of this section is centered on the areas of expertise and science where the ELU concepts and method appear to have potential value. One of the first questions people have about ELUs is what they can be used for and who has worked with the resource to date. This conceptualization of ELUs is new, so applications and user communities are just emerging. One purpose for this white paper is to support and catalyze the work of finding those answers. Esri and the USGS will support some of this early work with technical and topical advisement, as that expertise is available.

Land Management Planning and Policy

Compare compositions of ELUs within countries to find justifications for bi-national collaboration. For instance, two countries may have desertification issues, and studying the ELUs could indicate the drivers are similar or quite different.

Forestry

Forest and other vegetation studies often rely on sampling to characterize both the cover and the physical environment of large landscapes. ELUs should be considered as a potential framework for stratifying the landscape to ensure that no environmental or land-cover element is excluded and to improve the representativeness of the sample by reducing sampling error.

ELUs should also be explored as a means to understand the basic ecological drivers across forested regions and to aid in the development of regional or large landscape-scale forest management units. Forest management units (FMUs) are frequently used for timber inventory and planning. They are important for managing timber sales and for managing interventions such as prescribed burns or seeding. The boundaries for the units are often determined by both scientific and practical considerations such as the composition and age of the forests, natural boundaries such as rivers and lakes and administrative boundaries. As we seek sustainability in our forests by maintaining biodiversity, productivity, and regeneration capacity, we need a better understanding of the essential structures that drive processes, functions, and interactions. Strategies for using ELU to define FMU may prove very useful.

Biology

ELUs can be used for keystone species habitat and range identification. For example, the northern jaguar's habitat is more specific than the broad-brush characterization in the International Union for Conservation of Nature (IUCN) and the World Wildlife Fund (WWF) datasets. Use sightings data to identify the ELUs where sightings have occurred and determine which adjacent ELUs are compatible, then select all those ELUs that will show areas that should be managed with deference to sustaining or not extirpating the presence of northern jaguars.

Ecology

Assessing Impacts to Ecosystems from Climate Change

Climate change modelers may find ELUs useful for assessing impacts to ecosystems in several ways. Some models may simply require a map of ecosystems or habitats or land cover as an input dataset, and ELUs may provide a useful surrogate. Other models may predict areas where climate change is likely to occur, and those areas combined with ELUs can show which ELUs may experience new climates.

In addition to the ELUs, the global bioclimate layer used to model the ELUs may be very useful in and of itself as a data resource for climate change modeling. Downscaling is a term used by the climate change modeling community to refer to developing finer spatial resolution data than is typically available, which is often in the tens of kilometers range. It is quite likely that the global bioclimates data, already at a relatively fine spatial resolution, may be usable as is, eliminating the need to downscale coarser resolution climate data.

Mapping Ecosystem Service Values

Increasing interest in assessments of the economic and social value of ecosystem goods and services has resulted in a number of recent attempts to map ecosystem service values. The basic unit of spatial analysis typically used in these assessments varies from land-cover classes to watersheds to geopolitical units. It is quite likely that the ELUs represent a robust spatial analysis unit and framework for these valuation assessments because the ecosystems are also the service-providing unit in the first place. Understanding which ecosystems are providing which services and where on the landscape should assist planners in thinking about the "bundling" dimension of ecosystem service provision.

Landscape Ecology

Composition and Structural Analysis

We suggest that ELUs provide a basis to understand structure and composition of landscapes. The patterns (clusters, corridors, fragmentation, networks, etc.) of ELUs within landscapes may be useful predictors of connectivity between ecosystems. Study is needed to understand whether analysis of ELUs can be used to define the edges of landscapes, and whether ELUs are sufficient to define edges within or between landscapes. For instance, are contiguous cells of ELUs or EFs an ecosystem, or does that vary depending on which ELU or EF is being considered?

Are ELUs or EFs a basis to understand fragmentation of landscapes and ecosystems?
Are ELUs or EFs a basis to understand heterogeneity within landscapes?

How well does diversity of ELUs or EFs correlate with observed biodiversity?

Comparative Ecology

For example, how would the Amazon rain forest compare to the central African rain forest in terms of heterogeneity, ELU composition, clustering, regionalization, etc.?

Studies of Disturbance and Diversity across the Same ELU Category

Tag ELU with weighted measures of intensity and disturbance; for example, relatively undisturbed, hot wet, plains, metamorphic versus highly disturbed, hot wet, plains, etc.? Can resilience and stability be qualified in some measure by looking at levels of disturbance and measures of species diversity between similar ELUs or across unlike ELUs?

Conservation

Assessing Species Distributions

Species range maps depict areas in which species have been observed or are predicted to occur. An overlay of species distribution maps on ELUs can provide information on why species are located in certain areas, what their environmental "envelopes" (resource requirements, that is, composition of ELUs) are, and what areas are unsuitable for occupation. This type of application may be useful for identifying species niches and for understanding the primary and secondary environmental controls on species distributions. The ELUs should be very useful in predicting species distributions when species environmental requirements are known. The data may help to explain why some species are generalists and found in many different habitats, while others are restricted to particular habitats.

An additional possibility is species range or habitat may not merely correlate with ecological land units or facets. Other factors such as similar levels of diversity, biomass, elevation, or distance to people may play roles. All of these data are available, globally, as services in this collection as shown on page 2.

Representation Analysis of Ecosystems in Protected Areas

One fundamental tenet of global biodiversity conservation is to protect the representative ecosystems of the earth. Ideally, safeguarding every ecosystem on the planet from degradation/conversion is possible. One application of the ELUs is to assess the composition of protected areas. For a given geography of interest, combining the protected areas data with the ELU data will provide useful information on which ecosystems are well represented, which are moderately represented, which are poorly represented, and which are unrepresented. Unrepresented or poorly represented ecosystems should be considered as candidates for inclusion in future protected areas or expansions of existing protected areas. Ecosystem representation should be one of the criteria for planning changes or additions to existing protected area networks. This application of the data is a type of gap analysis for biodiversity conservation planning.

Physical Geography

A long-standing tradition in geography is that characteristics of the landscape matter. Thresholds for various geographic activities vary based on landscape characteristics. Some geographic activities are binary in that they occur in certain circumstances and not at all in others. Ecological land units and facets should reflect or correlate to support understanding of many phenomena.

Human Geography

ELUs may be useful for predicting areas of conflict between human groups or humans/animals/natural areas due to climate change or other factors. The World Population Estimate layer has an essential component to understanding these relationships, which is the footprint of where humans are located.

Higher Education

For university professors, postdoctoral fellows, and teaching assistants, ELUs provide many opportunities:

- Ready-to-use content in the classroom for lectures, labs, or term projects, especially as this represents cutting-edge information about our world. This is a value-added proposition for your university, especially as cloud-based GIS layers and services are more efficient and much greener to use in workflows than traditional workstation GIS. Data and workflows for university lab settings often require time and effort to

procure, store, and prepare before being fully productive in a university setting that truly stimulates learning.

- Use of this content in research projects, including master's theses and doctoral dissertations. This content is extremely rich and represents a jumping-off point for studying diversity and the nature of ecological characterization. We finally have enough data to do this kind of work! It is globally consistent and in a framework that can accept additional data.

- Collaboration with Esri to improve this content by participating (through Esri mini grants) in the production of updated and improved editions of content that will be shared with the entire research community.

- Use of the content for university public outreach, such as Earth Day, National Geography Awareness Week (and GIS Day™ therein), and various climate change awareness events.

- While Esri has published this map and data, we recognize that very few universities have fully exposed their students and faculty to content such as this. Most students and faculty at universities are surprised to learn that Esri curates and publishes a host of ready-to-use content available in ArcGIS Online. This content includes basemaps; photo and special use imagery; consumer expenditure and demographic data; and data about the earth such as elevation, soils, geology, and species habitat. Nearly every foundational GIS layer is now available in ArcGIS Online, published by Esri or organizations and individuals using ArcGIS. The data behind these layers is either authoritative from government agencies or produced by organizations with widely acknowledged expertise in their respective fields. If your university has an Esri site license, this content is already available to you, free of charge, via ArcGIS Online. You only need to sign in as a named user in your university's ArcGIS Online organizational account.

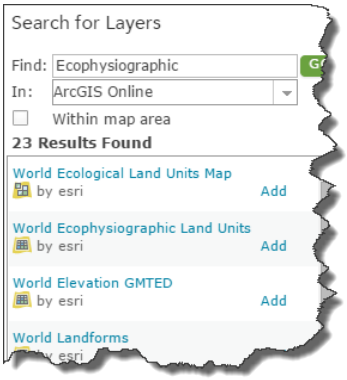
Appendix A: Getting Started with ArcGIS Online

Using this new ecological content only requires signing into your ArcGIS Online organizational account. You can sign in via a browser at arcgis.com or in ArcGIS for Desktop. The fact that you are reading this means that your university has at least one ArcGIS Online organizational subscription, and you may already have credentials for signing in. If you do not have credentials, start by contacting your department or university ArcGIS administrator, who will be able to create an account for you.

Sign in to verify whether your account is part of an ArcGIS Online organizational subscription. If you see the option My Organization, then your account is a user in an ArcGIS Online organizational subscription.

Once you have signed in

1. Click the MAP option. This opens the ArcGIS Online map.
2. Click the Add button, which will show a menu, and choose Search for Layers.
3. In the Find field, type: Ecophysiographic.
4. Set the In field to ArcGIS Online.
5. Uncheck the Within map area option and you should see the following:



6. Click Add to add the World Ecological Land Units Map and World Ecophysiographic Land Units (first two items shown) layers to the map.

7. Click the Done Adding Layers button.

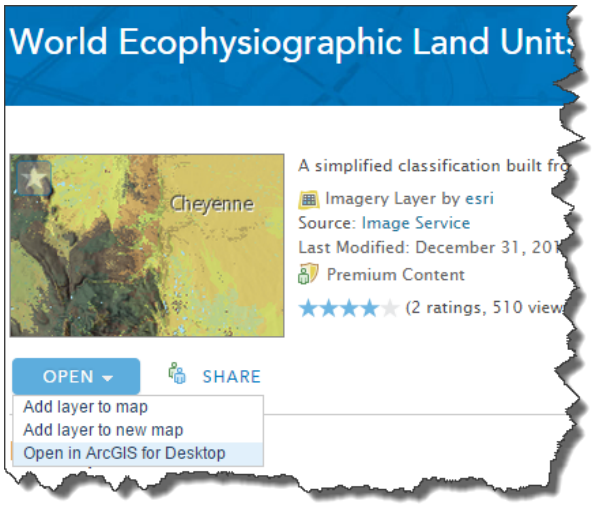
8. Click on the map to see a pop-up of the data values and explore the map by panning and zooming. One tip is to set the Land Units layer to 100% transparency and set the basemap to Imagery with Labels.

You can add the same content to ArcGIS for Desktop.

1. Click the button next to Land Units Layer.

2. On the menu, choose Show Item Details (the bottom choice). This will open the content item page, which contains the documentation, links to metadata, etc.

3. Click the OPEN button, and then choose Open in ArcGIS for Desktop.



4. Depending on your browser and its security settings, this will download a "pitem" file that will either automatically open in ArcMap™ software or require you to open it, which will cause it to open in ArcMap. You may be prompted for your ArcGIS Online credentials to finish the process.

5. Explore the resultant layer in ArcMap, or use the layer as an input to a geoprocessing tool.

Appendix B: Learning about the ELU Collection and Using It in ArcGIS

This section will cover the best ways to get started learning about the global ecological services and how to use these services as layers in Esri's ArcGIS software.

Visualization and Exploration Techniques

The first hurdle in this area is unfortunately due to technical limitations of ArcGIS. These limitations meant we had to publish the 2014 ELU and 2014 and 2015 EF services as single color services—despite there being 3,923 unique types of ELUs and 47,650 types of facets (EFs). Thus, to begin exploring this data, it will be necessary to make some changes to how these services are displayed, as the default we provided is not very useful.

Here are some ways to get started:

1. In ArcMap, using unique values, set all the colors to black and assign the legend that way. In the ArcMap table of contents; edit one or more colors for specific types of ELUs/EFs to highlight them. Note that some values may only match several cells that cannot be seen when zoomed to the entire world.

2. An alternative to step 1 is to start by setting all the colors to No Color.

3. In ArcGIS Online, click the Image Display option and set the stretch type to either Minimum and Maximum or Standard Deviations and check the Dynamic range adjustment option, which does a decent job at displaying the layer.

4. In either ArcMap or ArcGIS Online, you can additionally add a cached map service (World Ecophysiography Map) we produced that has the presymbolized look. We've used this option for demos, where we make the ELU, EF, and image service layers fully transparent, using them only for pop-ups or with the Identify tool. To add context, also add the World Boundaries and Places service.

Extracting Data to More Fully Explore the Values in a Study Area

Another of the ArcGIS limitations is how ArcMap and ArcGIS Online consume image services, and in particular, neither can show the attribute tables, so one additional tip is to use ArcMap and zoom to a study area and extract some data. This will give you a local raster that will be easier to work with and one that will have a raster attribute table, making it much easier to explore the data.

Here are the steps:

1. In ArcMap, add the ELU or EF service and zoom to a study area, like Colorado, and a healthy swath of the surrounding states.

2. Set the Data Frame's coordinate system to what would be useful to you (presuming Web Mercator is not).

3. In the table of contents, right-click the image service layer and choose Export Data.

4. Change the Extent option to Data Frame.

5. Change the Spatial Reference to Data Frame.

6. In the Output raster section, verify that the Raster Size (columns, rows) is smaller than 16,000 x 16,000 (though there is no need to select that option).

7. Set the location (I recommend a folder, as that is what I have mostly done).

8. Set the Name, then set the Image type to TIFF (again, because that is what I've mostly done).

9. Set the Compression type to LZW.

10. Click Save.

11. Add the resultant raster dataset to ArcMap, and open its properties.

12. Switch to the Symbology tab and change the left-most option to show Unique Values and use the ELU Field.

13. Click Apply.

14. Click the File Folder button in the upper right to open the Import Symbology window.

15. Download the World ELU Raster Colors Layer File, browse to where you saved the enclosed layer file, and choose that file.

16. Click OK or Apply. This will give you the colors we used on the Ecophysiography map service.

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Contact Esri

380 New York Street
Redlands, California 92373-8100 USA

1 800 447 9778
T 909 793 2853
F 909 793 5953
info@esri.com
esri.com

Offices worldwide
esri.com/locations

Printed in USA