Integrating Statistical and Expert Knowledge to Develop Phenoregions for the Continental United States

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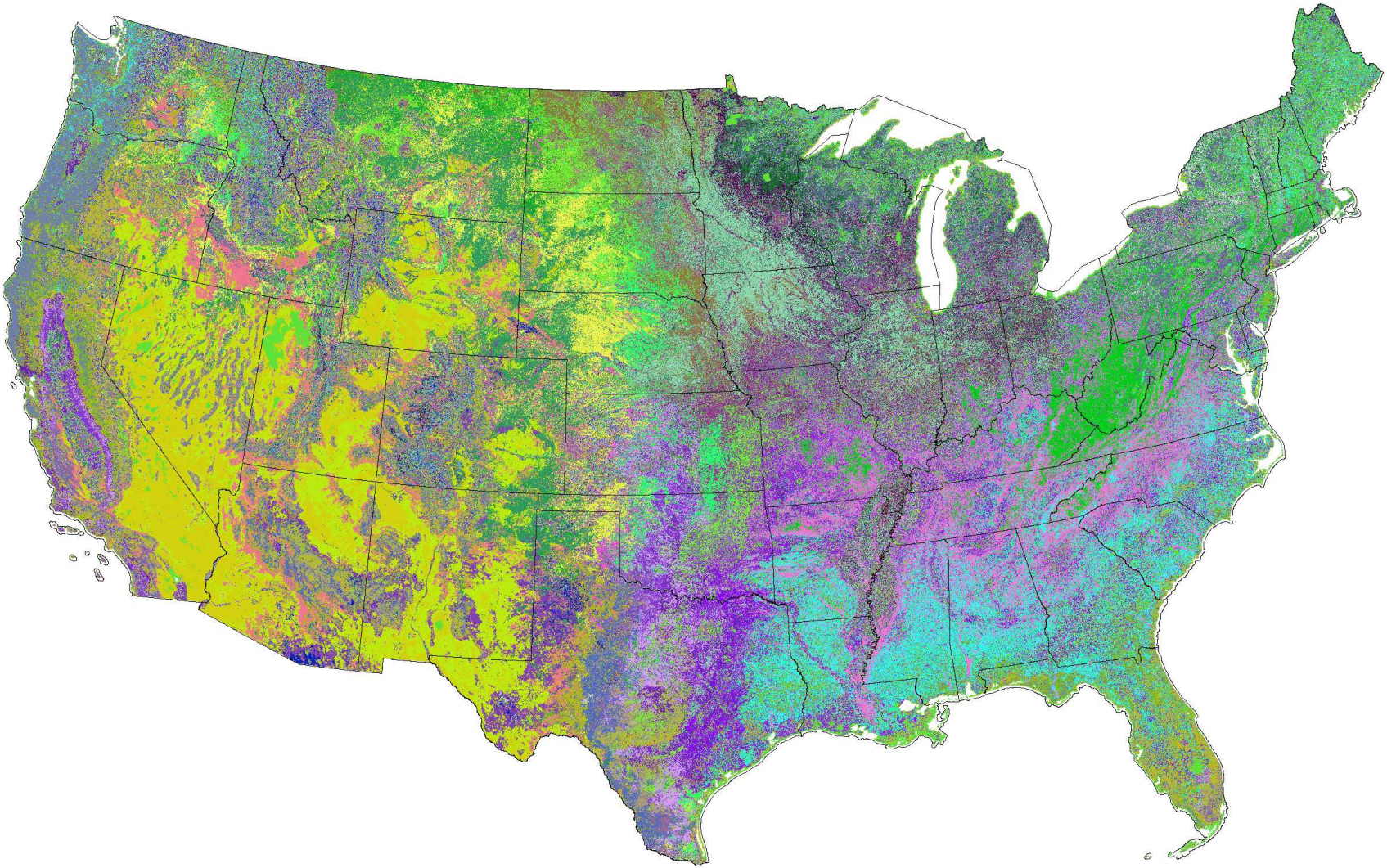
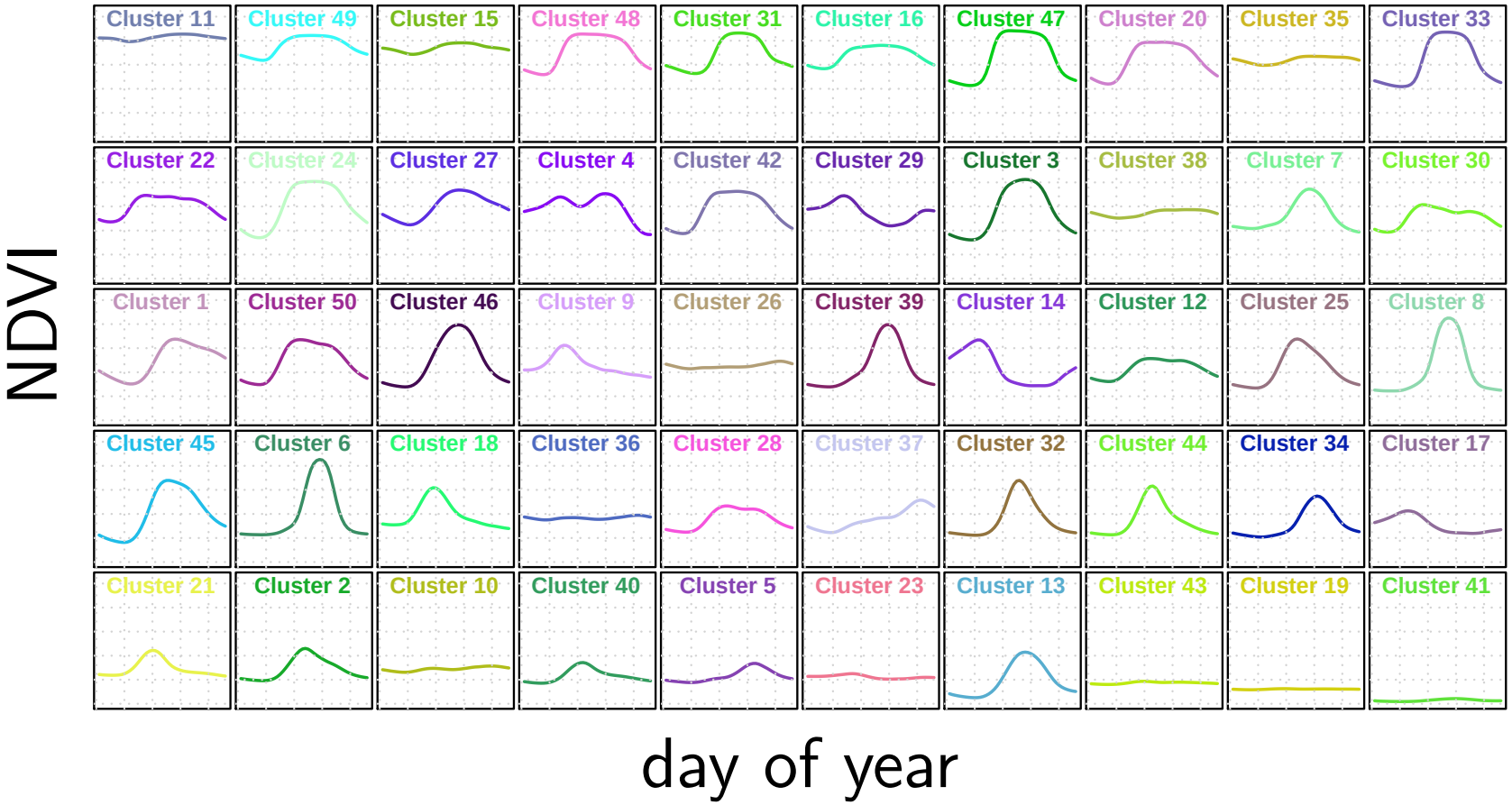
Clustering MODIS NDVI into Phenoregions

- Hoffman and Hargrove previously used *k*-means clustering to detect brine scars from hyperspectral data (Hoffman, 2004) and to classify phenologies from monthly climatology and 17 years of 8 km NDVI from AVHRR (White et al., 2005).
- This data mining approach requires high performance computing to analyze the entire body of the high resolution MODIS NDVI record for the continental U.S.
- >87B NDVI values, consisting of ∼146.4M cells for the CONUS at 250 m resolution with 46 maps per year for 13 years (2000–2012), analyzed using *k*-means clustering.
- The annual traces of NDVI for every year and map cell are combined into one 327 GB single-precision binary data set of 46-dimensional observation vectors.
- Clustering yields 13 phenoregion maps in which each cell is classified into one of *k* phenoclasses that represent prototype annual NDVI traces.

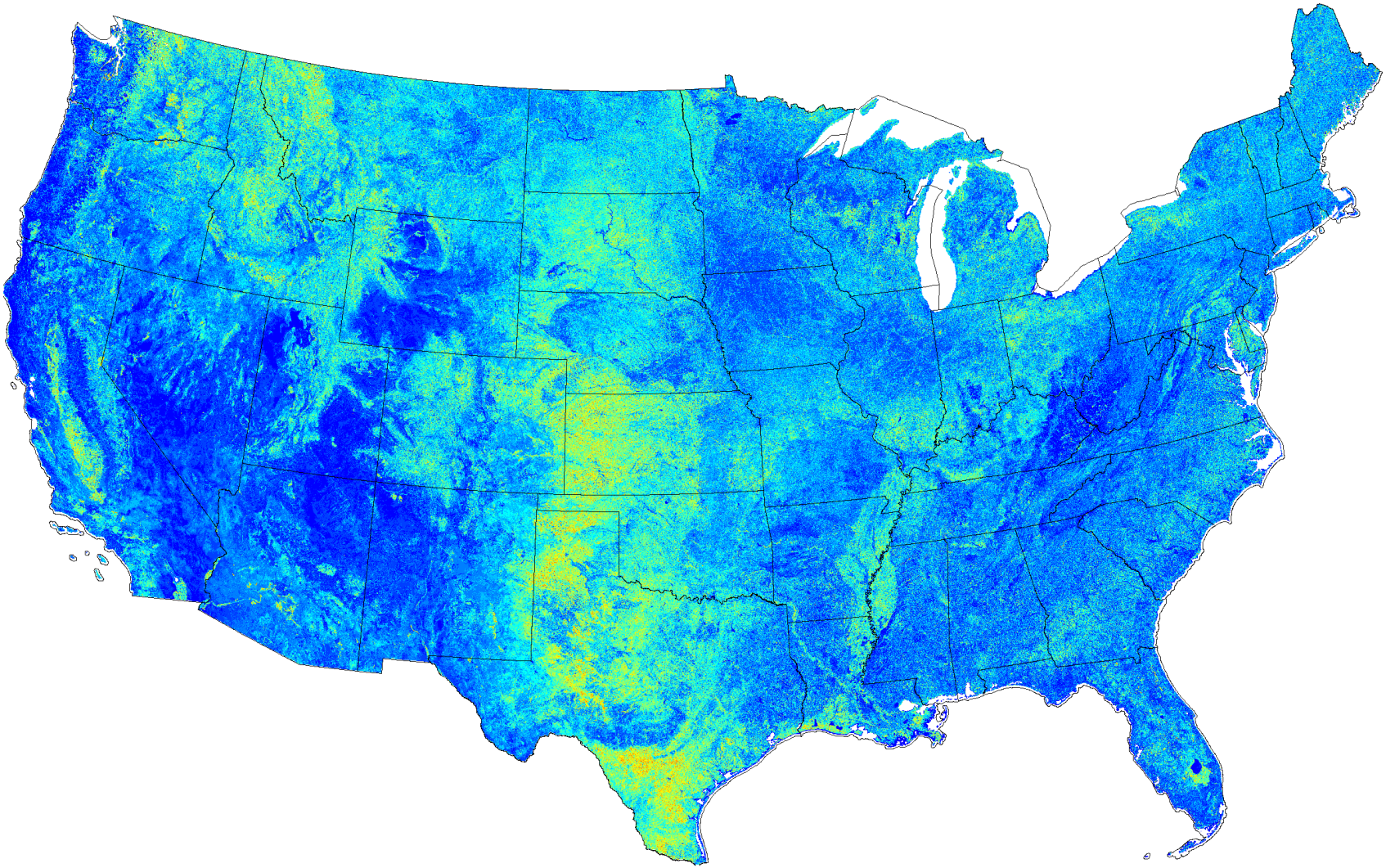
50 Phenoregions for year 2012 (Random Colors)



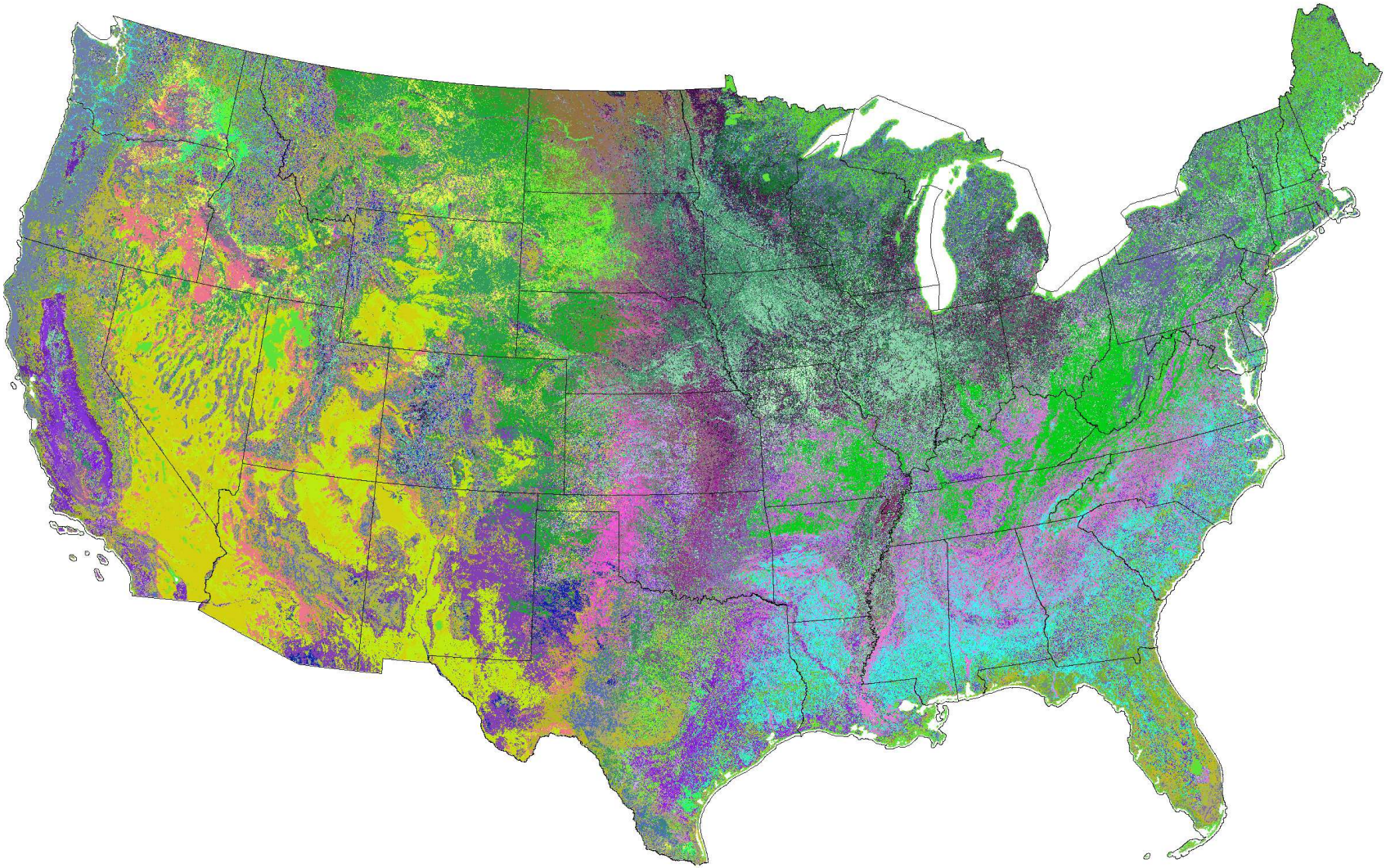
50 Phenoregion Prototypes (Random Colors)



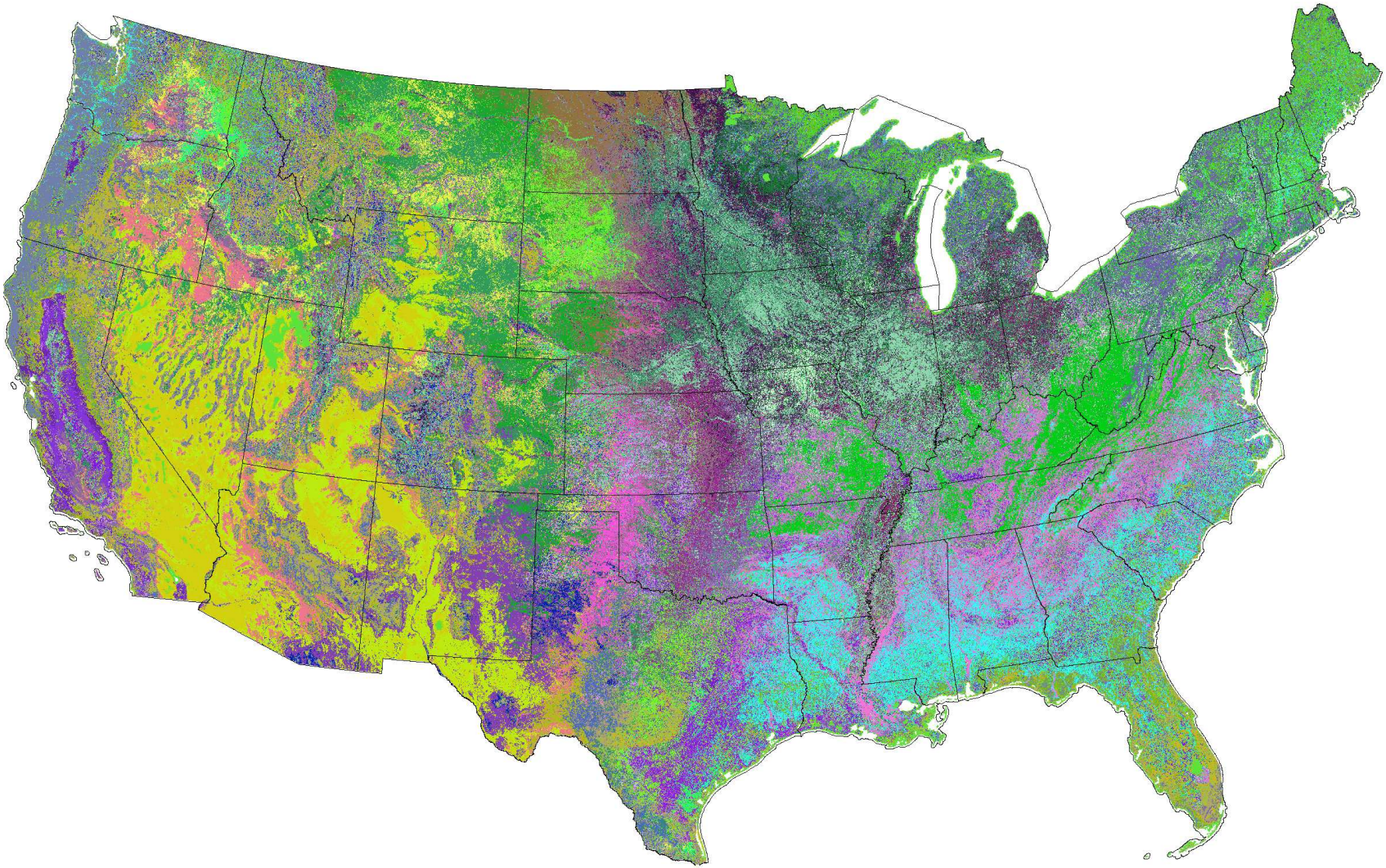
50 Phenoregions Persistence



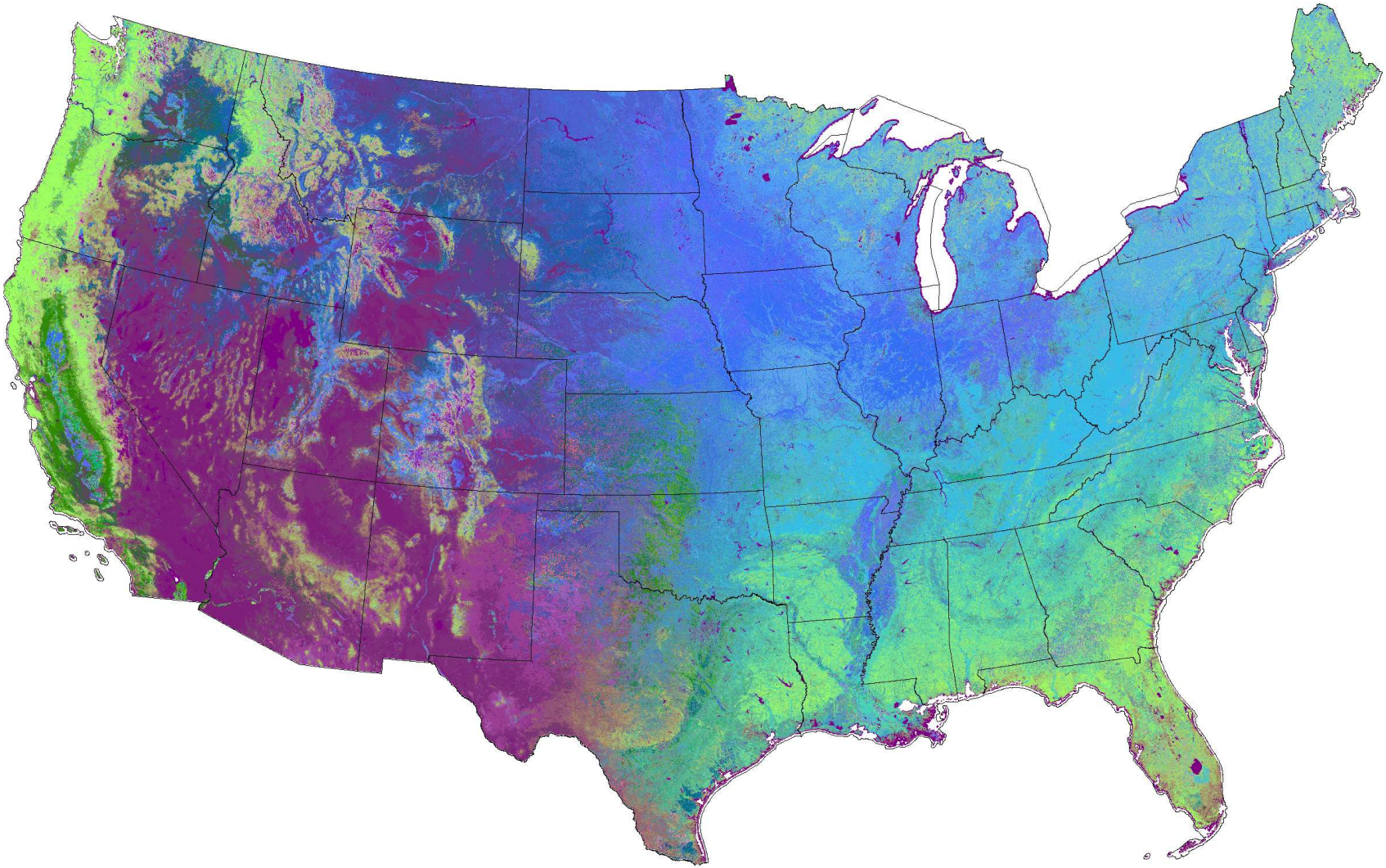
50 Phenoregions Mode (Random Colors)



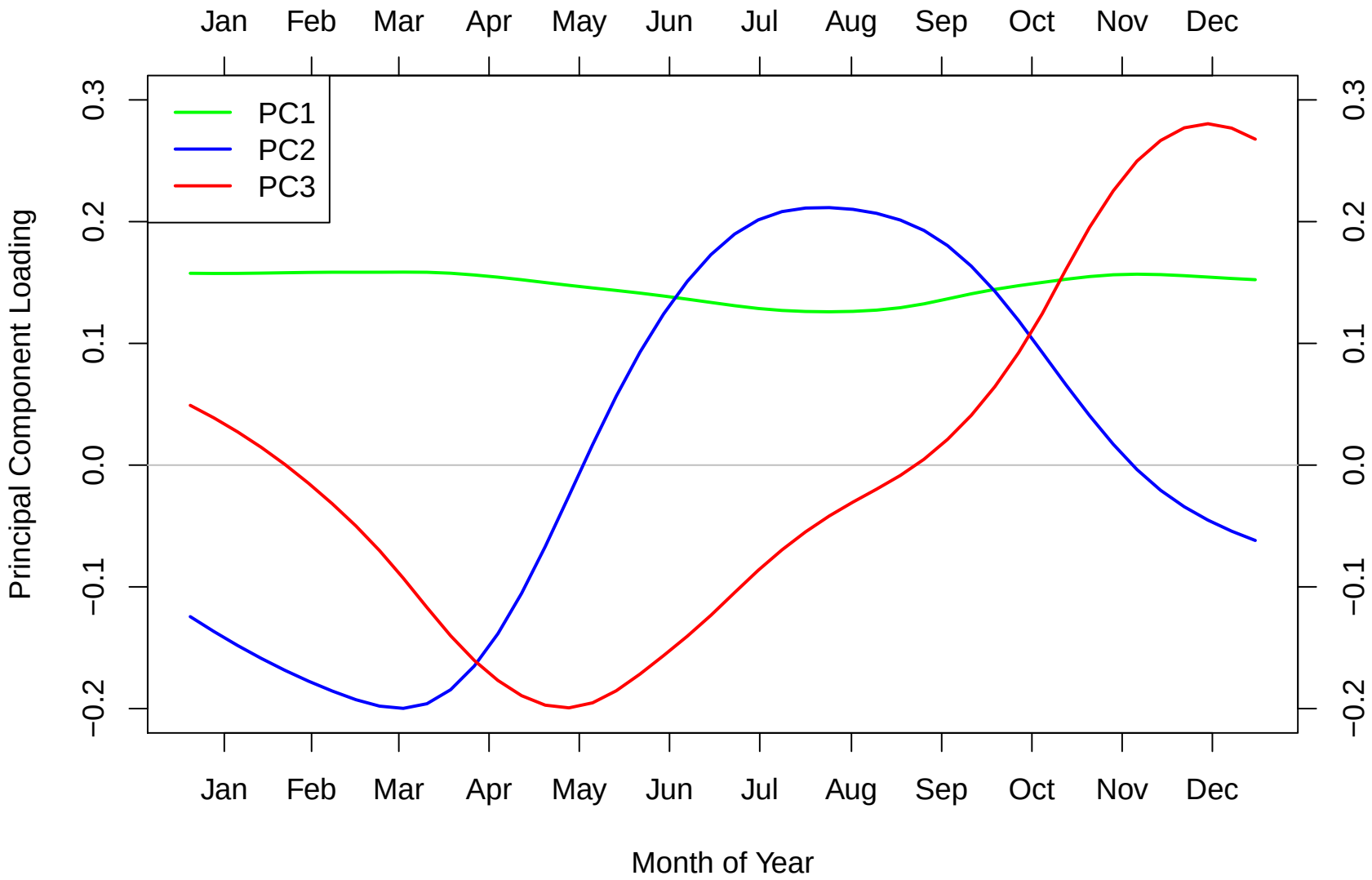
50 Phenoregions Max Mode (Random Colors)



50 Phenoregions Max Mode (Similarity Colors)



50 Phenoregions Max Mode (Similarity Colors Legend)



Phenoregions Clearinghouse

National Phenological Ecoregions (2000-2011) - Google Chrome

National Phenological E ×

https://www.geobabble.org/phenoregions/

National Phenological Ecoregions (2000–2011)

William W. Hargrove, Forrest M. Hoffman, Jitendra Kumar, Joseph P. Spruce, and Richard T. Mills
January 14, 2013

Jump to 50 National Phenoregions

Jump to 100 National Phenoregions

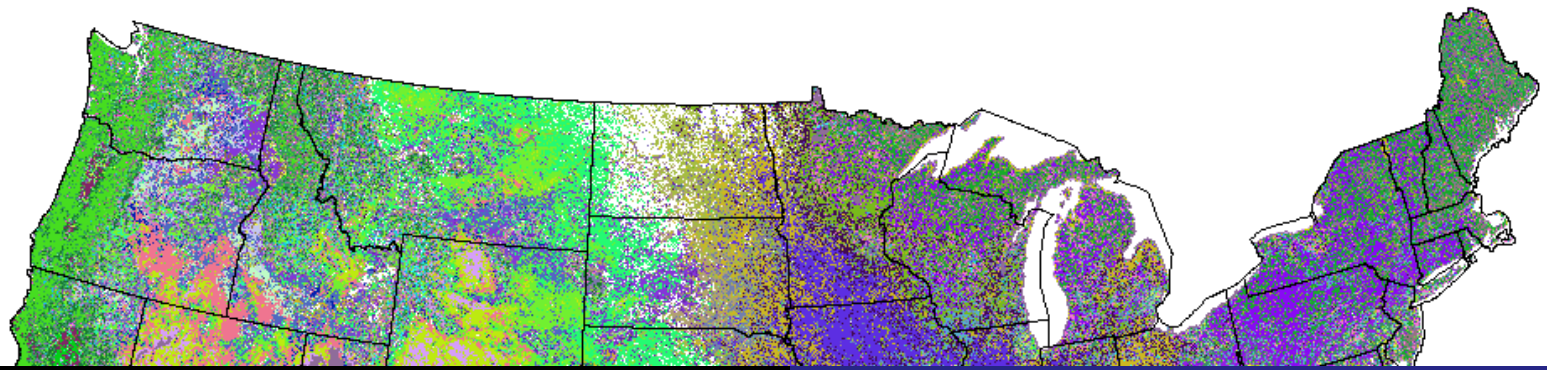
Jump to 200 National Phenoregions

Jump to 500 National Phenoregions

Jump to 1000 National Phenoregions

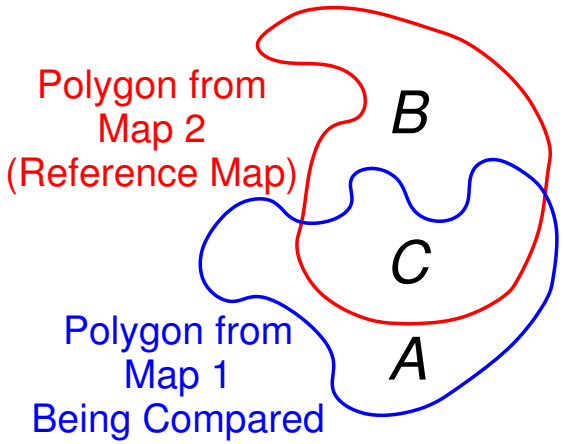
Jump to 5000 National Phenoregions

50 Most-Different National Phenological Ecoregions (2000–2011)



Mapcurves: A Method for Comparing Categorical Maps

- Hargrove et al. (2006) developed a method for quantitatively comparing categorical maps that is
  - independent of differences in resolution,
  - independent of the number of categories in maps, and
  - independent of the directionality of comparison.



Goodness of Fit (GOF) is a unitless measure of spatial overlap between map categories:

$$\text{GOF} = \sum_{\text{polygons}} \frac{C}{B+C} \times \frac{C}{A+C}$$

- GOF provides "credit" for the area of overlap, but also "debit" for the area of non-overlap.
- Mapcurves comparisons allow us to reclassify any map in terms of any other map (*i.e.*, color Map 2 like Map 1).
- A greyscale GOF map shows the degree of correspondence between two maps based on the highest GOF score.

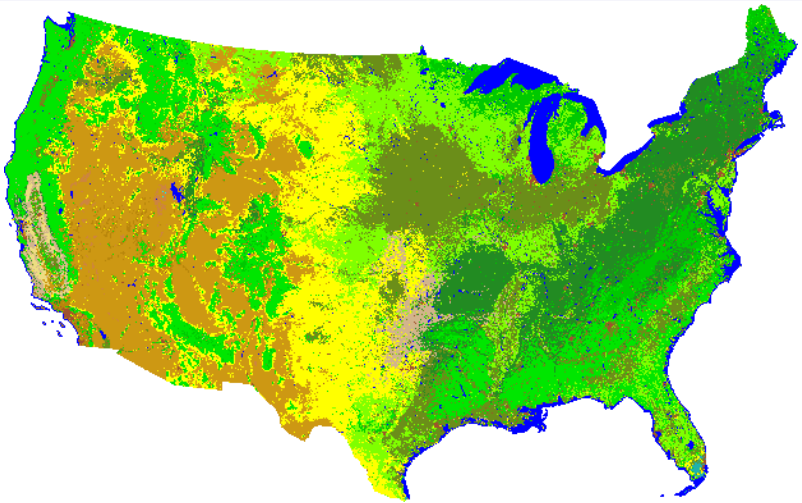
Two 2-Way Comparisons with Land Cover Maps

Cluster	IGBP Land Cover	Olson's Global Ecoregions
1	Evergreen Needleleaf Forest	cool conifer forest
2	Grasslands	cool grasses and shrubs
3	Cropland/Natural Vegetation Mosaic	cool forest and field
4	Croplands	cool forest and field
5	Grasslands	cool grasses and shrubs
6	Croplands	corn and beans cropland
7	Cropland/Natural Vegetation Mosaic	cool forest and field
8	Croplands	corn and beans cropland
9	Grasslands	hot and mild grasses and shrubs
10	Grasslands	cool grasses and shrubs
11	Evergreen Needleleaf Forest	cool conifer forest
12	Grasslands	hot and mild grasses and shrubs
13	Water	inland water
14	Savannas	savanna (woods)
15	Evergreen Needleleaf Forest	cool conifer forest
16	Evergreen Needleleaf Forest	conifer forest
17	Open Shrublands	semi desert sage
18	Grasslands	cool grasses and shrubs
19	Open Shrublands	semi desert shrubs
20	Deciduous Broadleaf Forest	deciduous broadleaf forest
21	Grasslands	cool grasses and shrubs
22	Croplands	broadleaf crops
23	Open Shrublands	semi desert sage
24	Deciduous Broadleaf Forest	cool broadleaf forest
25	Cropland/Natural Vegetation Mosaic	crops, grass, shrubs

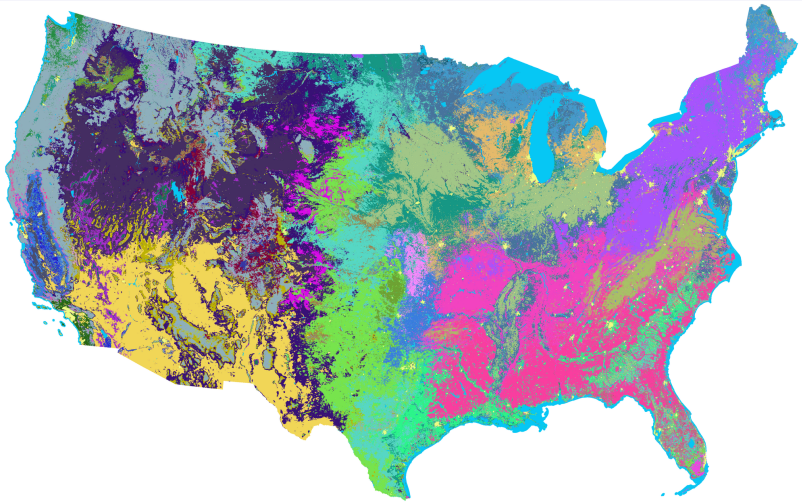
Two 2-Way Comparisons with Land Cover Maps

Cluster	IGBP Land Cover	Olson's Global Ecoregions
26	Evergreen Needleleaf Forest	cool conifer forest
27	Evergreen Needleleaf Forest	cool conifer forest
28	Grasslands	hot and mild grasses and shrubs
29	Woody Savannas	woody savanna
30	Grasslands	hot and mild grasses and shrubs
31	Deciduous Broadleaf Forest	cool broadleaf forest
32	Croplands	cool crops and towns
33	Deciduous Broadleaf Forest	cool broadleaf forest
34	Grasslands	hot and mild grasses and shrubs
35	Evergreen Needleleaf Forest	cool conifer forest
36	Grasslands	dry woody scrub
37	Grasslands	hot and mild grasses and shrubs
38	Evergreen Needleleaf Forest	cool conifer forest
39	Croplands	corn and beans cropland
40	Open Shrublands	semi desert sage
41	Water	inland water
42	Deciduous Broadleaf Forest	deciduous broadleaf forest
43	Open Shrublands	semi desert shrubs
44	Grasslands	cool grasses and shrubs
45	Evergreen Needleleaf Forest	cool conifer forest
46	Croplands	corn and beans cropland
47	Deciduous Broadleaf Forest	cool broadleaf forest
48	Evergreen Needleleaf Forest	conifer forest
49	Evergreen Needleleaf Forest	conifer forest
50	Croplands	woody savanna

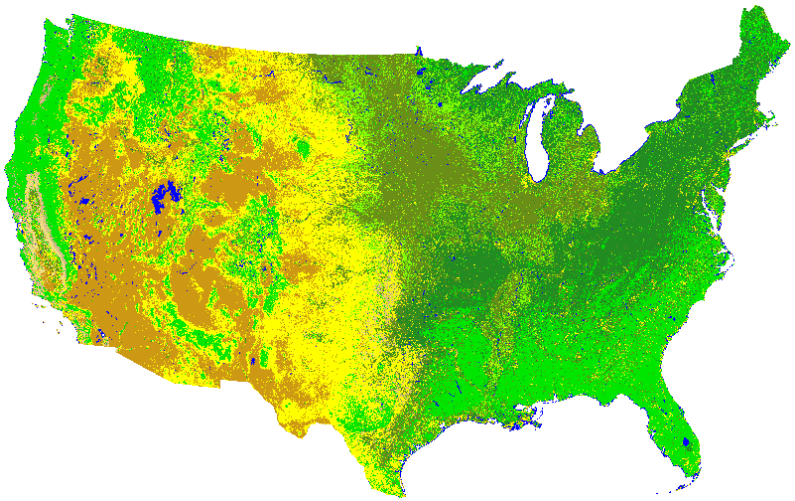
Phenoregions Reclassed Using Land Cover Types



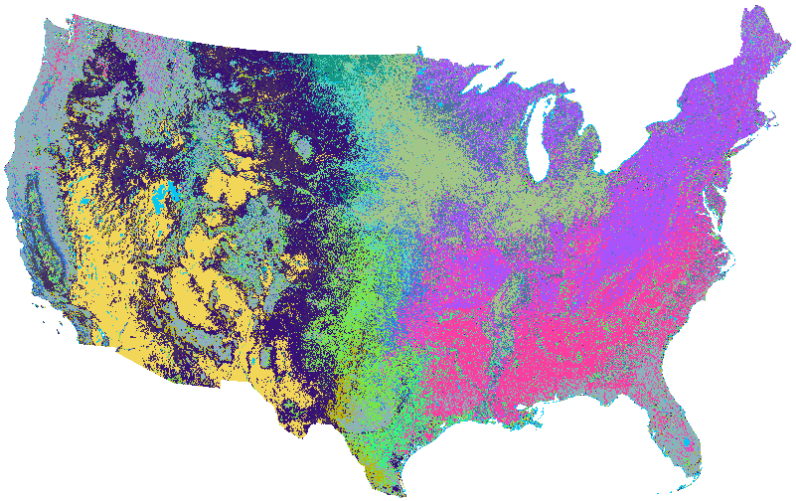
(a) IGBP Land Cover



(c) Olson's Global Ecoregions

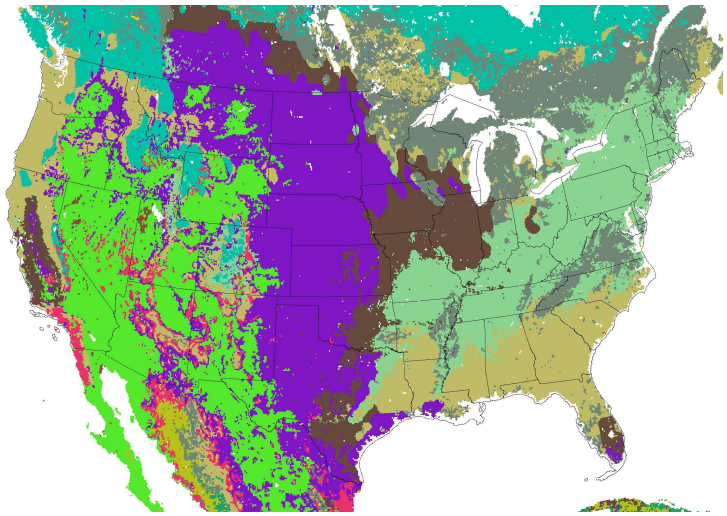


(b) 50 Phenoregions Reclassed

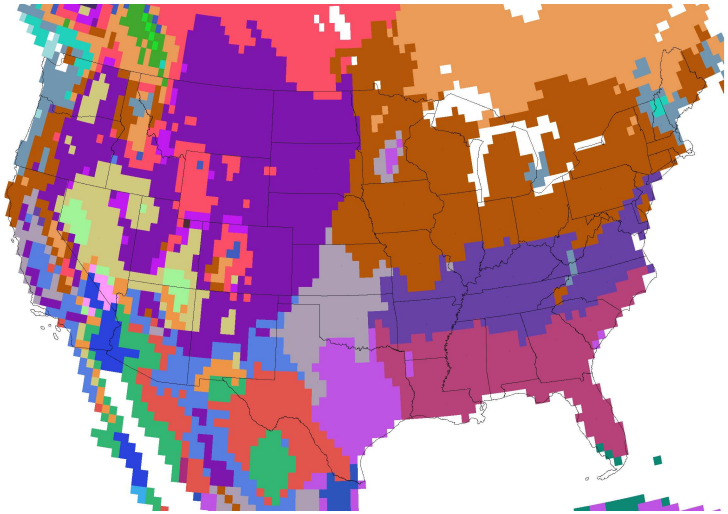


(d) 50 Phenoregions Reclassed

Expert-Derived Land Cover/Vegetation Type Maps



Foley Land Cover



Holdridge Life Zones

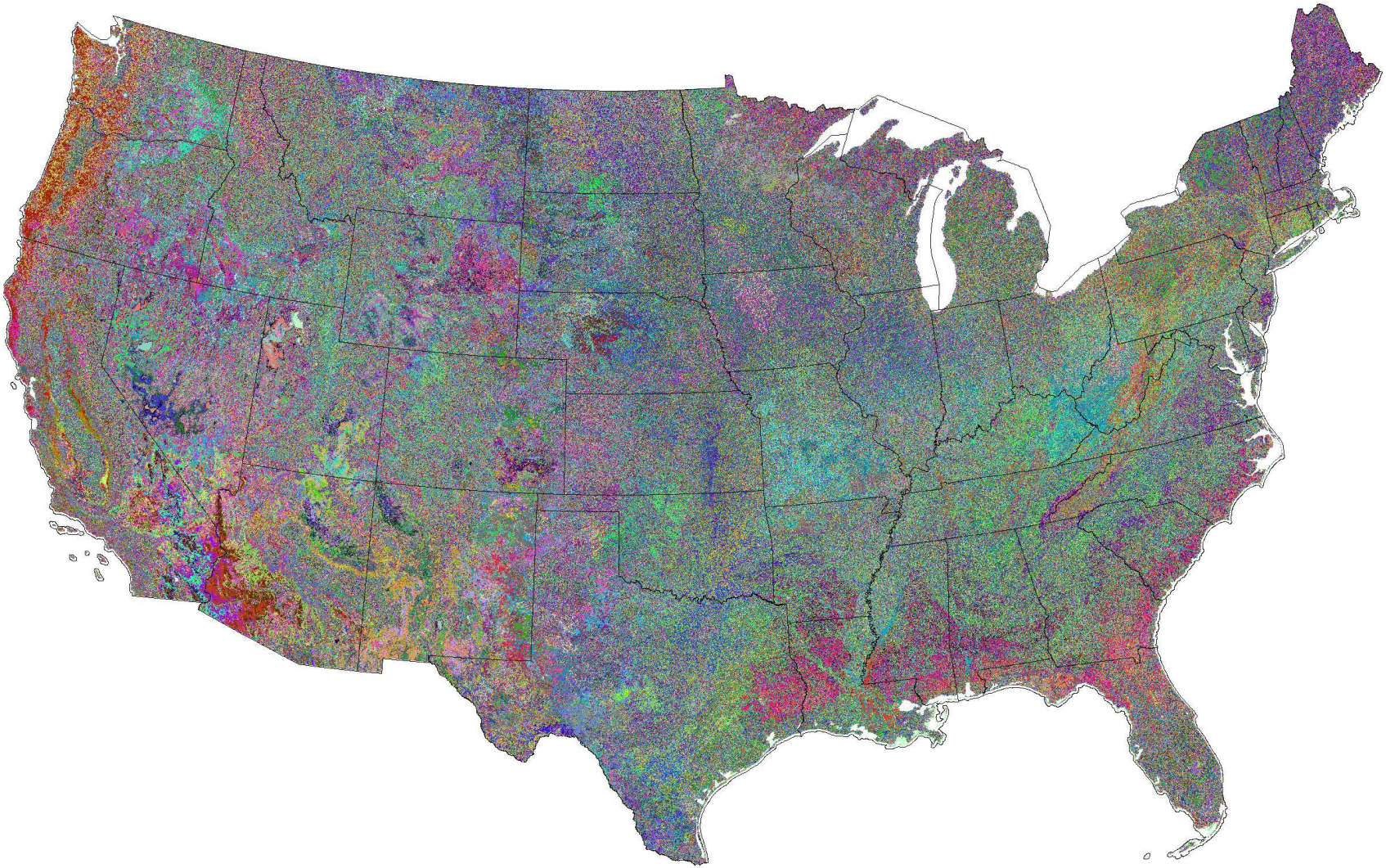
	Expert Map	# Cats
1.	DeFries UMd Vegetation	12
2.	Foley Land Cover	14
3.	Fedorova, Volkova, and Varlyguin World Vegetation Cover	31
4.	GAP National Land Cover	578
5.	Holdridge Life Zones	25
6.	Küchler Types	117
7.	BATS Land Cover	17
8.	IGBP Land Cover	16
9.	Olson Global Ecoregions	49
10.	Seasonal Land Cover Regions	194
11.	USGS Land Cover	24
12.	Leemans-Holdridge Life Zones	26
13.	Matthews Vegetation Types	19
14.	Major Land Resource Areas	197
15.	National Land Cover Database 2006	16
16.	Wilson, Henderson, & Sellers Primary Vegetation Types	23
17.	Landfire Vegetation Types	443

Label Stealing: Having your cake and eating it too!

- Clustering is an unsupervised classification technique, so phenoregions have no descriptive labels like **Eastern Deciduous Forest Biome**.
- **Label stealing** allows us to perform automated "supervision" to "steal" the best human-created descriptive labels to assign to phenoregions.
- We employ the **Mapcurves GOF** to select the best ecoregion labels from ecoregionalizations drawn by human experts.
- We consider an entire library of ecoregion and land cover maps, and choose the label with the highest GOF score for every phenoregion polygon.

Patchwork Crazy Quilt of Multiple Land Cover Types

1000 Phenoregions Max Under (Random Colors)



Category	Land Cover Label	Land Cover Map
1	Acadian Low-Elevation Spruce-Fir-Hardwood Forest	landfire vegetation type
2	Agriculture-Pasture and Hay	landfire vegetation type
3	Alpine meadows & barren	ktlamb
4	Barren	landcover.slcr
5	Barren or Sparsely Vegetated	landcover.usgs
6	Bluestem/Grama	ktlamb
7	Bluestem Hills, MLRA 76	mlra
8	Boreal Evergreen Forest/Woodland	foleylandcover
9	Boreal	fvvcode
10	Boreal moist forest	holdridgezonesnormal
11	Broadleaf Deciduous Forest	landcover.usgs
12	Brown Glaciated Plain, MLRA 52	mlra
13	California Central Valley and Southern Coastal Grassland	GAP 240m laea
14	California Central Valley Mixed Oak Savanna	GAP 240m laea
15	California oakwoods	ktlamb
16	California steppe	ktlamb
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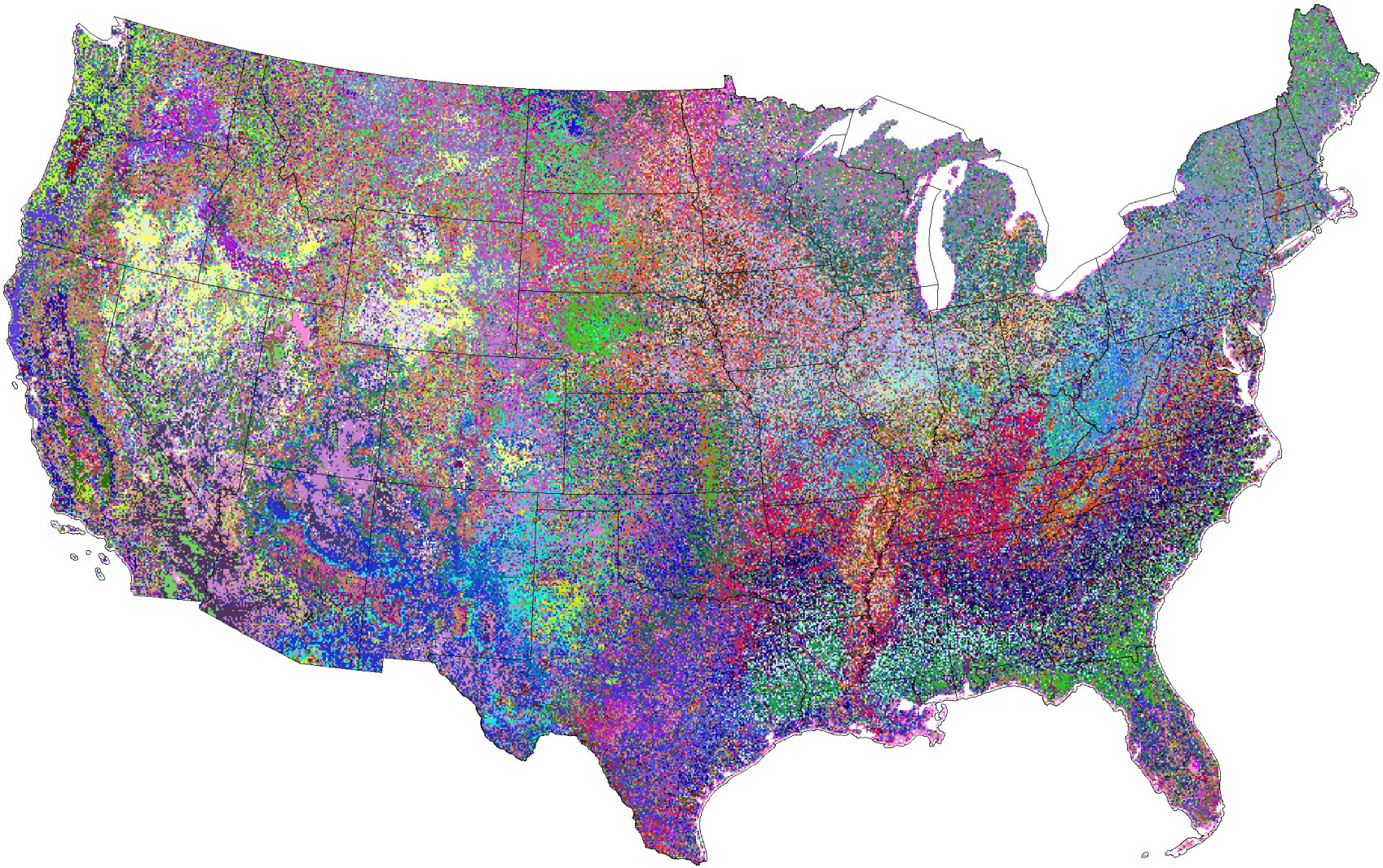
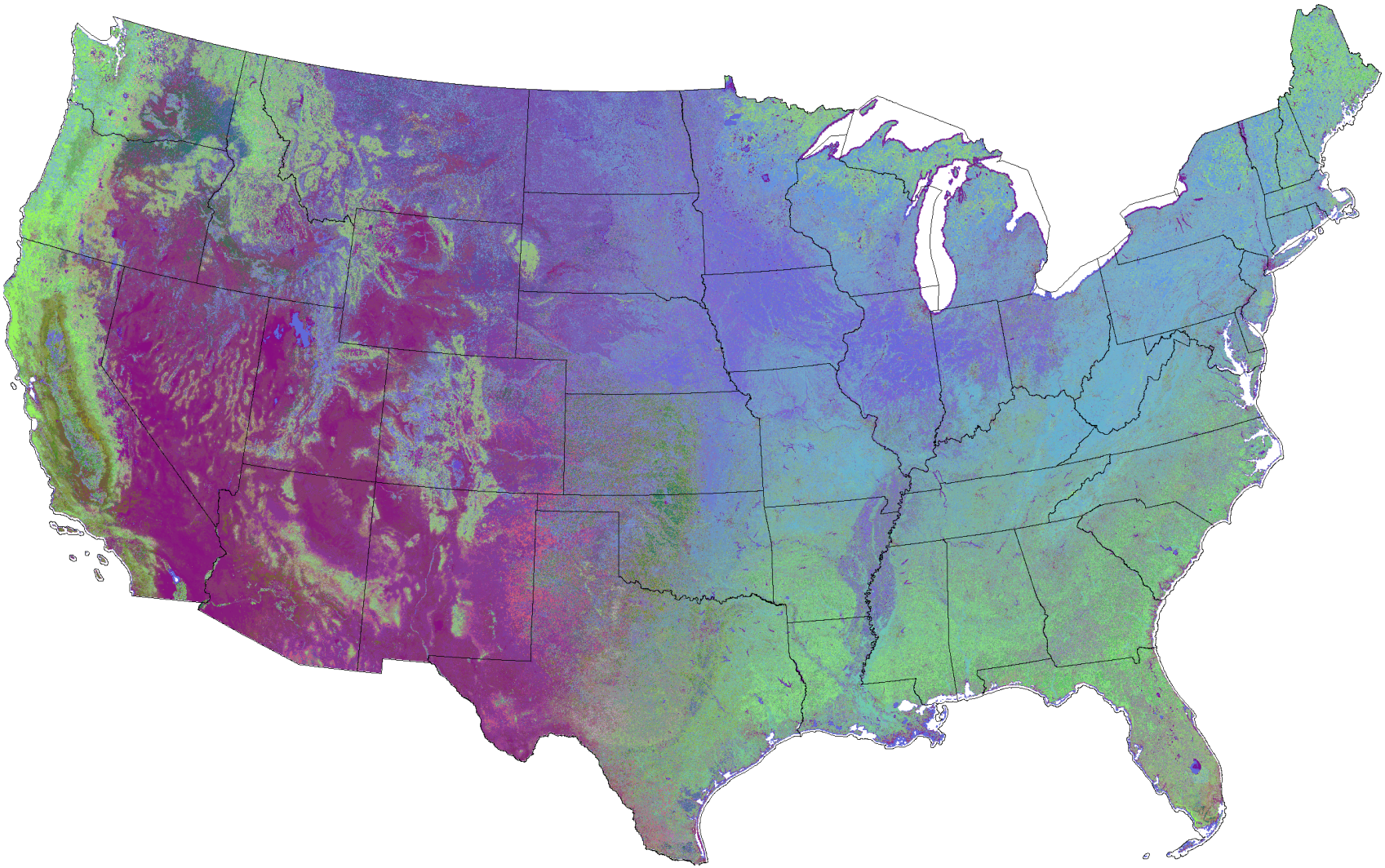
222	Warm temperate moist forest	holdridgezonesnormal
223	Warm Temperate Moist Forest	leemansholdridgezones
224	[water]	ktlamb
225	Water	landcover.slcr
226	Western Great Plains Mesquite Woodland and Shrubland	GAP 240m laea
227	Western Great Plains Shortgrass Prairie	landfire vegetation type
228	Western ponderosa	ktlamb
229	Western Rio Grande Plain, MLRA 83B	mlra
230	Western spruce/Fir	ktlamb
231	Wheatgrass/Bluegrass	ktlamb
232	Wheatgrass/Needlegrass	ktlamb
233	Willamette and Puget Sound Valleys, MLRA 2	mlra
234	Woodland/Cropland Mosaic	landcover.usgs
235	Woody wetlands	NLCD2006 240m laea

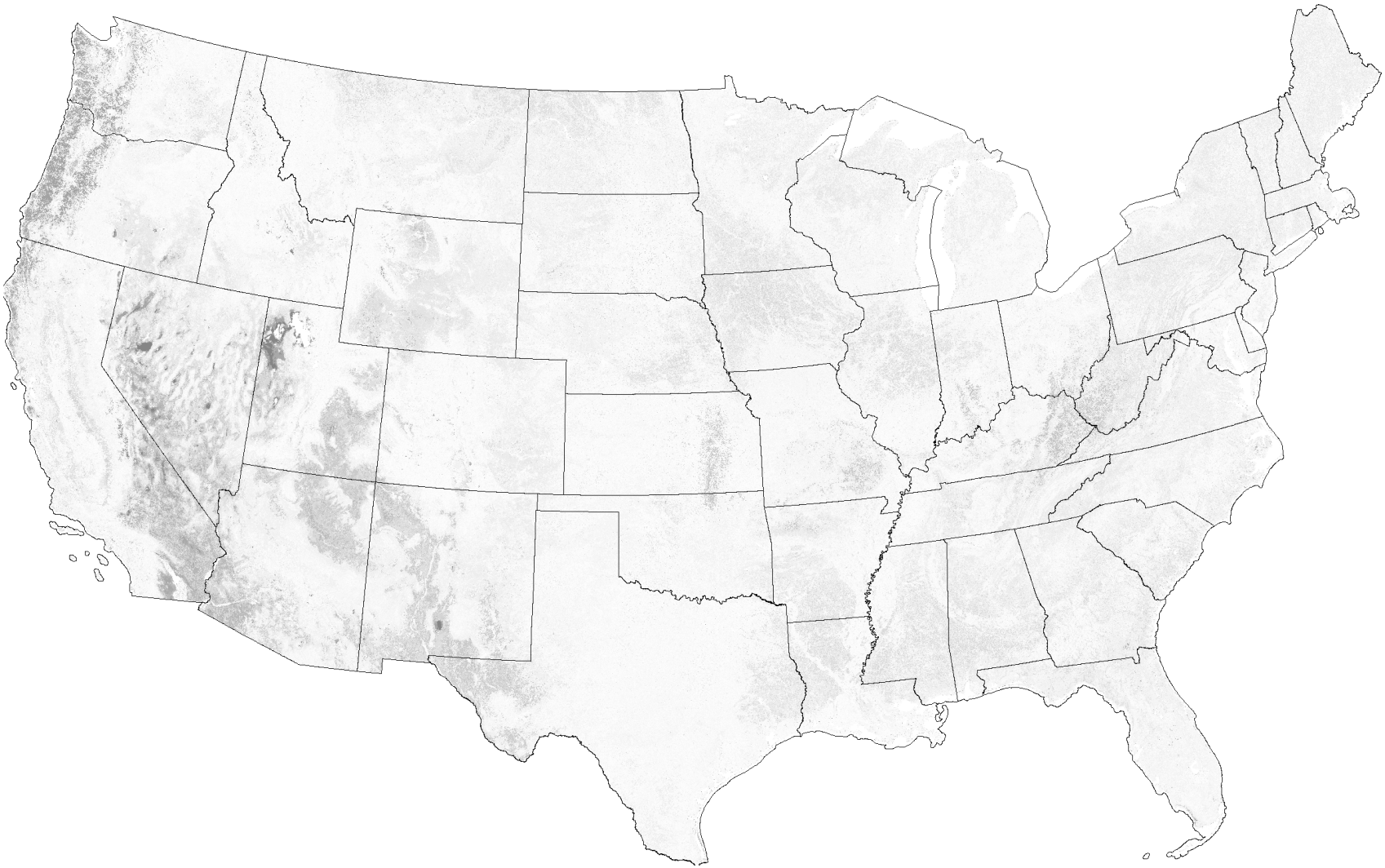
1000 Phenoregions Reclassed into 235 Land Cover Types



1000 Phenoregions Reclassed into 235 Land Cover Types



1000 Phenoregions Reclassed Goodness of Fit



Composition of the 235 Land Cover Types Map

	Map	Cats	WCats	WClusts	%Area
10.	Seasonal Land Cover Regions	194	43	160	19.45
9.	Olson Global Ecoregions	49	12	96	12.36
3.	Fedorova, Volkova, and Varlyguin World Vegetation Cover	31	4	93	10.69
17.	Landfire Vegetation Types	443	27	85	9.09
6.	Küchler Types	117	34	81	7.87
14.	Major Land Resource Areas	197	42	107	7.18
12.	Leemans-Holdridge Life Zones	26	8	54	5.27
11.	USGS Land Cover	24	7	21	4.85
4.	GAP National Land Cover	578	19	124	4.48
5.	Holdridge Life Zones	25	9	38	4.15
2.	Foley Land Cover	14	7	48	3.86
15.	National Land Cover Database 2006	16	8	47	3.24
13.	Matthews Vegetation Types	19	5	18	2.49
16.	Wilson, Henderson, & Sellers Primary Vegetation Types	23	2	9	1.46
7.	BATS Land Cover	17	4	10	1.23
8.	IGBP Land Cover	16	3	4	0.80
1.	DeFries UMd Vegetation	12	2	5	0.25
	TOTAL		**235**	**1000**	**100%**

#	Category	Land Cover Label	Land Cover Map	Percent Area
1	176	Subboreal	fvvcode	5.28%
2	179	Subtropical	fvvcode	4.25%
3	73	Evergreen Coniferous Forest	landcover.usgs	3.87%
4	67	Open Shrubland	foleylandcover	3.74%
5	35	corn and beans cropland	landcover.oge	3.48%
6	29	cool conifer forest	landcover.oge	2.93%
7	32	Cool temperate moist forest	holdridgezonesnormal	2.55%
8	64	Desert Shrubland/Grassland (Creosote, Saltbush, Mesquite, Sand Sage)	landcover.slcr	2.27%
9	55	Deciduous Forest (Oak, Hickory, Sweet Gum, Southern Pines) with Cropland and Pasture	landcover.slcr	2.25%
10	28	cool broadleaf forest	landcover.oge	2.23%
11	66	Sparsely Vegetated Desert Shrublands	landcover.slcr	2.14%
12	188	Warm temperate moist forest	holdridgezonesnormal	2.06%
13	180	Subtropical moist forest	holdridgezonesnormal	2.05%
14	160	semi desert sage	landcover.oge	1.87%
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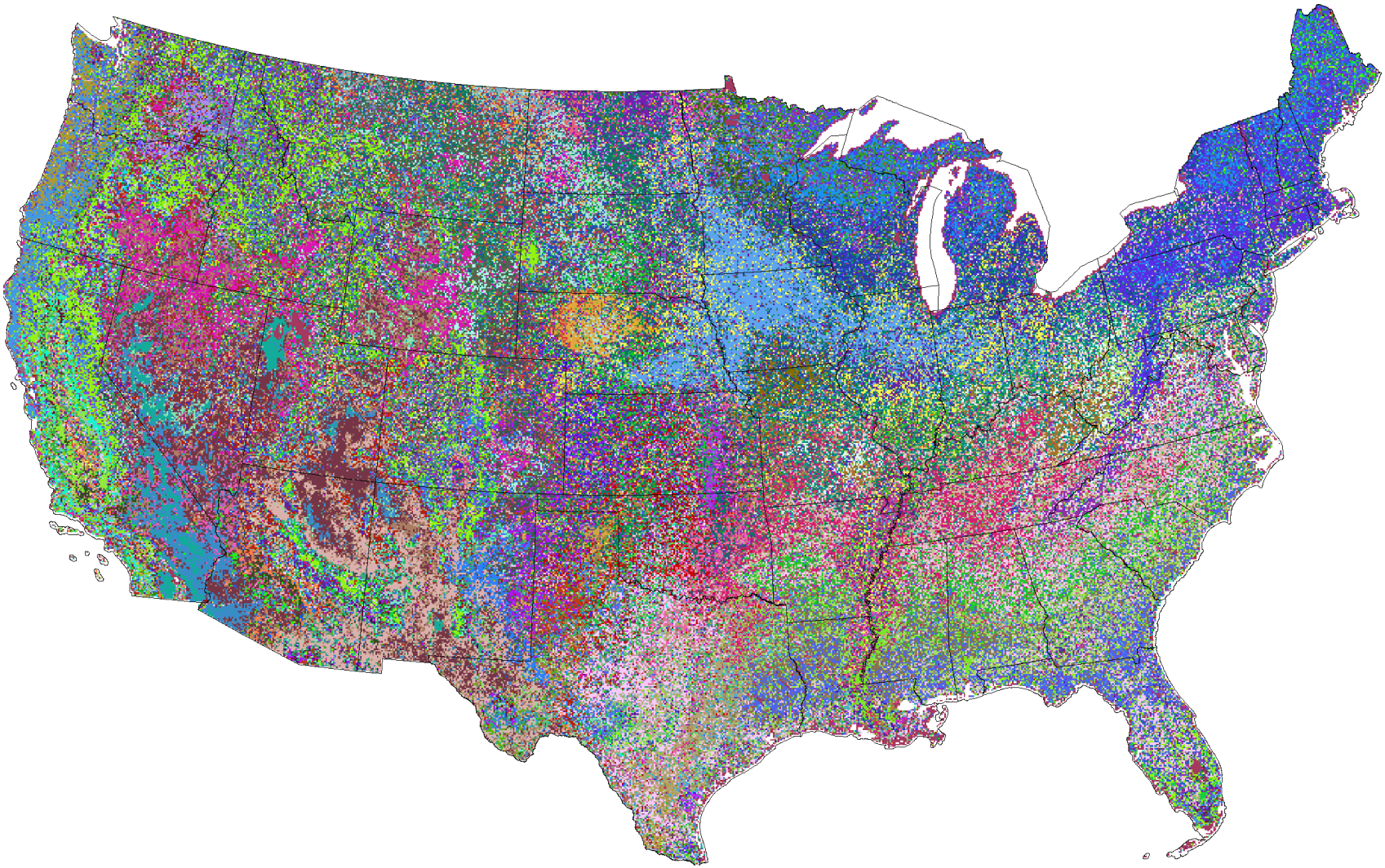
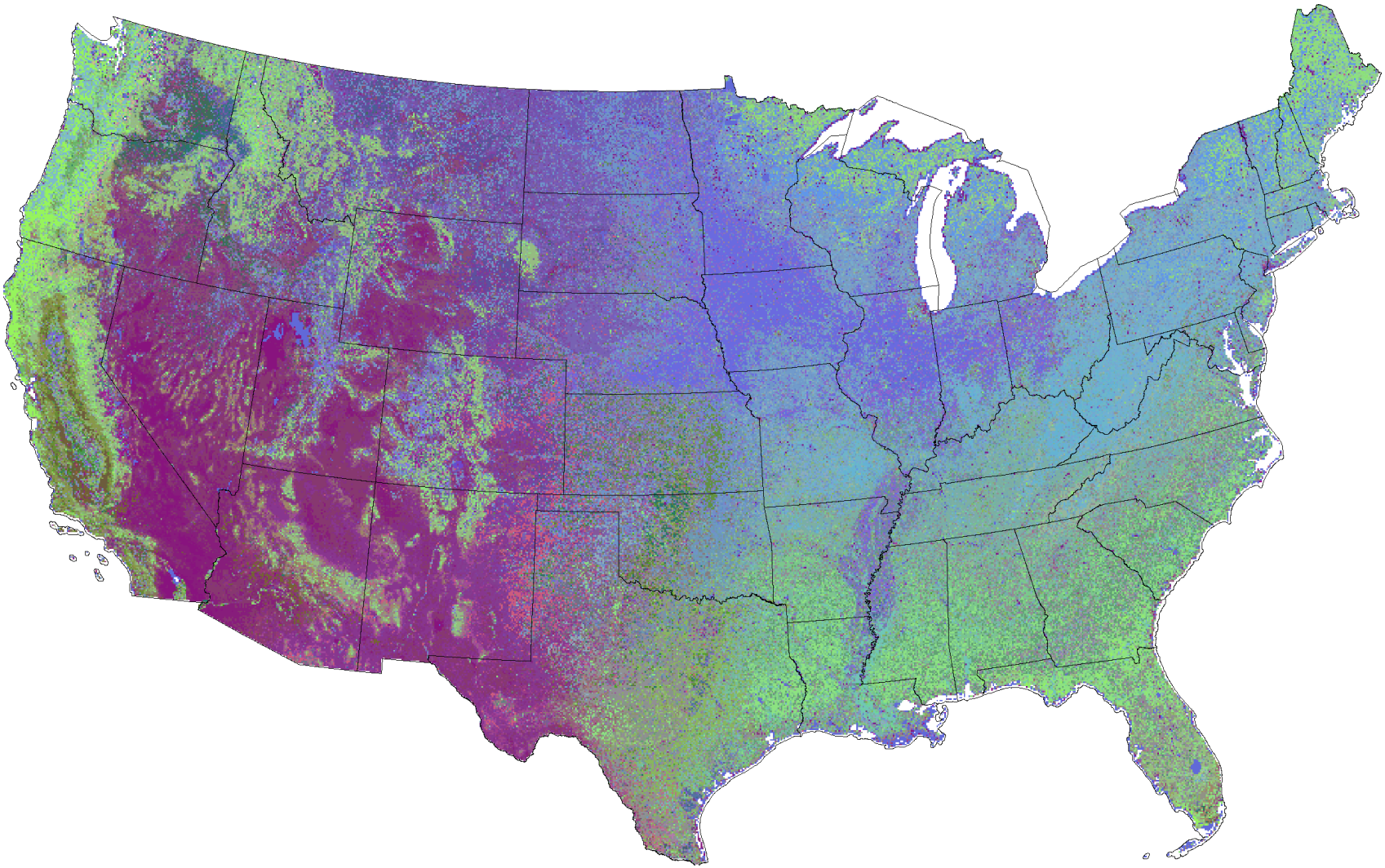
187	120	Northern hardwoods/Spruce	ktlamb	0.01%
188	102	Laurentian-Acadian Alkaline Conifer-Hardwood Swamp	landfire vegetation type	0.01%
189	51	NASS-Vineyard	landfire vegetation type	0.01%
190	2	Alpine meadows & barren	ktlamb	0.01%
191	143	Pseudotsuga menziesii Forest Alliance	landfire vegetation type	0.01%
192	134	Olympic and Cascade Mountains, MLRA 3	mlra	0.01%
193	79	Evergreen Needleleaf Forest (Lodgepole Pine and Douglas Fir)	landcover.slcr	0.01%
194	125	North Pacific Maritime Mesic Subalpine Parkland	GAP 240m laea	0.00%
195	80	Evergreen Needleleaf Forest (Lodgepole Pine, Englemann Spruce, Ponderosa Pine)	landcover.slcr	0.00%
196	157	Saltbrush/Greasewood	ktlamb	0.00%
197	106	Mediterranean California Red Fir Forest	GAP 240m laea	0.00%

1000 Phenoregions Reclassed into 197 Land Cover Types



1000 Phenoregions Reclassed into 197 Land Cover Types



Uses for Label Stealing

- Borrowing ecoregion, land cover, or vegetation type labels for unsupervised classifications.
- Automated attribution of disturbance agents through comparison of a *ForWarn* disturbance map with ADS aerial sketchmaps, wildfire perimeters, tornado track maps, and fuel treatment maps through time.
- Determination of the most important driving variable for phenoregions maps through comparison with separate maps of slope, aspect, solar input, elevation, soil types, etc.
- Automated recognition of species composition of forest vegetation through comparison of a phenoregions map with individual tree species range maps.

Acknowledgments

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