DIGITIZED MAP OF BIOTIC COMMUNITIES FOR PLOTTING AND COMPARING DISTRIBUTIONS OF NORTH AMERICAN ANIMALS

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Abstract—An ecologically based classification system, when accompanied by digitized maps of biotic communities, has been shown to be useful for plotting and assessing affinities of plants and animals in the southwestern United States and northwestern Mexico. Because these maps show ecological relationships of plants and animals with their environment, maps of biotic communities can be especially informative when delineating and describing affinities of habitats. We have expanded the classification system and prepared a digitized, ecologically based, color map of the biotic communities of North America to assess distributions of organisms on a continental as well as regional scale. As such, this map also can be used as a sample frame to design and stratify surveys of animals.

Resumen—Se ha demostrado que un sistema de clasificación ecológicamente basado, cuando se acompaña de mapas digitalizados de comunidades bióticas, es servicial para la representación y evaluación de afinidades de fauna y flora del suroeste de los Estados Unidos de América y el noroeste de México. Porque estos mapas muestran las relaciones ecológicas entre fauna y flora con su medio ambiente, mapas de comunidades bióticas pueden ser especialmente informativos a la hora de delimitar y describir afinidades de hábitat. Hemos ampliado el sistema de clasificación y preparado un mapa digitalizado a color, ecológicamente basado, de las comunidades bióticas de Norte América para evaluar las distribuciones de organismos a nivel continental así como regional. Este mapa también se puede usar como un modelo para diseñar y estratificar muestreos de animales.

Biotic communities are recognizable habitat assemblages that evolved within regional landscapes and are characterized by particular suites of plants and animals evolving within regional climatic patterns (Brown et al., 1998). As such, biotic communities are useful in describing habitat affinities of particular taxa of plants and animals and determining their biogeographical distribution (e.g., Brown 1982, 1994).

Incorporating the work and terminology of a broad range of ecologists and biogeographers, we developed a hierarchical classification formulated on the limiting effects of moisture and temperature minima on structure and composition of vegetation. This effort eventually resulted in a digitized, computer-compatible classification system for the biotic communities of Arizona, the Southwest, and North America (Lowe and Brown, 1973; Brown and Lowe, 1974*a*, 1974*b*; Brown et al., 1979; Brown, 1980, 1982, 1994; Brown et al., 1998). Attendant with these efforts were a series of maps delineating vegetation as the mapable reality of boundaries of biotic communities (Brown, 1973; Brown and Lowe, 1982, 1994; Reichenbacher et al., 1998).

Maps of biotic communities have been used by anthropologists (e.g., Floyd et al., 2003), archeologists (e.g., Huckell, 1996), climatologists (e.g., Davidowitz, 2002), ecologists (e.g., Lange et al., 2000), and other scientists interested in assessment, delineation, and stratification of biotic resources, along with identification of natural areas (e.g., Martin, 1979). The maps and classification system have, therefore, been used by the Rangelands Group of the United States Environmental Monitoring and Assessment Program of the United States Environmental Protection Agency, the Arizona and New Mexico game and fish departments, and other agencies charged with biotic resource inventory (e.g., Arizona Game and Fish Department Heritage Data Management System, 2006). Both the classification and maps have been used by PhotoAssist, Inc., Bethesda, Maryland, to design the biome map series of stamps issued by the United States Postal Service and have assisted the mapping division of National Geographic Magazine in delineating community boundaries of the Sonoran Desert. Moreover, the biogeographical validity of the various categories of hierarchy is statistically testable through use of climatic data, and the system has been used to digitally plot distributions of numerous plants and animals, including those in the Southwest Environmental Information Network maintained by the Vascular Plant Herbarium at Arizona State University at http://seinet.asu. Two recent books on Arizona reptiles (Brennan and Holycross, 2005, 2006) also employed digitized maps of biotic communities based on the classification system.

In March 2007, a search of the scientific literature using the Internet (http://scholar.google.com) listed >1,000 citations for either the biotic-community classification system or an accompanying map. Citations accompanied articles pertaining to general biogeographical comparisons (e.g., Paysen et al., 2000; DeSilva and Medelin, 2002; Coblentz and Ritters, 2004; Flesch and Hahn, 2005), vegetation communities and plant occurrences (e.g., White and Vankat, 1993; Roth, 2004; Barton, 2005; Laughlin et al., 2005), archeological sites (e.g., Cannon, 2000), regional climate studies (e.g., Enscore et al., 2002), and, most commonly, distributions of plants and animals (e.g., Turner et al., 2003; Ellis et al., 2004; Goldberg and Schwalbe, 2004; Luna-Soria and López-González, 2005; Hatten et al., 2005).

The system has been widely used by biologists who seek to associate taxa with particular biotic

TABLE 1—Areal extent of biotic communities of North America in square kilometers and square miles.

Biotic community	km²	miles²
Adirondack-Appalachian Alpine Tundra	454	176
Adirondack-Appalachian Subalpine Conifer Forest	17,050	6,609
Alaskan Swamp Scrub	43,872	17,005
Alaskan Tundra	167,554	64,946
Alaskan-Alpine Tundra	486,317	188,502
Alaska-Yukon Subarctic Conifer Forest	919,286	356,325
California Chaparral	33,620	13,032
California Coastalscrub	26,675	10,339
California Evergreen Forest and Woodland	62,363	24,173
California Valley Grassland	71,395	27,674
Campechian and Veracruz Savanna Grassland	14,935	5,789
Campechian Montane Evergreen Forest	96,083	37,243
Campechian Semi-evergreen Forest	107,047	41,493
Canadian (Low Arctic) Tundra	2,285,755	885,982
Canadian Taiga	4,631,309	1,795,143
Caribbean Cloud and Montane Evergreen Forests	18,543	7,188
Caribbean Dry Deciduous and Semi-deciduous Forests	108,720	42,141
Caribbean Lowland Evergreen and Semi-evergreen Forests	55,289	21,431
Caribbean Savanna Grassland	36,932	14,315
Caribbean Thornscrub	12,302	4,769
Cascade-Sierran Alpine Tundra	4,430	1,717
Cascade-Sierran Montane Conifer Forest	149,033	57,767
Cascade-Sierran Subalpine Conifer Forest	55,070	21,346
Central American (Guanacaste) Dry Forest	32,717	12,681
Central American Cloud Forest	15,171	5,880
Central American Evergreen Rain Forest	161,476	62,590
Central American Páramo	267	104
Central American Savanna Grassland	68,716	26,635
Central American Semi-evergreen Forest	47,939	18,582
Chihuahuan Desertscrub Cochise-Tranpecos subdivision	172,272	66,774
Chihuahuan Desertscrub-Mampimi subdivision	129,466	50,182
Chihuahuan Desertscrub-Saldan subdivision	78,323	30,359
Chihuahuan Interior Chaparral	30,221	11,714
Floridian Evergreen Forest	2,125	824
Great Basin Conifer Woodland	297,755	115,413
Great Basin Desertscrub	331,917	128,654
Great Basin Montanescrub	28,533	11,060
Great Basin Shrub-Grassland	570,630	221,182
Greenlandian Coastal Tundra	363,613	140,940
Guatemalan Cloud Forest	15,101	5,853
Guatemalan Evergreen Forest and Woodland	67,217	26,054
Guatemalan Montane Conifer Forest	3,356	1,301
Guerreran Dry Deciduous Forest	139,278	53,986
Guerreran Evergreen Forest and Woodland	41,846	16,220
Guerreran Savanna Grassland	13,202	5,117
Guerreran Thornscrub	35,495	13,758
Gulf Coastal Grassland	51,907	20,120
Madrean Evergreen Forest and Woodland	217,840	84,456
Madrean Montane Conifer Forest	37,028	14,353
Mohave Desertscrub	124,035	48,077
Nayarit Semi-evergreen Forest	34,166	13,243
Northeastern Deciduous Forest–Beech-Maple	206,814	80,163
Northeastern Deciduous Forest–Conifer-Deciduous	1,060,706	411,140
Northeastern Deciduous Forest–Maple-Basswood	122,453	47,464

TABLE 1—Continued.

Biotic community	km^2	miles^2
Northeastern Deciduous Forest–Mixed Mesophytic	187,260	72,584
Northeastern Deciduous Forest–Oak-Chestnut	192,060	74,445
Northeastern Deciduous Forest–Oak-Hickory	384,534	149,049
Northeastern Deciduous Forest–Oak, Pine-Hickory	391,875	151,895
Northeastern Deciduous Forest, Western Mesophytic	187,116	72,528
Oregonian Coastal Conifer Forest	123,813	47,991
Oregonian Deciduous and Evergreen Forests	36,495	14,146
Plains Grassland–Midgrass Communities	838,205	324,897
Plains Grassland–Shortgrass Communities	853,585	330,858
Plains Grassland–Tallgrass Communities	602,853	233,672
Polar (High Arctic) Tundra	609,576	236,278
Rocky Mountain and Great Basin Alpine Tundras	51,396	19,922
Rocky Mountain Montane Conifer Forest	554,197	214,812
Rocky Mountain Subalpine Conifer Forest	396,921	153,851
San Lucan Dry Deciduous Forest	5,480	2,124
San Lucan Evergreen Forest and Woodland	1,190	461
San Lucan Thornscrub	6,879	2,667
Semidesert Grassland	507,772	196,818
Sinaloan Dry Deciduous (Monsoon) Forest	67,459	26,148
Sinaloan Thornscrub	62,121	24,079
Sitka Coastal Conifer Forest	209,045	81,028
Sonoran Desertscrub-Arizona Uplands subdivision	54,020	20,939
Sonoran Desertscrub-Central Gulf Coast subdivision	23,481	9,101
Sonoran Desertscrub-Lower Colorado River Valley subdivision	131,249	50,873
Sonoran Desertscrub-Plains of Sonora subdivision	21,433	8,308
Sonoran Desertscrub-Vizcáino subdivision	75,444	29,243
Southeastern Deciduous and Evergreen Forests	541,875	210,036
Southwestern (Arizona) Interior Chaparral	10,671	4,136
Southeastern Deciduous and Evergreen Forests-Balcones subdivision	67,267	26,073
Tamaulipan Semi-deciduous Forest	38,104	14,770
Tamaulipan Thornscrub	187,962	72,856
Transvolcanic Alpine Tundra	331	128
Transvolcanic Evergreen Forest and Woodland	56,666	21,964
Transvolcanic Montane Conifer Forest	6,961	2,698
Veracruz Cloud Forest	5,866	2,274
Veracruz Evergreen Rain Forest	34,909	13,531
Veracruz Semi-evergreen Forest	35,256	13,666
Yucatán Dry Deciduous Forest	24,255	9,401
Yucatán Semi-deciduous Forest	15,894	6,160
Open Water Lakes	671,798	260,396
Permanent Ice and Snow	1,760,137	682,247
Southeastern Swamp and Riparian Forest	211,101	81,825
Undifferentiated Nearctic Wetlands	25,977	10,069
Undifferentiated Neotropical Wetlands	62,272	24,137
Total	24,238,426	9,395,062

communities or habitat types, and we found numerous citations in agency reports and journals relating vertebrate animal distributions to the terminology and maps of the classification system (e.g., Smith and Farrell, 2005*a*, 2005*b*; Swann et al., 2005; Moore and DiGiulio, 2006; Smith and Farrell, 2006). The system and accompanying maps are especially applicable to distributions of reptiles and amphibians, and we found citations pertaining to distributions of these species in such journals as *The Journal of Wildlife Management* (Freilich et al., 2005), Oecologia (Jones et al., 1985; Pfennig et al., 1991), and *The Southwestern Naturalist* (e.g., Turner et al., 2003; Goldberg and Schwalbe, 2004*b*).

To expand applicability of the biotic-classification system, we prepared a digitized map of the major biotic communities of North America compatible with those for Arizona and the Southwest (Fig. 1). For a base chart, using the GIS software ArcInfo, we enhanced the biotic-communities map (scale 1:10,000,000) developed by Reichenbacher et al. (1998) by adding political boundaries and some large rivers. Some of the larger biotic communities were then divided into recognizable subdivisions: e.g., those of Braun (1967) and Greller (1988) for the Northeastern Deciduous Forest, Shelford (1963) and Sims (1988) for Plains Grassland, Shreve (1951) for the Sonoran Desert, Moravka (1977) for the Chihuahuan Desert, and West (1988) for the Great Basin Desert. We also added Balcones Woodland as described and delineated by Blair (1950) for the Edwards Plateau region in Texas (Fig. 1). In digitizing the map, we also calculated the area of each biotic community to facilitate stratification of future surveys (Table 1).

The choice of colors was carefully considered and was modeled after the color scheme developed by Gaüssen (1953, 1955) and adapted by Udvardy (1975) for world vegetation. In this ecological-classification system, arid habitats are represented by pale colors, the shades becoming progressively darker in wetter communities until the most mesic entities are represented by solid, dark colors. Cold habitats are cold, dull colors—grays, dark blues, and purples. As communities become progressively warmer, colors representing them become brighter until the brilliant warm colors of the tropics—yellows, oranges, scarlets, and magentas. As a general rule, tundra communities are shades of gray, temperate grasslands are depicted in various tones of brown, conifer forests are purples and blues, temperate forests and chaparral are combinations of blues and greens, thornscrubs and savannas are yellows and oranges, tropical deciduous forests are shades of red, and tropical evergreen forests are violets and magentas. Selecting the actual color to represent a biotic community, although complex and difficult due to the number of communities involved, was greatly facilitated through use of a Pantone (1995) color wheel by which >3,000 color shades are arranged according to the percentage sequence of 4 basic colors (cyan, magenta, yellow, and black). ArcMap was used to assign each community cyan, magenta, yellow, and black color values. For publication purposes, we exported the ArcMap file as a new, encapsulated postscript (EPS) file. The actual color selected for each biotic community was a compromised combination of colors intended to illustrate moisture and temperature gradients, formation-class, and discernability on a continental scale.

Literature Cited

Arizona Game and Fish Department Heritage Data Management System. 2006. Plant abstract element code PDAST8H411. Arizona Game and Fish Department, Phoenix.

Blair, W. F. 1950. The biotic provinces of Texas. Texas Journal of Science 2:93–117.

Braun, E. L. 1967. The deciduous forests of eastern North America. Hafner Publishing Co., New York.

Brennan, T. C., and A. T. Holycross. 2005. A field guide to amphibians and reptiles of Maricopa County. Arizona Game and Fish Department, Phoenix.

Brennan, T. C., and A. T. Holycross. 2006. A field guide to amphibians and reptiles in Arizona. Arizona Game and Fish Department, Phoenix.

Brown, D. E. 1973. The natural vegetative communities of Arizona (map: scale 1:500,000). Arizona Resources Information System (ARIS), Phoenix.

Brown, D. E. 1980. A system for classifying cultivated and cultured lands within a systematic classification of natural resources. Journal of the Arizona-Nevada Academy of Science 5:48–53.

Brown, D. E. (editor). 1982. The biotic communities of the American Southwest – United States and Mexico. Desert Plants (1–4):1–341. Reprinted and revised 1994 as Biotic communities: southwestern United States and northwestern Mexico by the University of Utah Press, Salt Lake City.

Brown, D. E., and C. H. Lowe. 1974*a*. A digitized computer-compatible classification for natural and potential vegetation in the Southwest with particular reference to Arizona. Journal of the Arizona Academy Science 9(supplement 2):1–11.

Brown, D. E., and C. H. Lowe. 1974*b*. The Arizona system for natural and potential vegetation – illustrated summary through the fifth digit for the North American Southwest. Journal of the Arizona Academy Science 9(supplement 3):1–56.

Brown, D. E., and C. H. Lowe. 1982. Biotic communities of the Southwest (scale 1:1,000,000). General Technical Report RM-78, United States Forest Service, Fort Collins, Colorado. Reprinted and revised 1994 by University Utah Press, Salt Lake City.

Brown, D. E., C. H. Lowe, and C. P. Pase. 1979. A digitized classification system for the biotic communities of North America, with community (series) and association examples for the Southwest. Journal of the Arizona-Nevada Academy Science 14, Supplement. 1:1–16.

Brown, D. E., F. W. Reichenbacher, and S. E. Franson. 1998. A classification of North American biotic communities. University of Utah Press, Salt Lake City.

Cannon, M. D. 2000. Large mammal relative abundance in pithouse and pueblo period archaeofaunas from southwestern New Mexico: resource depression among the Mimbres-Mogollon? Journal of Anthropological Archaeology 19:317–347.

Coblentz, D. D., and K. H. Ritters. 2004. Topographic controls on the regional-scale biodiversity of the south-western USA. Journal of Biogeography 31:1125–1138.

Davidowitz, G. 2002. Does precipitation variability increase from mesic to xeric biomes? Global Ecology and Biogeography 11:143.

Desilva, H. G., and R. A. Medelín. 2002. Are land bird assemblages functionally saturated? An empirical test in Mexico. Oikos 96:169–181.

Ellis, D. H., C. H. Ellis, B. A. Sabo, A. M. Rea, J. Dawson, J. K. Fackler, C. T. Larue, T. G. Grubb, J. Schmitt, D. G. Smith, and M. Kéry. 2004. Summer diet of the peregrine falcon in faunistically rich and poor zones of Arizona analyzed with capture-recapture modeling. Condor 106:873–886.

Enscore, R. E., B. J. Biggerstaff, T. L. Brown, R. E. Fulgham, P. J. Reynolds, D. M. Engelthaler, C. E. Levy, R. R. Parmenter, J. A. Montenieri, J. E. Cheek, R. K. Grinnell, P. J. Ettestad, and K. L. Gage. 2002. Modeling relationships between climate and the frequency of human plague cases in the southwestern United States, 1960–1997. American Journal of Tropical Medicine and Hygiene 66:186–196.

Flesch, A. D., and L. A. Hahn. 2005. Distribution of birds and plants at the western and southern edges of the Madrean sky islands in Sonora, Mexico. United States Department of Agriculture Forest Service Proceedings RMRS-P-36:80–87.

Freilich, J. E., R. J. Camp, J. J. Duda, and A. E. Karl. 2005. Problems with sampling desert tortoises: a simulation analysis based on field data. Journal of Wildlife Management 69:45–56.

Gardea-Torresday, J. L., S. Artega, K. J. Tiemann, R. Chianelli, N. Pingitore, and W. Mackay. 2001. Absorption of copper (II) by creosote bush (*Larrea tridentata*): use of atomic and x-ray absorption spectroscopy. Environmental Toxicology and Chemistry 20:2572–2577.

Gaüssen, H. 1953. A proposed ecological vegetation map. Surveying and Mapping 13:168–173.

Gaüssen, H. 1955. Expression des milieux par des formules écologiques: Leur représentation cartographique. Pages 257–269 in Les divisions écologiques du monde: moyens d'expression, nomenclature, cartographie. Colloques Internationaux du Centre National de la Recherche Scietifique 59. L'Anée Biologique, Série 3, Tome 31. Centre Nacional de la Recherch Scientifique, Paris.

Goldberg, C. S., and C. R. Schwalbe. 2004. Considerations for monitoring a rare anuran (*Eleutherodactylus augusti*). Southwestern Naturalist 49:442–448.

Greller, A. M. 1988. Deciduous forest. Pages 287–316 in North American terrestrial vegetation (M. G. Barbour and W. D. Billings, editors). Cambridge University Press, Cambridge, United Kingdom.

Hatten, J. R., A. Averill-Murray, and W. E. Van Pelt. 2005. A spatial model of potential jaguar habitat in Arizona. Journal of Wildlife Management 69:1024–1033.

Huckell, B. B. 1996. The archaic prehistory of the North American Southwest. Journal of World Prehistory 10:305–373.

Jones, K. B., L. P. Kepner, and T. E. Martin. 1985. Habitat islands in western Arizona: a deterministic assemblage. Oecologia 66:595–601.

Laughlin, D. C., J. D. Bakker, and P. Z. Fule. 2005. Understory plant community structure in lower montane and subalpine forests, Grand Canyon National Park, Arizona. Journal of Biogeography 32:2083–2102.

Lowe, C. H., and D. E. Brown. 1973. The natural vegetation of Arizona. Arizona Resources Information System (ARIS) Cooperative Publication 2:1–53.

Luna-Soria, H., and C. A. López-González. 2005. Abundance and food habits of cougars and bobcats in the Sierra San Luis, Sonora, Mexico. United States Department of Agriculture Forest Service Proceedings RMRS-P-36:416.

Martin, P. S. 1979. A survey of potential natural landmarks, biotic themes, of the Mohave-Sonoran desert region. Heritage Conservation and Recreation Service, United States Department of the Interior, Tucson, Arizona.

Moore, W., and A. Digiulio. 2006. Description and behaviour of *Goniotropis kuntzeni* larvae (Coleoptera: Caraabidae: Paussinae: Ozaenini) and a key to genera of Paussinae laravae. Zootaxa 1111:1–19.

Moravka, D. J. 1977. A biogeographical analysis of the Chihuahuan Desert through its herpetofauna. Junk, The Hague, The Netherlands.

Pantone. 1995. Process color system guide. Carlstadt, New Jersey.

Paysen, T. E., R. J. Ansley, J. K. Brown, G. J. Gottfried, S. M. Haase, M. G. Harrington, M. G. Naroag, S. S. Sackett, and R. C. Wilson. 2000. Fire in western shrubland, woodland, and grassland ecosystems. United States Department of Agriculture Forest Service General Technical Report RMRS-GTR-42:121–159.

Pfennig, D. W., M. L. G. Loeb, and J. P. Collins. 1991. Pathogens as a factor limiting the spread of cannibalism in tiger salamanders. Oecologia 88: 161–166.

Reichenbacher, F., S. E. Franson, and D. E. Brown. 1998. The biotic communities of North America (scale 1:10,000,000). University of Utah Press, Salt Lake City.

Roth, D. 2004. *Pediocactus bradyi*, Brady's pincushion cactus status report. Navajo Natural Heritage Program, Window Rock, Navajo Nation.

Shelford, V. E. 1963. The ecology of North America. University of Illinois Press, Urbana.

Shreve, F. 1951. Vegetation and flora of the Sonoran Desert. Volume I, vegetation. Carnegie Institute of Washington Publication 591:1–192.

Sims, P. L. 1988. Grasslands. Pages 265–286 in North American terrestrial vegetation (M. G. Barbour and W. D. Billings, editors). Cambridge University Press, Cambridge, United Kingdom.

Smith, C. I., and B. D. Farrell. 2005*a*. Historical biogeography of longhorn cactus beetles: the influence of Pleistocene climate changes on American desert communities. United States Department of Agriculture Forest Service Proceedings RMRS-P-36:135–139.

Smith, C. I., and B. D. Farrell. 2005*b*. Range expansions in the flightless longhorn cactus beetles, *Moneilema gigas* and *Moneilema armatum*, in response to Pleistocene climate changes. Molecular Ecology 14: 1025–1044.

Smith, C. I., and B. D. Farrell. 2006. Evolutionary consequences of dispersal ability in cactus-feeding insects. Genetica 126:323–334.

Swann, D. E., T. M. Mau-Crimmins, and E. W. Stitt. 2005. In search of the Madrean line: biogeography of herpetofauna in the sky island region. United States Department of Agriculture Forest Service Proceedings RMRS P-36:149–153.

Turner, D. S., P. A. Holm, E. B. Wirt, and C. R. Schwalbe. 2003. Amphibians and reptiles of the Whetstone Mountains, Arizona. Southwestern Naturalist 48:347–355.

Udvardy, M. D. F. 1975. World biogeographical provinces. Co-Evolution Quarterly. Map, scale 1:39,629,000

West, N. E. 1988. Intermountain deserts, shrub steppes, and woodlands. Pages 210–230 in North American terrestrial vegetation (M. G. Barbour and W. D. Billings, editors). Cambridge University Press, Cambridge, United Kingdom.

Submitted 30 October 2006. Accepted 1 April 2007. Editor was Mark Eberle.