Towards a National GIS Model to Map Terrestrial Ecosystems in Mongolia: A Pilot Study in the Gobi Desert Region

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ABSTRACT

In Mongolia, partners from national and aimag governments, academia and NGOs have developed regional conservation plans that balance the government commitment to protection of natural habitats with planned development of mineral resources and related infrastructure. A key input is a mapped classification of major habitat types, or ecosystems, to represent the range of natural habitats and function as a surrogate for biodiversity. We developed a GIS model to map ecosystems across the Mongolian Gobi Desert region by comparing the distribution of plant communities and major vegetation types, taken from field surveys and national maps, with patterns of above-ground biomass, elevation, climate and topography derived from remote sensing. The resulting mapped classification is organized as a hierarchy of 1) biogeographic regions, 2) terrestrial ecosystem types based on vegetation, elevation and geomorphology, and 3) landforms. This provides a first-iteration map to support landscape-level conservation planning and a model framework that can support field surveys and future model revisions, with other applications to land use planning, research, surveys and monitoring. To facilitate that, the GIS results are

publicly available either for download or to view and query in a web-based GIS available at:
<http://s3.amazonaws.com/DevByDesign-Web/MappingAppsVer2/Gobi/index.html>.

Keywords: ecosystems, ecological classification, ecological delineation, GIS, remote sensing, conservation planning

INTRODUCTION

In collaboration with national and provincial governments, Universities and NGOs, TNC has produced landscape level conservation plans for Eastern Mongolia and the Gobi Desert region to guide protection and mitigation (Heiner et al., 2013; Kiesecker et al., 2010). A third assessment of the remaining Central and Western regions will finish in July 2015. A key component of landscape-level conservation planning is a mapped classification of major habitat types, or ecosystems, to represent the range of natural habitats and function as a surrogate for biodiversity.

Since the 1970s, extensive field surveys by joint Mongolian-Russian expeditions have produced several national and regional maps of vegetation and ecosystems (e.g. Vostokova and Gunin, 2005; Yunatov et al., 1979) at map scales of 1:1 to 1:2 million. The applications of these maps are limited by the coarse spatial scale. In recent years, several advances in remote sensing products and tools have enabled vegetation mapping and landscape classification at a finer spatial scale, based on documented, replicable quantitative methods and field data. These include Landsat TM (NASA, 2011) for high spectral resolution image classification, the Normalized Difference Vegetation Index (NDVI) (e.g. MODIS; NASA, 2012) to measure above-ground biomass at a range of spatial and temporal scales, and digital elevation models (DEMs) (e.g. SRTM; NASA, 2005) for measuring elevation and classifying topography or landforms. One advantage of a data-driven modeling approach is that the source data and model can be iteratively revised as new field data becomes available, and initial results can guide spatial sampling of survey design to inform revisions.

In Mongolia, there is a need for a regional-level mapped classification of vegetation and physical habitat that is accurate at a coarse but consistent spatial scale and based on transparent, well-documented methods and source data. Several vegetation maps have been developed using Landsat 5 TM images for National Protected Areas in the Gobi Desert study area (von Wehrden et al., 2006a; von Wehrden et al., 2006b; von Wehrden et al., 2009a). A Landsat-based approach is not feasible for a study area as large as the Gobi Desert region. We developed a GIS model to map ecosystems across the Gobi region by comparing the distribution of plant communities and major vegetation types, taken from field surveys and national maps, with patterns of above-ground biomass, elevation, climate and topography derived from remote sensing. The result is a first iteration mapped classification of the Gobi Desert region to support landscape-level conservation planning, as well as other applications including land use planning, research, surveys and monitoring.

STUDY AREA

The study area is the Mongolian portion of the Central Asian Gobi Desert ecoregion, as delineated by the World Wildlife Fund (WWF) Mongolia Programme Office for the National Gap Assessment (Chimed-Ochir et al. 2010). This region covers 510,000 km^2, or the southern third (32%) of the country, and is a cold desert with a continental climate and long, cold winters. Mean annual precipitation ranges from less than 40 mm in extreme arid areas to over 200 mm in the Gobi-Altai mountains (Hijmans et al., 2005) and inter-annual variation is high.

METHODS

Our approach to developing a mapped ecosystem classification is based on regional mapped classifications of ecological systems developed in the United States and Latin America that define ecological systems as groups of biological communities occurring in similar physical environments and influenced by similar ecological processes. This framework is organized by biogeographic regions (e.g. ecoregions) and four categories of spatial pattern or patch type: matrix, large patch, small patch and linear. As such, this framework considers multiple scales of organization, environmental patterns and processes that influence habitat structure and function, and the classification units are practical to map and identify in the field, thereby addressing a critical need for practical, medium-scale ecological units to inform conservation and management decisions (Comer et al., 2003). For the Gobi Desert region, we developed a terrestrial ecosystem classification that is a hierarchy of 1) biogeographic regions, 2) terrestrial ecosystem types based on vegetation, elevation and geomorphology, and 3) landforms.

1. Biogeographic regions. Biogeographic regions represent broad, regional patterns of climate, physiography and related variation in species and genetics. For most ecosystem types distributed across the study area, stratification by biogeographic zone may capture regional differences in species composition and environmental patterns. To define and map biogeographic zones, we chose the four ecoregions delineated by the National Gap Assessment (Chimed-Ochir et al., 2010): Eastern Gobi, Gobi-Altai Mountain Range, Southern Gobi-Altai and the Dzungarian Gobi Desert. To capture the unique biogeography of the Trans-Altai Gobi Desert in southwestern Mongolia (N. Batsaikhan, pers. comm.), we further divided the Southern Gobi-Altai ecoregion based on the Trans-Altai Gobi Desert Landscape-Ecological zone delineated by Vostokova and Gunin (2005).

2. Ecosystem types. We defined the set of focal ecosystem types based on botanical studies (Grubov, 1982; Hilbig, 1995) and national maps of vegetation and ecosystems (Yunatov et al., 1979; Chimed-Ochir et al., 2010) and developed a GIS model that functions at two levels, or spatial scales. First, matrix-forming types, such as desert steppe, are broadly distributed and mapped here according to coarse-scale patterns of annual productivity, elevation and precipitation. Second, patch-forming types, such as oases or wet depressions, form distinct patches and are mapped here at a relatively fine scale based on topography, surface hydrology and satellite imagery. Source data and mapping methods are listed in Table 1.

Matrix-forming systems cover most of the land area and follow broad patterns of climate and precipitation. These include extreme arid desert, true desert, semi-desert, desert steppe, dry steppe and mountain steppe. In the Gobi Desert region, precipitation, vegetation productivity, and the spatial distribution of plant communities are highly correlated (von Wehrden and Wesche, 2007). Based on this strong relationship, we developed a predictive model of the distribution of general steppe and desert types based on above ground biomass, annual precipitation, and elevation sampled with 1,145 survey records of diagnostic plant communities collected by von Wehrden et al. (2006c, 2006d, 2006e, 2009b) and Wesche et al. (2005). Above-ground biomass is the 11-year (2000-2011) mean NDVI during the growing season (June through September) from MODIS 13A3 (NASA 2012). Precipitation values are 50 year (1950-2000) monthly averages from WorldClim (Hijmans et al. 2005). Based on the results (Figure 1), we chose NDVI thresholds to define six classes of biomass, combined with elevation and landforms to map the predicted distribution of eight matrix-forming vegetation types: barren, extreme arid desert, true desert, semi-desert, desert steppe and steppe. We further divided steppe into dry steppe and mountain steppe based on elevation, and mountain rough terrain based on landforms.

Patch-forming systems include five general types and sets of mapping methods, described below. These five types were identified by experts and in literature (Grubov, 1982; Hilbig, 1995) as important habitat and sources of water and forage that have high value for wildlife, livestock and people. All are groundwater-dependent ecosystems, with sparse and patchy distribution following groundwater hydrology. These systems support high species diversity and provide critical habitat, particularly for small mammals, reptiles and birds, and provide valuable forage for large desert mammals.

i. *Wet depressions*: dry river beds or salty depressions with shallow water table following broad drainage patterns. These areas typically support distinct vegetation types including Saxaul (*Haloxylon ammodendron*) forest stands and Siberian elm (*Ulmus pumila*) and contain physically diverse soil types due to near-surface groundwater and hydrology. We mapped these features using a GIS topographic model that delineates potential riverine wetlands based on regional flow accumulation and local topography of the stream channel (Smith et al., 2008), as derived from a hydrologically conditioned digital elevation model (DEM) at 3 arc-second (77m) resolution (Lehner et al., 2008).

ii. *Dense vegetation*: large patches of closely-spaced tall shrubs and trees, typically near oases, including Tamarisk (*Tamarix ramosissima*), Poplar (*Populus diversifolia)*, Elm and Saxaul. We mapped these features with a soil-adjusted total vegetation index (SATVI) (Marsett et al., 2006) derived from Landsat 5 TM satellite imagery (NASA, 2011) with acquisition dates between June 15 and September 28, 2011. The SATVI was developed specifically to measure above-ground biomass of aridlands vegetation. Dense vegetation in an arid desert setting produces distinct high SATVI values. We classified areas with high SATVI values as dense vegetation, and separated the results by likely water source or hydrology into patches occurring in either a) dry stream beds and wet depressions (described above) or b) spring-fed seeps.

iii. *Ephemeral water bodies*: we digitized the boundaries and point locations of 1,200 water bodies at map scale 1:200,000 through manual interpretation of the 2011 Landsat 5 TM satellite imagery described above.

iv. *Sand massives:* large areas of sand dunes that we digitized manually from 1:200,000 scale topographic maps. The unique hydrology of sand dunes often creates small wetlands that support distinct plant communities and habitat with high species diversity.

v. *Mountain valleys:* mapped as valley bottoms, per the landform classification (described below), in mountain steppe or rugged mountain vegetation, per the matrix-forming ecosystem classification.

3. Landforms. Matrix-forming ecosystem types form a heterogeneous, patchy mosaic of plant communities formed by topography, disturbance regimes and successional cycles. Within these ecosystem types, patterns of plant species composition generally follow topographic environmental gradients. To capture this ecological, environmental and genetic diversity, we stratified these widespread ecosystem types by landforms defined and mapped according to a cluster analysis of a topographic soil moisture index, insolation and terrain ruggedness, derived from a hydrologically conditioned DEM at 3 arc-second (77m) resolution (Lehner et al., 2008), as described in Table 1.

RESULTS

The GIS model maps 15 ecosystem types across 5 biogeographic zones, producing 67 unique combinations of biogeographic region and ecosystem type. Stratifying matrix-forming ecosystem types by landforms produces 193 unique combinations of biogeographic region, ecosystem type and landform. The source data and mapping methods are listed in Table 1 and the result is shown in Figure 2.

A validation using 285 field survey records collected in 2012 yielded an overall accuracy of 65%. These records were collected during three surveys in 1) Gobi-Altai Aimag, 2) Alashan Gobi Desert (Southern Ovorkhangai, Omnogobi around Gobi Gurvansaikhan

National Park, and Dundgobi) and 3) Eastern Gobi Desert (Eastern Omnogobi and Dornogobi). Most of the errors were misclassification of matrix-forming types, and specifically misclassification of true desert as semi-desert in Gobi-Altai Aimag and desert steppe as semi-desert in the Alashan Gobi Desert. The model performed best (80%) in the Alashan Gobi Desert. The error matrix is shown in Table 2.

DISCUSSION

This demonstrates a method for defining and mapping ecosystems across a large region based on limited survey data and globally-available datasets. As such, this type of GIS model can be developed and updated relatively quickly, and the results are appropriate to support landscape-level conservation planning as well as regional land use planning, research, surveys and monitoring. A key assumption is that it is possible to accurately predict and map the distribution of major vegetation types at a simple thematic (formation) level based on globally-available datasets measuring above-ground biomass, elevation and climate factors. The initial validation results appear to support this.

Ecological classification is an iterative process. Additional field validation is a critical next step to test and revise the model using a combination of methods and datasets, including 1) field surveys, 2) research plots established by several long-term rangeland studies, and 3) fine-scale vegetation maps developed for smaller areas within the Gobi Desert study area. The current model results can guide the spatial sampling design of field surveys that will inform future revisions.

All the patch-forming types defined and mapped by this model are groundwater-dependent systems that have high value for wildlife, livestock and people. The model result includes only large patches, due to the coarse spatial scale, and generally does not capture small water sources such as small oases or springs. These features have been mapped in existing 1:100,000 topographic maps, but are often ephemeral.

The model does not explicitly define or map Saxaul forest, which is a unique and productive habitat type and also groundwater-dependent. However, the ‘wet depression’ type may be a useful predictor of Saxaul forest occurring in areas with near-surface groundwater, based on descriptions of Saxaul ecology and site characteristics (Hilbig, 1995) and our field surveys. Saxaul forests have been delineated across Mongolia at a coarse scale for the National Atlas (Dorjgotov, 2009).

The model is based on relationships between spatial distribution of ecosystems and environmental gradients, and does not consider interactions between factors. Many multivariate methods exist for future iterations, including Classification and Regression Tree (CART) analysis and cluster analysis (e.g., hierarchical agglomerative clustering, fuzzy C-means clustering). These methods require field data well-distributed across the study area.

A similar ecosystem mapping and conservation planning process in Western and Central Mongolia will be complete in July 2015. We hope to produce one national GIS model, based on a multivariate model and field survey data, by combining and revising the results from the Gobi Desert region and Eastern, Central and Western Mongolia. That will require a major data mining and data sharing effort among the National University of Mongolia, the Mongolian Academy of Sciences, international researchers and non-governmental organizations (NGOs). One challenge will be classifying and mapping matrix-forming steppe types, including dry-, meadow- and forest-steppe, for which NDVI-derived biomass is not a reliable predictor of plant community composition. To map forest, a promising data source is a high-resolution global dataset predicting percent forest cover derived from Landsat TM (Hansen et al., 2013).

IMPLICATIONS

In the face of rapid development of natural resources, landscape-level biogeographic information is a critical reference for guiding protection, management and mitigation actions. Our results indicate that for arid lands, it is possible to map major vegetation and habitat types according to gradients of biomass and physical environmental factors using globally available datasets and in a relatively short time frame. This information can be the basis for landscape-level conservation planning that is a critical input to effective mitigation of mining and energy development, and can also inform land use planning, research and monitoring.

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Table 1. Terrestrial Ecosystem Classification: Source datasets and mapping methods. The ecosystem classification is organized as a hierarchy of (i) biogeographic zones, (ii) ecosystem types based on vegetation and (iii) landforms.

Biogeographic Regions

Djungarian Gobi, Gobi-Altay, Southern Gobi, Eastern Gobi (Chimed-Ochir et al. 2010)

Trans-Altai Gobi: N. Batsaikhan pers. comm. Digitized from Vostokova and Gunin (2005).

Ecosystems - Matrix-forming follow broad patterns of climate and elevation

barren *extreme arid* * *true desert* * - characteristic desert shrubs, Haloxylon and Rheaumaria, dominate. *semi desert* * - grasses appear, mixed with desert shrubs. *desert steppe* * - Stipa grasses dominate. steppe	• NDVI (MODIS 13A3, 1 km resolution) above ground biomass, growing season (June – Sept.), 11 year mean (2000-2011), classified according to 1,145 survey records of diagnostic plant communities. • elevation • landforms (see below)

dry steppe *: elevation < 1400

mountain steppe (pediments and gentle slopes): elevation > 1400 AND Landform = flat or gentle slopes

mountains rough terrain: elevation > 1400 AND Landform = hills or steep slopes

Ecosystems - Patch-forming follow finer-scale patterns of hydrology and soil types and microclimate.

Wet depressions: dry river beds or salty depressions with shallow water table following broad drainage patterns

small basins: drainage area < 1,000 km^2 large basins: drainage area > 1,000 km^2 mountain valleys: elevation > 1400 m	• DEM-derived topographic model (Smith et al. 2008) at 3-arc second (78m) resolution. • elevation

Dense vegetation: large patches of closely-spaced tall shrubs and trees, typically near oases, including Tamarisk, *Populus*, Elm and Saxaul

seeps: spring-fed dry river beds: shallow water table	• Soil-adjusted total vegetation index (SATVI) from Landsat 5 TM (July -September 2010 and 2011), resampled to 3 arc-second (78m) resolution. • DEM-derived topographic model (Smith et al. 2008) at 3 arc-second (78m) resolution.

ephemeral water bodies	digitized manually from Landsat 5 TM satellite imagery
sand massives	digitized manually from 1:200k topographic maps

Landforms capture finer-scale variation in plant communities following patterns of hydrology, soil types and microclimate. They are used here to stratify five matrix-forming ecosystem types (* labeled above).

rough steep N-facing rough steep S-facing hills N-facing hills S-facing upland low flat depression valley, water track	mapped by cluster analysis of three DEM-derived topographic indices at 3-arc second (78m) resolution: • Topographic moisture index (CTI; Moore et al. 1991) • Insolation (SolarFlux; Rich et al. 1995) • Terrain ruggedness (VRM; Sappington et al. 2007)

Table 2. Accuracy assessment results. Error matrix cross-tabulating observed and modeled ecosystem types to measure producer's accuracy, user's accuracy and overall accuracy based on data from three field surveys. Results varied by region:

1) Gobi-Altai Aimag: n = 94, overall accuracy = 59%.
2) Alashan Gobi Desert (Southern Ovorkhangai, Omnogobi around Gobi Gurvansaikhan National Park, and Dundgobi): n = 70, overall accuracy = 80%.
3) Eastern Gobi Desert (Eastern Omnogobi and Dornogobi): n = 121, overall accuracy = 61%.
4) combined: n = 285, overall accuracy = 65%.

	FIELD SURVEY													
	barren	extreme arid	true desert	semi desert	desert steppe	dry steppe	mountain steppe	wet depression	mountain valley	dense veg riparian	dense veg spring	sand massive	row total	user's accuracy
GIS MODEL														
barren														
extreme arid	1	2	2										5	40%
true desert		5	26	1	2								34	76%
semi desert			20	34	14	2							70	49%
desert steppe				9	54	8	1						72	75%
dry steppe					3								3	0%
mountain steppe					2	1	7						10	70%
wet depression	1		3	7	8			35					54	65%
mountain valley						2			3				5	60%
dense veg riparian					1			3		8			12	67%
dense veg spring								1		1	9		11	82%
sand massive					2							7	9	78%
column total	2	7	51	51	86	13	8	39	3	9	9	7	overall accuracy: 65%	
producer's accuracy	0%	29%	51%	67%	63%	0%	88%	90%	100%	89%	100%	100%		

Figure 1: Vegetation classification based on biomass of diagnostic plant communities.

This box plot shows the distribution of plant community survey records (n=1,145) across the range of 11-year mean NDVI values. Based on the distribution of several diagnostic plant communities, we chose thresholds of NDVI to define six classes of above ground biomass and map matrix-forming ecosystem vegetation types.

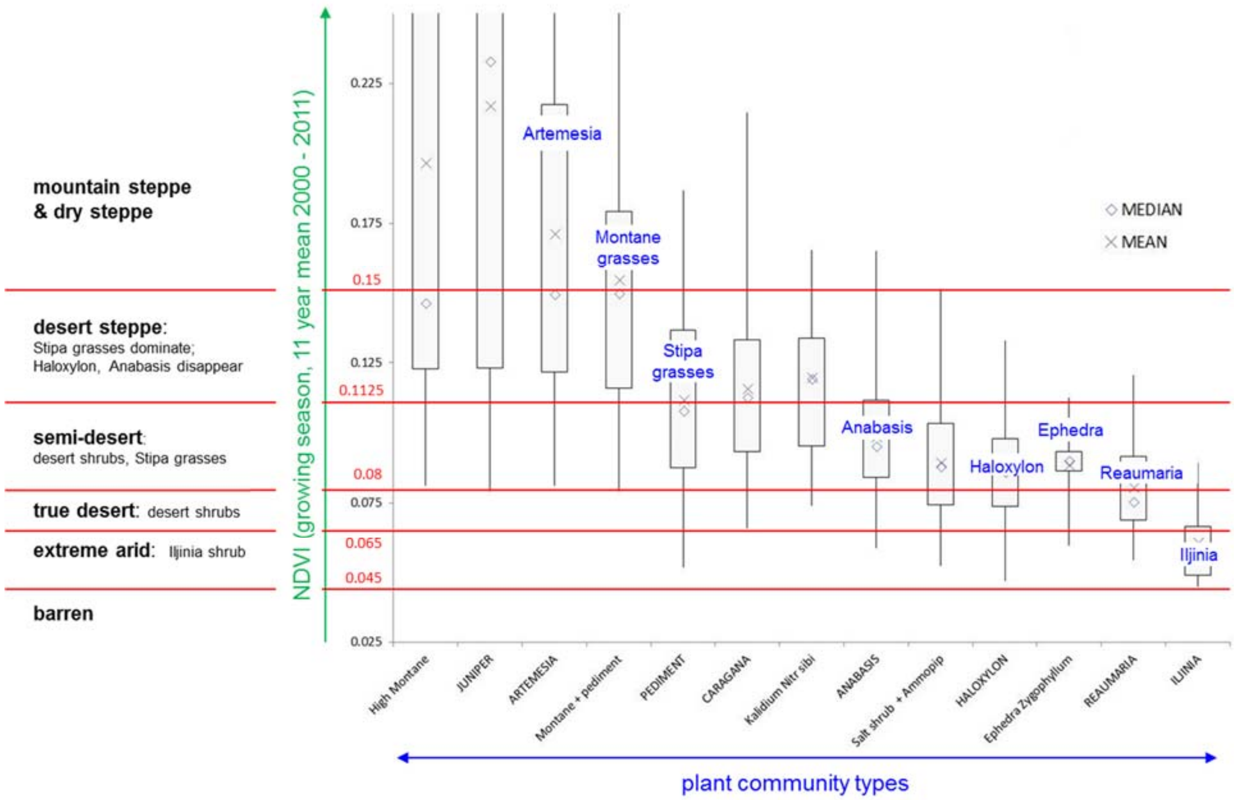

Figure 2: Terrestrial Ecosystem Classification

Map showing GIS model result.