Capacity building for
Mongolian Ministry of Environment and Green Development (MEGDT)
in relation to biodiversity and conservation in the southern Gobi Desert

Final Report: ANNEX D: Connectivity Report and GIS Database contents

Modeling habitat connectivity of a nomadic migrant
facing rapid infrastructure development:
Khulan habitat connectivity in the Southeast Gobi Region, Mongolia

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INTRODUCTION

The Mongolian Gobi region is part of the largest steppe ecosystem in the world that supports its historic wildlife assemblage, including long distance wildlife migrations (Batsaikhan et al. 2014), as well as traditional nomadic pastoralism. Globally, temperate grasslands and savannas such as the Central Asia steppes, the North American Great Plains and the South American Pampas are the most converted and least protected biome (Hoekstra et al. 2015). The Mongolian Gobi region currently supports 33 animals listed as nationally threatened or endangered (Clark et al. 2006, Terbish et al. 2006, Gombobataar et al. 2012), including the world's largest remaining populations of Khulan (Equus hemionus), Mongolian gazelle (Procapra gutturosa), Goitered gazelle (Gazella subgutturosa), wild Bactrian camel (Camelus ferus) and Siberian ibex (Capra sibirica) (Kaczensky et al. 2015, Mallon 2008a, Mallon 2008b).

However, the wildlife and pastoral livelihoods of this area are threatened by rapid growth in mining and related infrastructure. Mining development in the Gobi region is occurring faster than the national trend. In 2012, 24% of the area had been leased for exploration and another 32% available for lease (MMRE 2012). The largest active projects include the Nariin Sukhait / Ovoot Tolgoi coal mine, the Tavan Tolgoi (TT) coal mines and the Oyu Tolgoi (OT) copper mine. Though the direct impacts of mining on land and water are significant and can reach far beyond the mine site, an urgent threat to wide-ranging wildlife is created by transportation infrastructure and traffic to support mining operations that create barriers to movement (Ito et al. 2005, Ito et al. 2013, Kaczensky et al. 2011, Kaczensky et al. 2006, Olson 2012, Lkhagvasuren et al. 2011, Lkhagvasuren 2000).

Protected areas alone cannot effectively conserve the current populations of this region's iconic wide-ranging plains ungulates, including khulan or Asiatic Wild Ass (*Equus hemionus*), Mongolian gazelle (*Procapra gutturosa*) and Saiga Antelope (*Saiga tatarica*). In the deserts and grasslands of Central Asia, vegetation productivity is highly variable and irregular in time and space (von Wehrden et al. 2012, von Wehrden et al. 2010, Zhang et al. 2010, Yu et al. 2004, Fernandez-Gimenez and Allen-Diaz 1999). Steppe productivity and surface water availability varies spatially, seasonally and between years in response to precipitation. Nomadic migrants such as Khulan and Mongolian gazelle have evolved to track these dynamic resources, covering large distances to follow vegetation growth that follows precipitation (Mallon and Zhigang 2009, Mueller et al 2008, Mueller and Fagan 2008).

Khulan home ranges as high as 70,000 km^2 have been reported in the Southeast Gobi (Kaczensky et al. 2011a). Mongolian gazelle home range sizes range from 14,000 to 32,000 km^2 in the Mongolian Eastern Steppe (Olson et al 2010). Saiga migrations cover 200 – 1,000 km annually and also track productivity (Singh et al. 2010a). This dependence on long and shifting movements to access dynamic forage and water resources makes grassland ungulates vulnerable to habitat fragmentation and increases their exposure to hunting, livestock competition, and disease (Berger 2004), particularly during dzud events (extreme climate events, often a combination of summer and/or winter drought with deep snow or ice - Begzsuren et al., 2004). For example, during the 2015/2016 dzud, due to deep snow in parts of Mongolia, gazelle moved long distances to use disturbed habitat where gazelle had not been observed previously, and many died trying to cross railway fence (pers. comm. B. Lkhagvasuren). The most significant threat to Khulan and Mongolian gazelle in Mongolia is the loss of access to habitat and water due to barriers created by transportation infrastructure (Ito et al. 2013, Lkhagvasuren et al. 2011, Kaczensky et al. 2006) – either fences along borders and railways (Olson 2012, Kaczensky et al. 2011a, Ito et al. 2005, Lkhagvasuren 2000), or high traffic, as in the case of the Tavan Tolgoi coal road.

The viability of populations and movements of grassland ungulates have important implications for herders, other wildlife and rangelands in general. Wide ranging plains ungulates perform important ecological functions, including redistributing nutrients that may influence diversity patterns of plant communities (Mazancourt et al. 1998) and provide a prey base for predators and scavengers. Wild ungulates also represent an important food source for subsistence hunters (Olson 2008) and hold high cultural and aesthetic values (Kaczensky 2006, Chimedsengee et al. 2009).

The khulan is red-listed as near-threatened globally (Kaczensky et al. 2015), and 75% of the world's population is in Mongolia where it is regionally endangered (Clark et al. 2006). Khulan occur in three biogeographic regions across Southern Mongolia: the Dzungarian Gobi, the Transaltai Gobi and the Southeastern Gobi (Figure 1). Of these three sub-populations, the Southeastern Gobi subpopulation is the largest and also covers the longest migrations and largest individual home ranges, likely due to the high spatio-temporal variability of forage and water resources (Kaczensky et al. 2011a), and so is most vulnerable to barriers and habitat fragmentation. The fenced Ulaanbaatar-Beijing railway is a barrier to the east, disconnecting 17,000 km^2 of suitable habitat east of the railway (Kaczensky et al. 2011a). The fenced border with China is a barrier to the south. Mining development and transportation infrastructure in this region are expanding rapidly, including two parallel mining roads connecting the Tavan Tolgoi coal mines and the Oyu Tolgoi copper mine to the Gashuun Sukhait border crossing and lying between Small Gobi Strictly Protected Areas A and B, and a railway under construction between Dalanzadgad and Sainshand (see Figure 1). Effective mitigation of these barriers is critical to the viability of the Southeastern Gobi khulan population and is the focus of several studies and conservation efforts including Lkhagvasuren et al. (2011), Olson (2012), Huijser et al. (2013), Wingard et al. (2014), CMS (2015a, 2015b) and the traffic study in Annex E of this report.

PROJECT DESCRIPTION

The goal of this project is to build capacity of MEGDT and the research community to map and analyze wildlife movement and habitat connectivity, by developing the following:

1) Training in landscape modeling using Circuitscape software (McRae et al. 2013), described below, including a self-paced tutorial (translated in Mongolian). This training was delivered by Brad McRae, the developer of Circuitscape, in September 2016 to GIS and wildlife staff from MEGDT, Administration for Land Affairs, Geodesy and Cartography (ALAGAC), the Mongolian Academy of Science, the National University of Mongolia, National Meteorology Agency (NMA), Dornogovi Department of Environment and Tourism (ETD) and Department of Land Affairs and Urban Development (DLAUD), Khovd ETD and DLAUD, Khentii DLAUD and Altai Tavan Bogd National Protected Area (NPA). See Annex I for the tutorial document, a link to tutorial datasets and a list of participants in the September 2016 training.

2) A case study to demonstrate how existing GIS datasets may be used to model movement and habitat connectivity of khulan in the Southeast Gobi region using Circuitscape The results identify key data gaps, provide a first iteration spatial model others can expand and improve, and may guide data collection, field surveys and monitoring. The current model is based on expert opinion and not on actual animal movement data. Models must be validated and improved with the best available animal movement data from collar studies and/or field observations.

3) A national GIS database containing datasets that may be used or modified to represent habitat, human activities and infrastructure. These datasets are organized in a consistent raster environment, geographic projection and file format to support modeling spatial distributions of wildlife habitat and movement. Other datasets can be easily incorporated into this modeling environment.

Though the focus of the case study is khulan movement, the modeling methods and the National GIS database may support research and conservation of other wide-ranging species in Mongolia. However, different focal species have different movement abilities and habitat requirements and constraints and the current expert opinion models have limitations. Models must be validated and improved with the best available animal movement data from collar studies and/or field observations.

Connectivity conservation can mitigate the effects of habitat fragmentation by maintaining movement among disjunct patches, e.g., by promoting gene flow, population rescue, and colonization of vacant habitat (Crooks and Sanjayan 2006). Moreover, connectivity will be increasingly critical for maintaining adaptive capacity (e.g., Sexton et al. 2011) and facilitating species range shifts under climate change. For these reasons, conserving connectivity is the most-often recommended climate adaptation strategy (Heller and Zavaleta 2009). In the disaster prone ("dzud" and drought events) Gobi environment, the possibility for temporary evasive movements is of further importance (e.g. Kaczensky et al. 2011b).

Circuitscape models connectivity using electric circuit theory, treating landscapes as conductive surfaces and taking advantage of connections between circuit and random walk theories (McRae et al. 2008). It incorporates all possible pathways connecting movement sources and destinations, modeling flow of movement via low-resistance routes. The results highlight important movement pathways, particularly pinch points where the lack of alternate pathways means the loss of a small amount of habitat could disproportionately reduce connectivity.

Some recent examples of Circuitscape's use in conservation planning include:

- predicting where mitigating road impacts on connectivity would reduce wildlife mortality in France (Girardet et al. 2015) and Canada (Koen et al. 2014).
- Multispecies connectivity planning in Borneo (Brodie et al. 2015).
- Connectivity for pumas in Arizona and New Mexico, USA (Dickson et al. 2013).
- Large landscape planning across Ontario, Canada (Bowman and Cordes 2015).
- Connectivity prioritization for Gibbons (Vasudev and Fletcher 2015).
- Corridors for tigers in India (Joshi et al. 2013, Dutta et al. 2015).
- Connectivity for Amur leopards in China (Jiang et al. 2015).
- Trans-boundary conservation of Persian leopards in Iran, Turkey, Armenia, and Azerbaijan (Farhadiniaa et al. 2015).
- Multi-scale connectivity planning in Australia (Lechner et al. 2015).
- Project movements of nearly 3000 species in response to climate change across the Western Hemisphere (Lawler et al., 2013).

KHULAN CASE STUDY

METHODS: Modeling Steps and Study Design

The Study area is the Southeast Gobi region, shown in Figure 1, which supports the largest Mongolian subpopulation of khulan (Kaczensky et al. 2011a) and is undergoing rapid development of mines and supporting infrastructure, including railways and roads with high mining traffic, and other related changes in land use and human impacts.

STEP 1: Define type of connectivity to be modeled

Representing the habitat and movement of nomadic migrants, and specifically khulan, in a spatial model is challenging because khulan use large home ranges and movements are irregular, following forage and water resources that are highly variable in time and space, and knowledge of habitat use and the factors influencing movement is limited. Spatial datasets to represent habitat features and factors that influence movement are also limited. Therefore, it was necessary to narrow the focus of modeling to a specific habitat feature and season or life stage: movement between water sources, or water points, during summer drought periods.

STEP 2: Define what is being connected

Spatial data available to map water points is limited. We developed two datasets of locations of water points from two sources: water point surveys and hydric (wet) vegetation from a spatial model of terrestrial ecosystems. The locations identified by these two data sources vary significantly, and each dataset has unique advantages and disadvantages, as described below.

1. Water points mapped in surveys by Aimags and River Basin Authorities (RBAs):
    a. The Galba Oosh Dolood RBA survey in winter 2015, covering the southern part of khulan range in the Southeast Gobi.
    b. Dorngovi Aimag survey of springs (2011).
    c. Omngovi Aimag survey of springs (2011).

    These are locations of confirmed surface water, but the datasets are collected and managed independently by the Aimags and RBAs, so survey methods and dates vary. These datasets do not include attributes to identify which water points are stable or ephemeral, or which are available to wildlife. For example, wells with pumps are available only to herders who can use the pumps. Of the water points that provide surface water available to wildlife, we had no information to identify which are used by khulan.

2. Hydric (wet) vegetation in the desert: dense vegetation with high above-ground biomass, based on the soil-adjusted vegetation index (SAVI, Marsett et al. 2006) derived from Landsat TM imagery, and occurring in wet depressions with shallow groundwater, based on a DEM-derived topographic model. This dataset is part of a spatial model of terrestrial ecosystems developed for a regional conservation assessment of the Gobi region in Southern Mongolia (TNC, 2013).

We assume these patches of wet, dense vegetation indicate shallow groundwater, and larger patches indicate more stable shallow groundwater. However, many patches may not provide surface water to wildlife. As with water points, we had no information to identify which are used by khulan. One advantage of this dataset is that it has been mapped with consistent methods and at consistent spatial scale across khulan range in Southern Mongolia.

From these two sources, we developed two sets of locations of possible water source locations, as described below, and shown in Figure 2.

<u>Scenario A</u>: Water point surveys: To cover the Southeast Gobi study area, we first selected water points in the Galba Oosh Dolood RBA survey, which covers only the southern part of the study area. For the remaining area outside the RBA, we added locations from the Dorngovi and Omnogovi surveys. From this set, we selected locations that met the following criteria (n=184):

a. within 2km of hydric (wet) vegetation, assuming water points closer to the wet vegetation and wet depressions are more stable.
b. undisturbed:
    i. more than 5 km from Soum centers or Aimag centers, and
    ii. outside mine or petro leases.
c. within current Khulan range and a 10km buffer.

<u>Scenario B</u>: Hydric (wet) vegetation patches larger than 2 km^2 area, converted to point locations (n=238).

<u>STEP 3</u>: Assign resistance scores and create the resistance layer

Landscape resistance to movement is a measure of the relative difficulty, i.e. energetic cost, and/or mortality risk of movement, and is based on features that influence movement and movement habitat. To represent landscape resistance and calculate a resistance surface, we identified factors that affect khulan movement and calculated spatial metrics of the individual impact of each factor, as listed below. In calculating the resistance surface, resistance factors can be represented as impermeable barriers or as a continuous range of values with higher values indicating higher resistance. The resistance surface is a measure of the cumulative effects of these factors.

Terrain roughness (Figure 3a): Khulan prefer open, flat terrain (Kaczensky et al., 2011a), so topographic variation or ruggedness is an indicator of predation risk or avoidance behavior. To measure topographic ruggedness, we calculated two metrics from a digital elevation model (DEM): topographic slope and Vector Ruggedness Measure (VRM; Sappington et al. 2007). VRM is a measure of local topographic roughness measured with a circular moving window with radius = 760 meters. The DEM source was SRTM (Jarvis et al. 2008, Lehner et al. 2008) resampled from 3 arc-second to 425 meter resolution and projected to UTM 48 North.

- Slope: We classified areas with slope greater than 3 degrees as an impermeable barrier. Note that at 425m resolution, areas with 3 degree slope or higher in reality contain steeper slopes and therefore this roughly approximates the 5 degree slope threshold described as a barrier by Kaczensky et al. (2011a).

- Ruggedness (VRM): We calculated VRM and rescaled the range of values from 0 to 1. Higher values indicate greater resistance.

Proximity to population centers (Figure 3b): areas around population centers (Aimag centers, Soum centers, border crossings) are often overgrazed (Fernandez-Gimenez 2001), and hunting (Wingard and Zahler 2006) and predation and harassment by dogs (Young et al. 2012) are common. Singh et al. (2010b) found that selection of calving areas by Saiga is driven by avoidance of human settlements. To represent the effects of distance from population centers on habitat use and habitat suitability, we calculated inverse of euclidean distance from population centers to 5 km, with values decreasing from one at the edge of each population center to zero at 5km distance. The locations and spatial footprint of population centers came from three sources:

a. urban areas delineated in the National GNS Land Use GIS database (ALAGaC 2014).
b. border crossings digitized from a topographic maps (map scale 1:2 million; MAS 2009).
c. nighttime lights (NOAA 2011).

We chose the 5km distance threshold based on a review of wildlife responses to roads and infrastructure by Benitez-Lopez et al. (2010) who reported that many studies observed avoidance of infrastructure and roads at distances up to 5km.

Active mine leases in 2015 (MRA 2015): We treated whole lease areas as fenced and impermeable. In each lease, the fenced area is likely smaller than the lease area, but those GIS datasets are not publicly available. Wildlife will use areas close to fences (Petra Kaczensky pers. comm.), so we did not consider distance from leases as a resistance factor.

Herder household density (Figure 3c):

Livestock grazing can affect plant species composition (Fernandez-Gimenez and Allen-Diaz 2001) and may impact availability and quality of habitat for wildlife, through exclusion and competition (Wingard et al. 2011, Yoshihara et al. 2008, Campos-Arceiz et al. 2004), or by reducing palatable species (Gana Wingard pers comm.). Olson et al. (2011) found that Mongolian gazelle avoid areas near herder households, and high densities of herder households may create barriers to movement and limit access to forage. Hunting (Wingard and Zahler 2006) and predation or harassment by feral dogs (Young et al. 2011, Buuveibaatar et al. 2009) are also likely to increase with proximity to and density of herder households.

Seasonal herder household locations were developed by Centre for Policy Research (CPR, 2010). In Omnogovi, this dataset only separates seasons Summer/Autumn from Winter/Spring. Therefore, to represent Summer household density, we used all locations labelled Summer or Autumn. We calculated the focal sum of locations within a circular moving window with radius = 10 km.

Landscape Resistance Surface

The resistance surface is a measure of the cumulative effects of terrain roughness, proximity to population centers and herder household density, calculated as follows:

1. Terrain ruggedness (VRM), values rescaled by dividing each value by maximum value to produce a range of values from 0 to 1 (max).
2. Proximity to population centers (inverse of Euclidean distance up to 5km), values rescaled 0-1.

3. Herder household density in Summer/Autumn, 10km radius moving window, values rescaled 0-1.
4. Sum of three factors, multiplied by 100. The results is a range of resistance values from 1 to 760. See Figure 4.

In the resistance surface, areas outside the study area and several features inside the study are treated as impermeable:

1. slope > 3^{o} Note that at 425m resolution, areas with 3 degree slope or higher in reality contain steeper slopes and therefore this roughly approximates the 5 degree slope threshold described as a barrier by Kaczensky et al. (2011a).
2. footprints of population centers (Soum and Aimags, ALAGaC).
3. mine and petroleum leases that we assume are fenced.

STEP 4: Map connectivity areas

After a sensitivity analysis to test various combinations of habitat features and various methods for calculating the resistance surface, we designed the scenarios described in Step 2 and generated maps of modeled electric current or movement flow for each scenario with the resistance surface described in Step 3. The results for the two scenarios are shown in Figures 5 and 6. Circuitscape provides several modes for modeling flow between habitat points or patches, which are treated as electrical nodes. We chose the all-to-one mode, which iteratively calculates a movement flow map for each node, representing flow between the focal node and all other nodes, and finally synthesizes these results into a single map showing the sum of flow maps for all nodes.

RESULTS and DISCUSSION

Model Scenarios

Until inputs and model results are validated with movement data and/or field surveys, these results must be interpreted with caution. The accuracy and validity of model results depend entirely on the accuracy of source data representing habitat features and resistance factors, the methods for calculating the resistance surface and other decisions about model design. Our datasets representing water sources and resistance factors have significant gaps and limitations, as described later. However, our model results identify several areas of likely high movement and constrained movement that support observations and research by wildlife biologists, shown in Figure 7.

In the Southeast Gobi, scenarios A and B both predict movement in the following areas:

- the wide depression lying southwest to northeast between Gashuun Sukhait border crossing and Sainshand. This is a large area, over 20,000 km^2, that is well-used by khulan, likely because of relatively low human settlement (N. Batsaikhan pers. comm.), and that will be significantly impacted by the railway under construction between Sainshand and Dalanzadgad.
- The area between Small Gobi SPA A and B. The two SPAs were designated specifically to conserve habitat of four migratory large mammals: khulan, black-tailed gazelle, argali and ibex, and other

biodiversity representative of the Galba Gobi and Borzon Gobi (Myagmarsuren and Namkhai, 2010). Therefore, the area joining the two SPAs is important for maintaining habitat connectivity and movement, and an area of great conservation concern because it is bisected by the parallel mining roads and high traffic between the Tavan Tolgoi coal mines and the Oyu Tolgoi copper mine to the Gashuun Sukhait border crossing. Mining traffic on these roads has significantly reduced khulan movements, and in particular across the Tavan Tolgoi coal road.

- Border zones, particularly between Hangi and Zamyn-Uud border crossings along the Southern border of Dornogovi Aimag.

Scenario A (Figure 5) predicts highest and most constrained movement between Small Gobi SPA A and B, as discussed above. The habitat points in Scenario B are surveyed water points that may under-represent water sources in northern part of study, and contain few locations east of the railway.

Scenario B (Figure 6) identifies two large areas of possible movement along the UB-Beijing railway Northwest and Southeast of Sainshand. That could be achieved simply by removal of sections of fence at locations away from population centers following methods described by Olson (2012), would re-connect 17,000 km^2 of suitable khulan habitat east of railway (Kaczensky et al., 2011a). Scenario B also predicts high use of Zagiin Us Nature Reserve and possible E-W movement north of the Nature Reserve, though these areas are at the northern edge of current khulan range. The habitat points in Scenario B are based on wet vegetation and may under-represent water sources in southern part of the Southeast Gobi study area. However, because the habitat points include 20-30 locations east of the UB-Beijing railway, the model results may be useful to suggest areas where khulan would cross the railway if not for the railway fences.

<u>Data gaps and limitations</u>

The water points datasets in Scenarios A and B were developed from two different sources with different spatial pattern and produced different model results. These datasets did not include information to identify which locations have water available for wildlife, which are ephemeral or more stable, or which are used by khulan.

Summer herder household density was the most influential factor in the resistance surface, far more than terrain, which is relatively gentle across the Southeast Gobi, and proximity to population centers, which affect only a small fraction of the study area. Therefore, summer herder household density was a primary driver of model results. Our dataset representing summer household locations included both summer and autumn locations, so may over-represent the area and magnitude of effects on khulan habitat use and movement.

Wildlife including khulan, Mongolian gazelle and Saiga avoid areas of high herder household density and other human activities (Kaczensky et al., 2011a; Olson et al., 2011; Singh et al., 2010b). However, herder household locations are seasonal, and avoidance behavior may also vary by season.

The effects of population centers on habitat use and quality including habitat avoidance, rangeland degradation and competition with livestock. In calculating the spatial extent of these cumulative impacts, we chose a maximum distance of 5km. The pattern of impacts from urban centers most likely extends further than 5km.

Roads and railways are not factors in the landscape resistance index. We did not include roads as a resistance factor because the effect of roads on khulan movements varies widely and depends largely on traffic volume, and existing GIS datasets for roads are incomplete and datasets for traffic volumes are unavailable. The existing fenced railway is an effective barrier to khulan movements. To model possible areas of movement across the railway corridor if fences were removed, we did not include the fenced railway as a factor in the resistance surface.

Future modeling, research and conservation will benefit from:

1. Improved data for water sources used by khulan, from field surveys and collar studies. Those data would include locations, and also information about seasonal and diurnal use. Some water sources used frequently by people and livestock during daytime are used by khulan at night. One example is Hatanbulag in Dornogovi Aimag (B. Lkhagvasuren pers. comm.). Similarly, some water sources may only be used seasonally, and that information could inform actions to improve access and minimize conflict or competition between wildlife and livestock. Datasets containing the locations of water sources should be managed carefully to prevent misuse by illegal hunters (pers. comm. B. Lkhagvasuren).
2. A more accurate and complete delineation of roads and infrastructure in a publicly-available dataset.
3. Estimates and monitoring of traffic volumes.
4. Research regarding how water availability varies with climate, specifically precipitation.
5. Improved data for locations of pastures and herder households by season. The database of seasonal locations compiled by CPR (2010) is a valuable resource, and should be regularly updated.
6. Research regarding khulan responses to herder households, human settlements and human land use, including avoidance distances and avoidance behavior by season.

<u>Recommendations for future modeling</u>

The focus of this modeling study was movements restricted to one habitat feature (water sources) during one season or life stage (summer drought periods). Other important habitat resources, life stages and factors affecting movement include:

- Water sources in other seasons. Water dependence is higher in spring and in winters without snow (Petra Kaczensky pers. comm.).
- Winter forage (Petra Kaczensky pers. comm.) .
- Sand massives: unique plants and ephemeral water sources (pers. comm. N. Batsaikhan).
- Deep snow: During the 2015/2016 dzud, due to deep snow in parts of Mongolia, gazelle moved long distances to use disturbed habitat where gazelle had not been observed previously. Many gazelle died trying to cross railway fence (pers. comm. B. Lkhagvasuren).
- The landscape resistance calculation could be modified to consider forage and water availability. For example, very dry true desert and semi-desert could be included in the resistance surface to indicate areas of higher resistance, i.e. higher energetic cost and lower habitat suitability. (pers. comm. N. Batsaikhan).

The spatial extent was the Southeast Gobi region, which supports one of the three Mongolian sub-populations of khulan. Expanding the spatial extent across Southern Mongolia would be useful to identify barriers and pinch points between the three subpopulations described by Kaczensky et al (2011a), and specifically between the Southeast Gobi study area and khulan range in Central and Western Omnogobvi and the Trans-Altai Gobi subpopulation.

We connected pairs of water points within fixed distances of one another. In each scenario, we treated all water points as having equal weight, but the model also allows for points or patches with differing characteristics to be connected with differing amounts of flow (e.g., more flow between higher quality patches). For example, it's possible to model greater flow between water points known to be used by khulan, or with less human disturbance, or that are known to persist in drought years.

Circuitscape can also be used to connect patches, such as protected areas, calculate pairwise effective distances between points or patches (giving a measure of their isolation from one another), and/or connect present and projected future ranges under climate change (e.g., Lawler et al. 2013). Genetic data are often used to parameterize and/or validate Circuitscape models (e.g., Yumnam et al. 2014), or to test for the effects of barriers on population connectivity in conjunction with Circuitscape (e.g., Blair et al. 2012, Sackett et al. 2012).

New hybrid methods are taking advantage of both circuit and least-cost methods. In their tiger study, Dutta et al. (2015) combined least-cost corridors and Circuitscape to map the most important and vulnerable connectivity areas connecting tiger reserves. And in their work on invasive mosquitoes, Medley et al. (2014) found that circuit and least-cost-based analyses complemented each other, with differing strengths at different movement scales and in different contexts. Using the two models in concert gave the most insight into mosquito movement and spread. Other papers that combine methods, taking advantage of different strengths for different processes and scales, include Rayfield et al. (2015), Lechner et al. (2015), and Fagan et al. (2016).

CONNECTIVITY CONSERVATION RESOURCES

Examples of successful connectivity conservation in policy and practice:

Pronghorn Migration Corridor**:** A Pronghorn (*Antilocapra americana*) Migration Corridor was recently designated in the Western United States of by a consortium of Federal and State agencies, NGOs and private land owners. This protects a 150 mile (270 km) migration corridor across an area of mixed public and private lands that has experienced rapid growth of oil and gas development and related roads and fences. On Federal and State lands, the designation specifically requires that future infrastructure projects and management plans be compatible with Pronghorn migration (USFS 2008; Berger and Cain, 2014). See http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev3_063055.pdf

The Western Governors Association Crucial Habitat and Corridors Initiative**:** In the Western United States, the Western Governors Association (WGA) was formed in 1984 to represent the governors of 19 states and coordinate regional efforts to develop public policy, research, data sharing and public education. Through a Crucial Habitat and Corridors Initiative, The WGA Wildlife Council has developed tools to identify and conserve crucial wildlife habitat and corridors and inform land use planning. The Crucial Habitat Assessment Tool (CHAT) is managed by the Western Association of Fish and Wildlife Agencies: http://www.westgov.org/wildlife-corridors-and-crucial-habitat.

Washington Wildlife Habitat Connectivity Working Group is a partnership representing government agencies, organizations, tribes, and universities in Washington State, US. This partnership produces tools and analyses that identify opportunities and priorities to provide habitat connectivity in Washington and surrounding habitats, including the Washington Connectivity Map (http://waconnected.org). This has informed Federal and State land management and infrastructure planning, including Federal Bureau of Land Management to Environmental Impact Statements (EISs) and management plan revisions; transportation corridors and mitigation strategies for highway improvement projects; and statewide electric transmission lines.

Infra Eco Network Europe (IENE): http://www.iene.info
including the handbook:
http://www.iene.info/wp-content/uploads/COST341_Handbook.pdf

EU Green Infrastructure Strategy: http://ec.europa.eu/environment/nature/ecosystems/index_en.htm

Jecami: analysing and mapping ecological connectivity online:
http://www.alpine-ecological-network.org/information-services/mapping-services

The Norwegian Institute of Nature (NINA) renewable reindeer project and their special issue in Journal of Animal Ecology, see http://www.nina.no/english/Research/Projects/Renewable-Reindeer

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Aune, K., Beier, P., Hilty, J., & Shilling, F. (2011). Assessment and planning for ecological connectivity: a practical guide. Wildlife Conservation Society. Bozeman, Montana. Available online:
http://www.wcsnorthamerica.org/Admin-Plus/Docustore/Command/Core_Download/EntryId/7292.aspx

Mitigation of Road Barriers

Van der Ree et al. (2015) have recently produced the Handbook of road ecology, a comprehensive collection of recent case studies, research and other resources that represent the current science and best practices to mitigate landscape fragmentation by roads.
http://www.wiley.com/WileyCDA/WileyTitle/productCd-1118568184.html

Connectivity Modeling Resources

CIRCUITSCAPE: http://www.circuitscape.org/

Core areas and resistance layers: Gnarly Landscape Utilities
Least-cost corridors: Linkage Mapper
Circuit theory: Circuitscape
Pinchpoints within corridors and restoration opportunities: Linkage Mapper

Beier P, Spencer W, Baldwin RF, McRAE BR. Toward best practices for developing regional connectivity maps. Conservation Biology. 2011 Oct 1;25(5):879-92.
Available online:
http://consbio-static.s3.amazonaws.com/media/publications/files/Beier_etal_2011_RegionalConnectivityMaps_2.pdf

GIS tools and information for designing wildlife corridors
http://www.corridordesign.org/

Conservation Corridor blog
http://www.conservationcorridor.org/

Figure 1: Khulan range and transportation infrastructure in the Mongolian Gobi-Steppe Ecosystem.

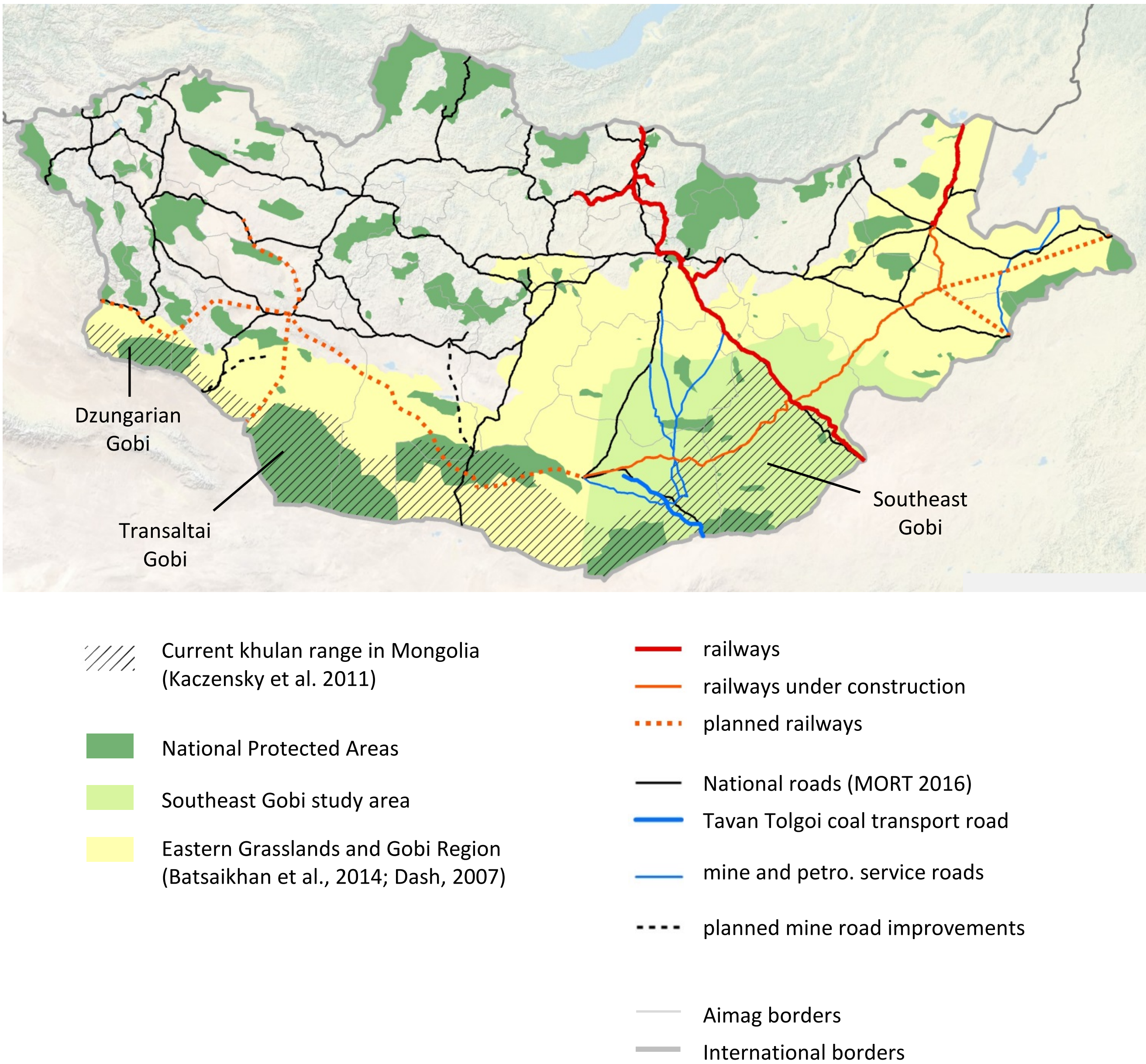


Figure 2: Locations of water sources across the Southeast Gobi region, from two sources: A) water point surveys by Galbo-Oosh Dolood River Basin Authority, Dorngovi Aimag and Omnogovi Aimag, and B) predicted by hydric (wet) vegetation from a spatial model of terrestrial ecosystems in the Southern Mongolia Gobi Region.

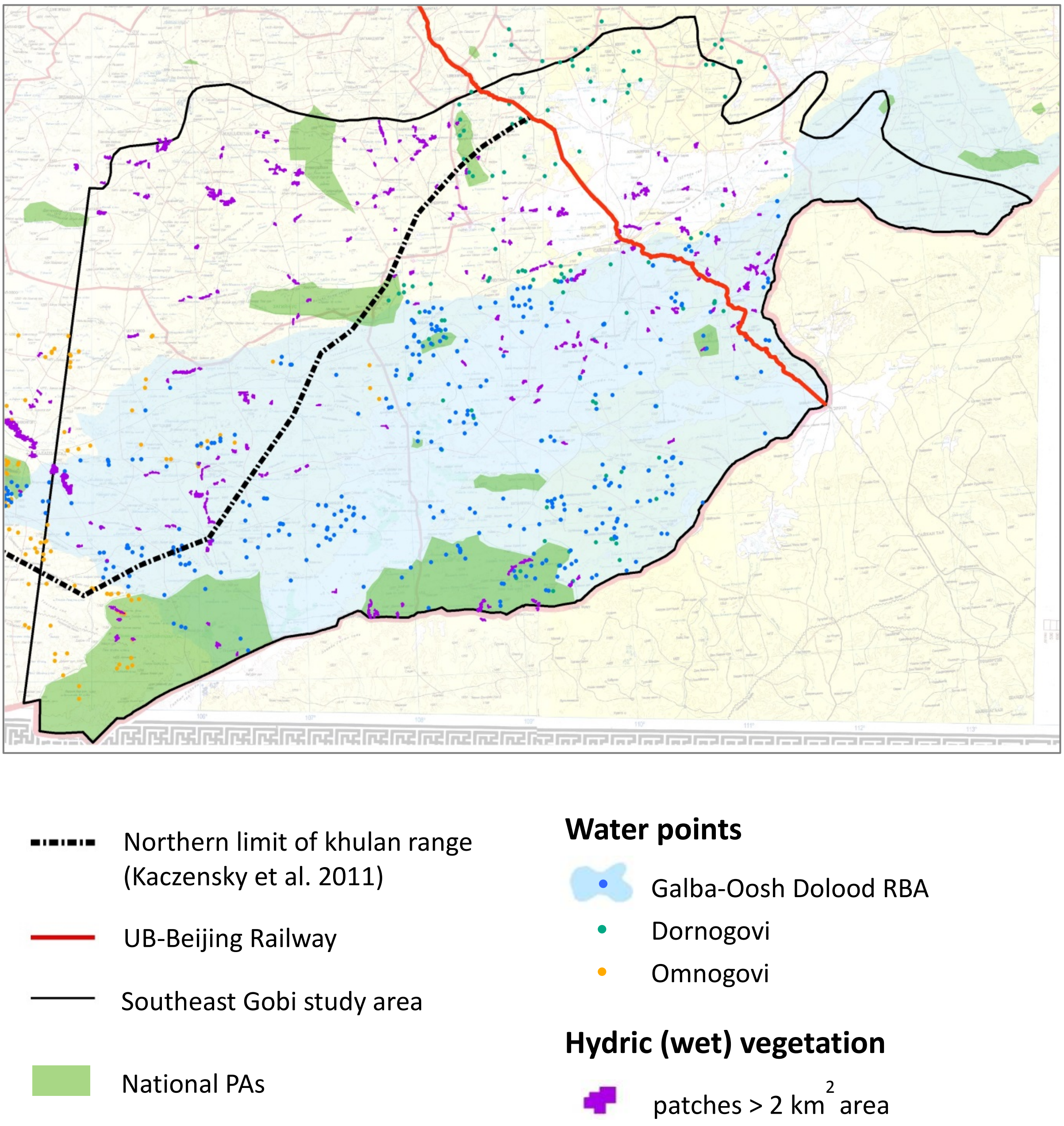


Figure 3: Factors representing resistance to movement: a) Terrain roughness (Vector Ruggedness Measure); b) proximity to population centers; c) herder household density in summer and autumn.

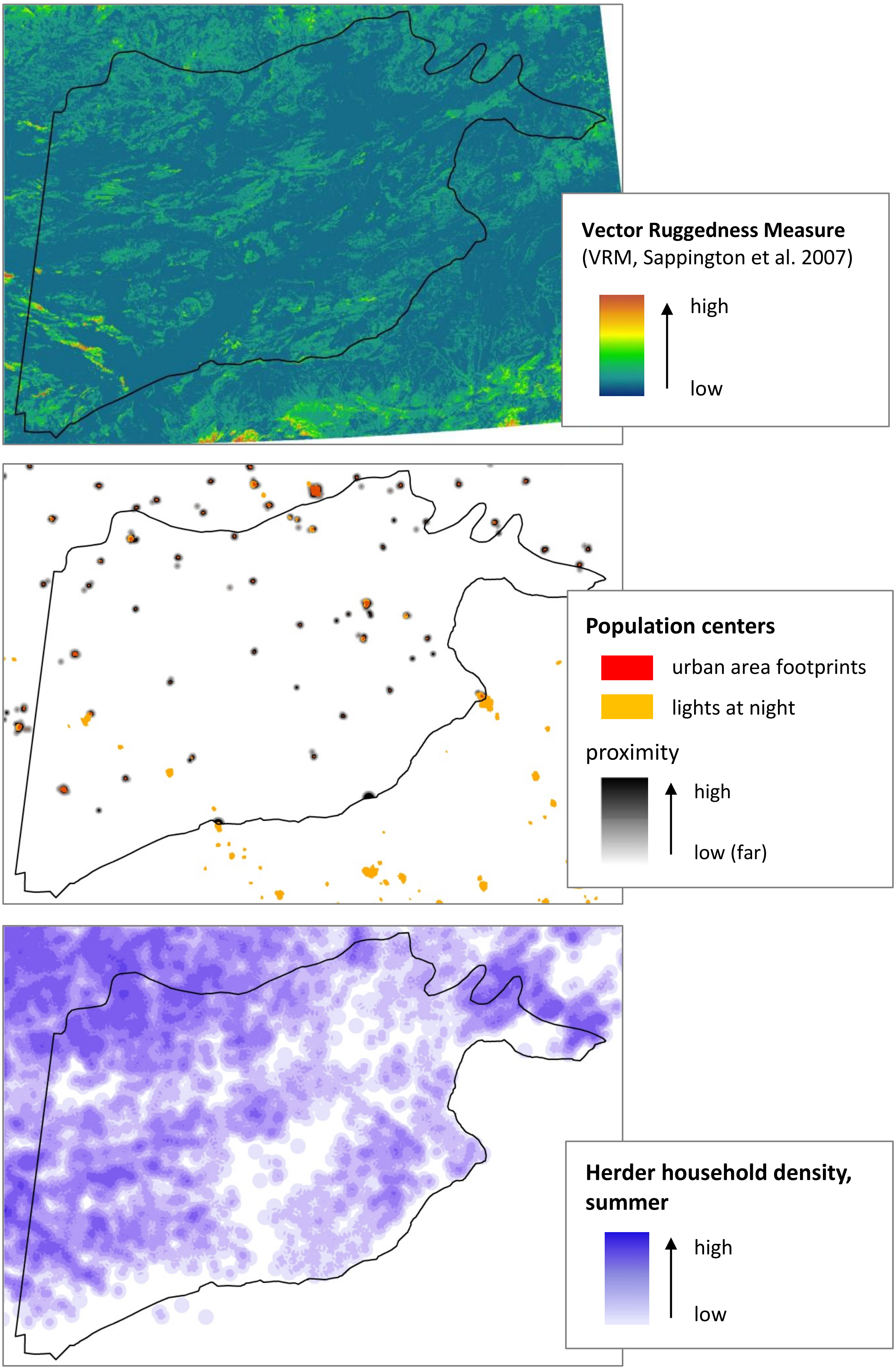


Figure 4: Landscape resistance to movement, an index of cumulative effect of terrain roughness, proximity to population centers and herder household density.

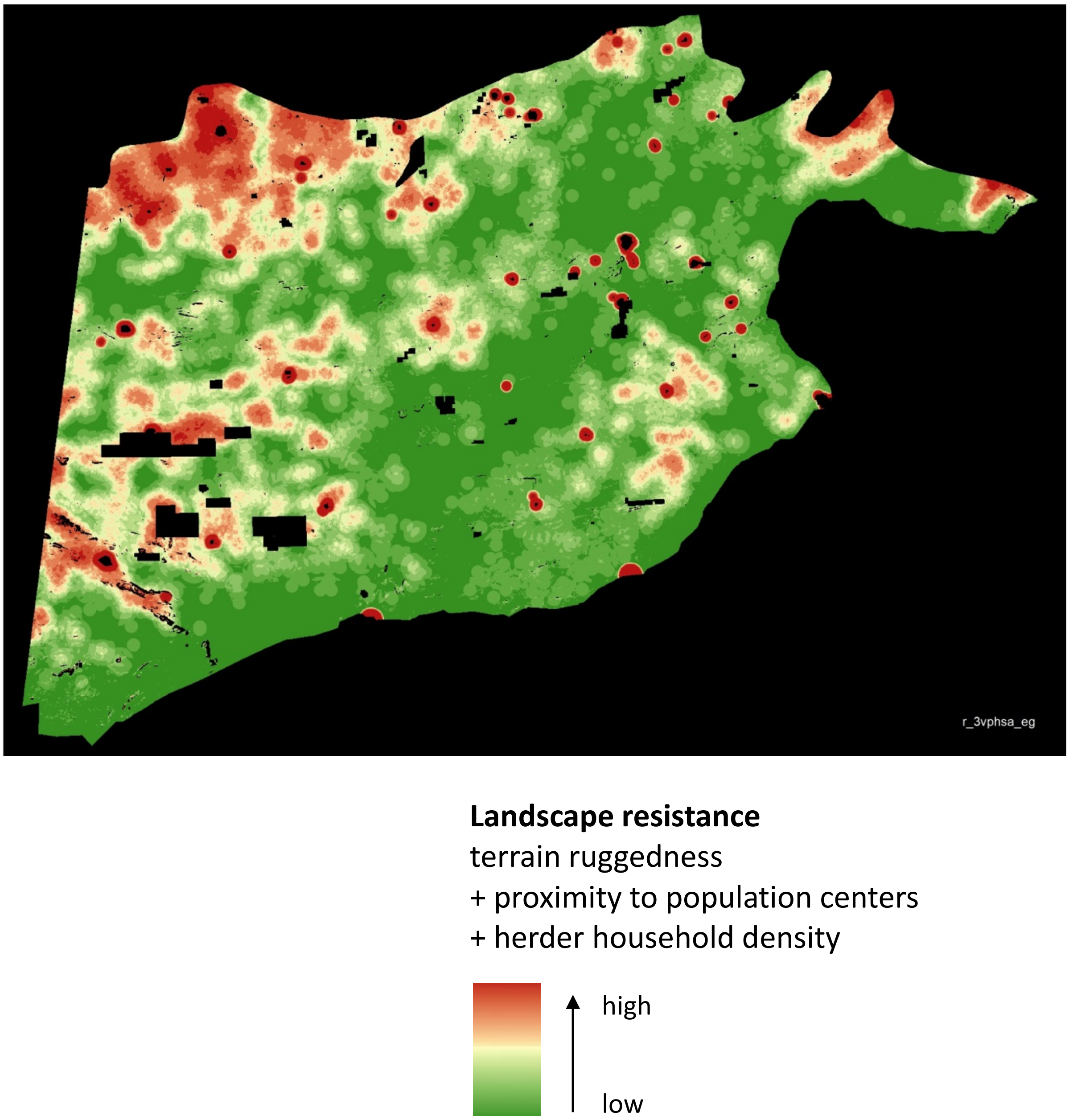
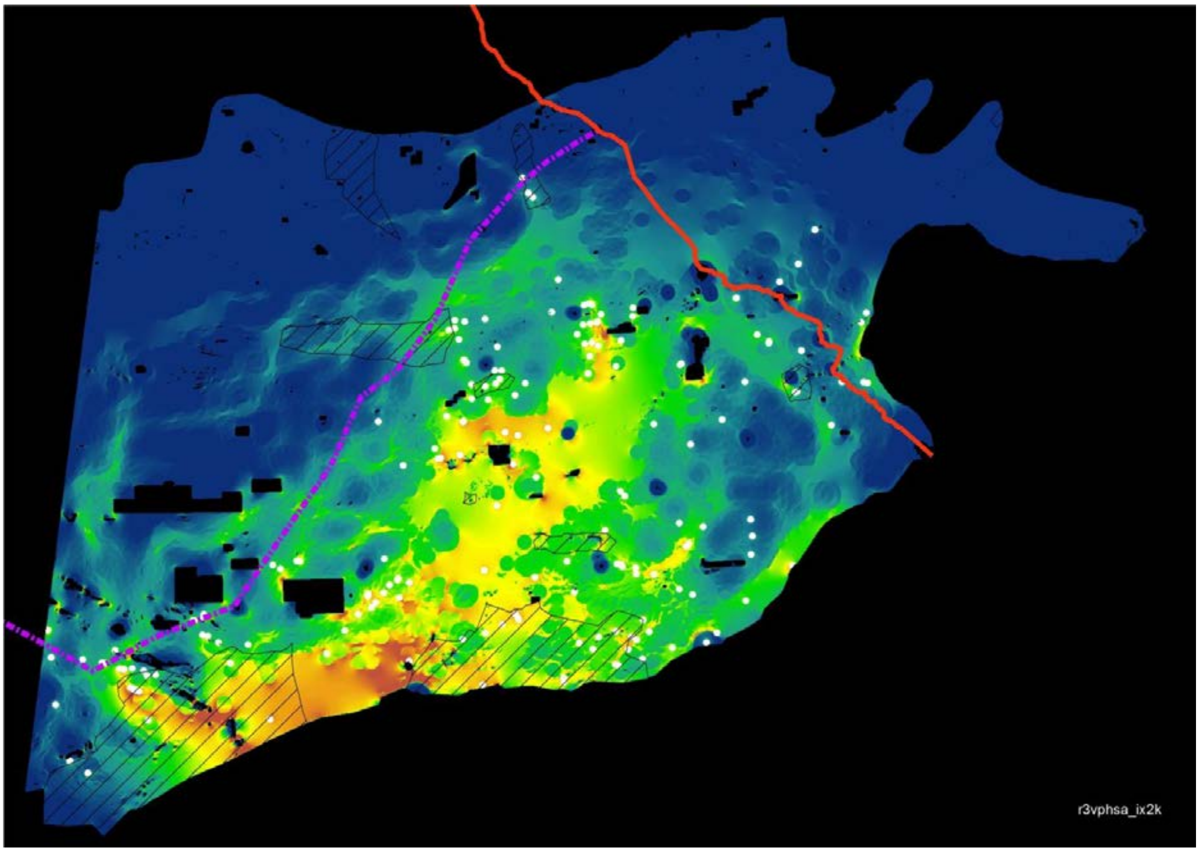


Figure 5: Scenario A: Southeast Gobi Circuitscape movement flow map. Water sources are water points from surveys by Galba-oosh Dolood RBA, Dorngovi Aimag and Omnogovi Aimag (n=184). Until inputs and model results are validated with movement data and/or field surveys, these results must be interpreted with caution.



UB-Beijing railway

Northern limit of khulan range (Kaczensky et al. 2011)

National PAs

water points

- within 2km of wet depressions
- undisturbed
- within khulan range

Circuitscape movement flow

high

low

Figure 6: Scenario B: Southeast Gobi Circuitscape movement flow map. Water sources are hydric (wet) vegetation patches larger 2 km^2 area (n=238). Until inputs and model results are validated with movement data and/or field surveys, these results must be interpreted with caution.

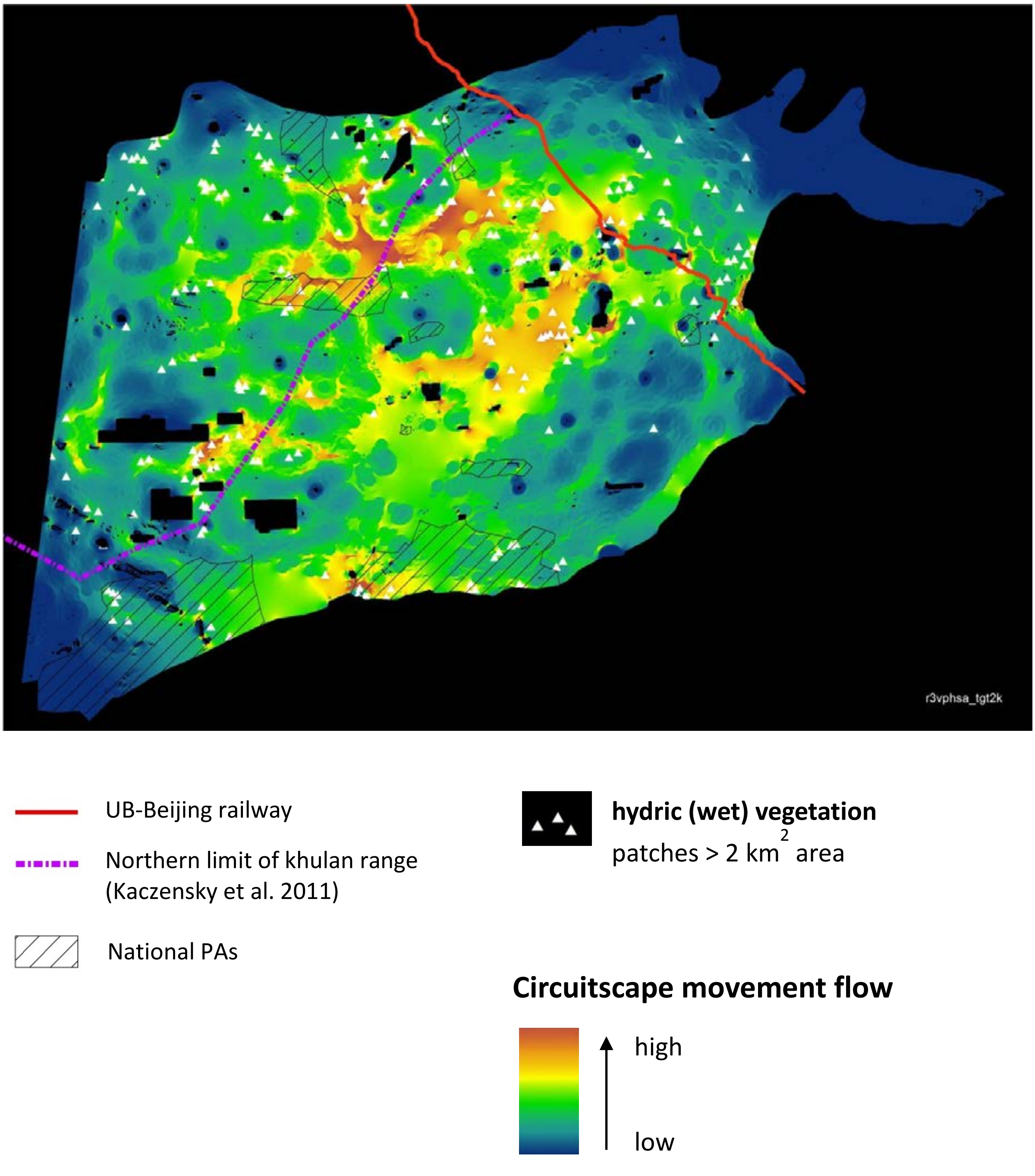
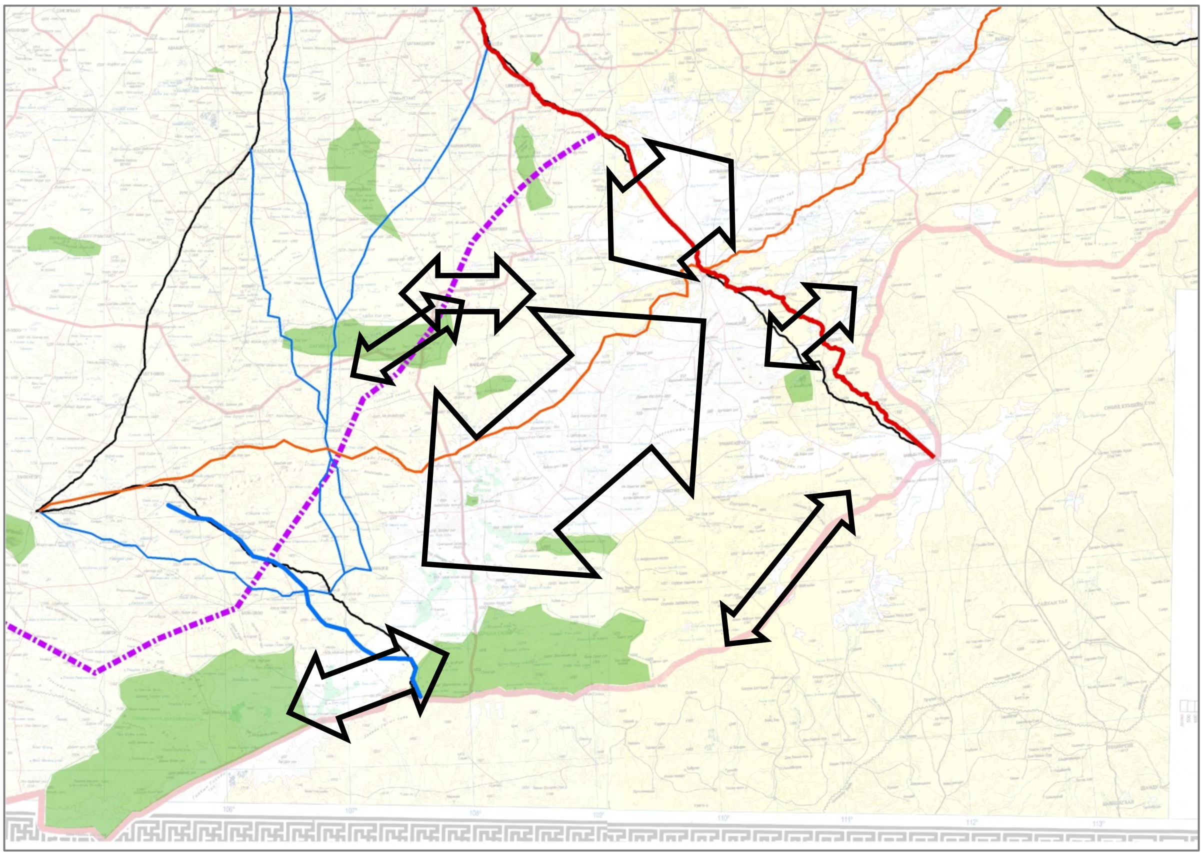


Figure 7: Areas of high khulan movement during summer drought periods, according to model scenarios. Until inputs and model results are validated with movement data and/or field surveys, these results should be interpreted with caution.



Northern limit of khulan range (Kaczensky et al. 2011)

National Protected Areas

UB - Beijing railway

railways under construction

National roads (MORT 2016)

TT coal transport road

mine service roads (Oyu Tolgoi ESIA 2012)

GIS database structure and contents

This GIS database contains datasets that may be used or modified to represent habitat, human activities and infrastructure. These datasets are organized in a consistent raster environment, geographic projection and file format to support modeling spatial distributions of wildlife habitat and movement. The database is available on request from MEGDT and TNC Mongolia Program.

GIS projection: WGS_1984_UTM_Zone_48N (WKID: 32648)

Raster resolution: 85m or 425m to match the resolution and grid environment of SRTM products at 3 and 15 arc-second resolution projected to UTM 48 North.

Raster file format: img (ERDAS Imagine)

	\PATH\ file name	description	resolution	source citation	method notes
	\TOPO				
1.	hy_dem3s_u48	DEM	85 m	NASA/JPL (2005); Lehner et al. (2008)	3 arc-seconds in WGS84 DD projected to UTM 48 north and resampled to 85m
2.	hy_dem15s_u48	DEM	425 m	NASA/JPL (2005); Lehner et al. (2008)	15 arc-seconds in WGS84 DD projected to UTM 48 north and resampled to 425m
3.	hy_slp3s_1ki	Slope, degrees * 1000	85 m		derived from (1.) DEM, ESRI ArcGIS Slope
4.	hy_slp15s_1ki	Slope, degrees * 1000	425 m		derived from (2.) DEM, ESRI ArcGIS Slope
5.	vrm_3s_1ki	Vector Ruggedness Measure	85 m	Sappington et al. (2007)	derived from (1.) DEM
6.	vrm_425_1ki	Vector Ruggedness Measure	425 m	Sappington et al. (2007)	derived from (2.) DEM
	\FOREST				
7.	tc_rs85_u48	percent forest cover (0-100)	85 m	Hansen et al. (2013)	3 arc-seconds WGS84 DD projected to UTM 48 north and resampled to 85m
8.	tc_rs425_u48	percent forest cover (0-100)	425 m	Hansen et al. (2013)	15 arc-seconds WGS84 DD projected to UTM 48 north and resampled to 425m
9.	t01_rs85_u48	forest cover: forest = 1, non-forest = 0	85 m	Hansen et al. (2013)	3 arc-seconds WGS84 DD projected to UTM 48 north and resampled to 85m
10.	t01_rs425_u48	forest cover: forest = 1, non-forest = 0	425 m	Hansen et al. (2013)	15 arc-seconds WGS84 DD projected to UTM 48 north and resampled to 425m
11.	dm_rs85_u48	data mask: water = 2	85 m	Hansen et al. (2013)	3 arc-seconds WGS84 DD projected to UTM 48 north and resampled to 85m
12.	dm_rs425_u48	data mask: water = 2	425 m	Hansen et al. (2013)	15 arc-seconds WGS84 DD projected to UTM 48 north and resampled to 425m

	\PATH\ file name	description	resolution	source citation	method notes
	\ECOSYSTEMS				
13.	tes_east	Eastern Grasslands terrestrial ecosystem classification	85 m	TNC (2011)	see E Grasslands TES metadata.pdf
14.	tes_gobi	Gobi Region terrestrial ecosystem classification	85 m	TNC (2013)	see Gobi TES metadata.pdf, P Mon Ranglands Gobi ecosystems.pdf
15.	tes_west	West & Central terrestrial ecosystem classification	85 m	TNC (in prep)	see West Central TES metadata.pdf
16.	river_wetland	riverine wetlands and wet depressions	85 m	WWF and TNC (2014)	see riverine wetland model.pdf, WWF report MEGD2014K7.pdf
	\LANDFORMS				
17.	landform_east	Eastern Grasslands landforms classification	85 m	TNC (2011)	see E Grasslands TES metadata.pdf
18.	landform_gobi	Gobi Region landforms classification	85 m	TNC (2013)	see Gobi TES metadata.pdf
19.	landform_west	West & Central landforms classification	85 m	TNC (in prep)	see West Central TES metadata.pdf
	\PORTFOLIO				
20.	NPA_2015_g	National Protected Areas, 2015	425 m	MEDGT (2015)	
21.	TNC_portfolio	TNC National Portfolio, 2016	425 m	TNC (2011, 2013, in prep)	
22.	WWF_proposed	WWF Proposed Protected Areas, 2010	425 m	Chimed-Ochir et al. (2010)	
	\DISTURBANCE\ HERDER_HOUSEHOLDS				See herder household locations.pdf
23.	fs5k_SuAu_rs	herder household density, summer/autumn, focal sum @ 5km radius *	425 m	CPR (2010)	ESRI ArcGIS Focal Statistics
24.	fs10k_SuAu_rs	herder household density, summer/autumn, focal sum @ 10km radius *	425 m	CPR (2010)	ESRI ArcGIS Focal Statistics
25.	fs5k_WiSp_rs	herder household density, winter/spring, focal sum @ 5km radius *	425 m	CPR (2010)	ESRI ArcGIS Focal Statistics
26.	fs10k_WiSp_rs	herder household density, winter/spring, focal sum @ 10km radius *	425 m	CPR (2010)	ESRI ArcGIS Focal Statistics
27.	e5i01_WiSp	herder household proximity, winter/spring, inverse of euclidean distance to 5km	425 m	CPR (2010)	ESRI ArcGIS Euclidean Distance
28.	h_WiSp_e5f5rs	winter/spring proximity (e5i01_WiSp) + density (fs5k_WiSp_rs) *	425 m		
29.	h_WSef_SAf_rs	herder household index, all seasons, proximity + density = h_WiSp_e5f5rs + fs10k_SuAu_rs *	425 m		
30.	h_WSf_SAf_rs	herder household index, all seasons, density = fs5k_WiSp_rs + fs10k_SuAu_rs *	425 m		
	\DISTURBANCE\ MINE_PETRO				
31.	minepetr_act	active mineral and petroleum leases	425 m	MRA (2015)	
32.	minpet_ei5k01	proximity (inverse of euclidean distance to 5km)	425 m		ESRI ArcGIS Euclidean Distance

	\PATH\ file name	description	resolution	source citation	method notes
	\DISTURBANCE\ POPULATION_CENTERS				
33.	ur_hi	High impact urban development (industrial, residential) = 1	425 m	ALAGaC (2014)	
34.	ur_hi01	High impact urban development (industrial, residential) = 1, no data = 0	425 m	ALAGaC (2014)	
35.	ur_md	Medium impact urban development (all types) = 1	425 m	ALAGaC (2014)	
36.	ur_md01	Medium impact urban development (all types) = 1, no data = 0	425 m	ALAGaC (2014)	
37.	ur_5k_sum	density(high impact) + density(all) + proximity(high impact) + proximity(all) *	425 m		
38.	border_x_g	border crossings = 1	425 m		digitized from topographic maps
39.	border_x_01	border crossings = 1, no data = 0	425 m		digitized from topographic maps
40.	bx_eu10kinv01	proximity (inverse of euclidean distance to 10km) *	425 m		ESRI ArcGIS Euclidean Distance
41.	nlite_15s_rs1	Nightime Lights *	425 m	NOAA (2011)	
42.	ur_max	Population Index = Max (ur_5k_sum, bx_eu10kinv01, nlite_15s_rs1) *	425 m		
	\DISTURBANCE\ TRANSPORTATION				
43.	roadstate_g	State roads = 1	425 m	MORT (2016)	
44.	t_rd1_01	State roads = 1, nodata = 0	425 m	MORT (2016)	
45.	t_rd1_e3i01	State roads proximity (inverse of euclidean distance to 3km) *	425 m		ESRI ArcGIS Euclidean Distance
46.	t_rd1_e5i01	State roads proximity (inverse of euclidean distance to 5km) *	425 m		ESRI ArcGIS Euclidean Distance
47.	t_rd1_f5rs	State roads density (focal sum, radius = 5km) *	425 m		
48.	t_rd2_g	State and Local roads = 1	425 m	MORT (2016)	
49.	t_rd2_01	State and Local roads = 1, nodata = 0	425 m	MORT (2016)	
50.	t_rd2_e3i01	State and Local roads, proximity (inverse of euclidean distance to 3km) *	425 m		ESRI ArcGIS Euclidean Distance
51.	t_rd2_e5i01	State and Local roads, proximity (inverse of euclidean distance to 5km) *	425 m		ESRI ArcGIS Euclidean Distance
52.	t_rd2_f5rs	State and Local roads, density (focal sum, radius = 5km) *	425 m		
53.	rway_g	Railways = 1	425 m	MORT (2016)	
54.	rway_01	Railways = 1, nodata = 0	425 m	MORT (2016)	
55.	rway_e5i01	Railways, proximity (inverse of euclidean distance to 5km) *	425 m		
56.	t_rd2rr_g	All transportation = 1	425 m	MORT (2016)	
57.	t_rd2rr_01	All transportation, nodata = 0	425 m		
58.	t_rd2rr_e3i01	All transportation, proximity (inverse of euclidean distance to 3km) *	425 m		ESRI ArcGIS Euclidean Distance
59.	t_rd2rr_e5i01	All transportation, proximity (inverse of euclidean distance to 5km) *	425 m		ESRI ArcGIS Euclidean Distance
60.	t_rd2rr_f5rs	All transportation, density (focal sum, radius = 5km) *	425 m		
61.	t_sum3_hy_rs	Transportation index = density(all) + proximity(State Roads and RR) + proximity(State Roads) *	425 m		

	\PATH\ file name	description	resolution	source citation	method notes
	\DISTURBANCE\ AGRICULTURE				
62.	ag_hi_g	High impact types of agriculture (crops, vegetables)	425 m	ALAGaC (2014)	
63.	ag_hi_ei3k01	proximity (inverse of euclidean distance to 3km) *	425 m		ESRI ArcGIS Euclidean Distance
64.	ag_md_g	Medium impact types of agriculture (crops, vegetables, wheat)	425 m	ALAGaC (2014)	
65.	ag_md_ei3k01	proximity (inverse of euclidean distance to 3km) *	425 m		ESRI ArcGIS Euclidean Distance
66.	ag_all_g	All types of agriculture (crops, vegetables, wheat, hay)	425 m	ALAGaC (2014)	
67.	ag_all_ei3k01	proximity (inverse of euclidean distance to 3km) *	425 m		ESRI ArcGIS Euclidean Distance
68.	ag_sumei3k_rs	Agriculture Index = proximity(high + medium + all) *	425 m		
	\DISTURBANCE\ DISTURBANCE_INDEX				See disturbance index calculation.pdf
69.	didx_sum6_rs	sum of five factors (30., 32., 42., 61., 68.) *	425 m		
70.	didx6max	max of five factors (30., 32., 42., 61., 68.) *	425 m		
71.	didx6max_slc	max of five factors classified: high (highest 5%), medium (5-45%), low (lowest 50%)	425 m		

* rescaled by dividing each value by the maximum value to produce a range of values from 0 (min) to 1 (max).

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