National Park Service
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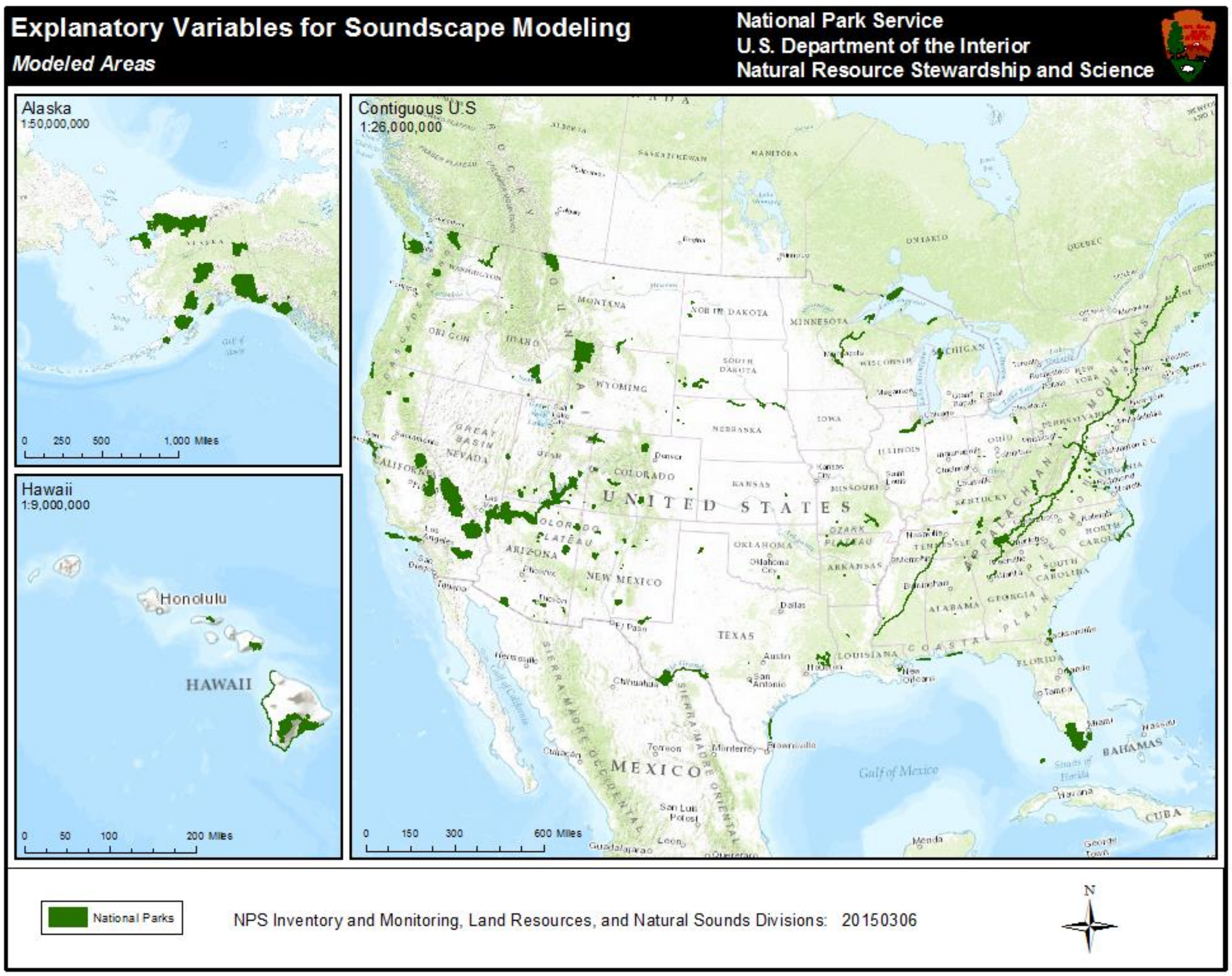
Natural Resource Stewardship and Science

Explanatory Variable Generation for Geospatial Sound Modeling

Standard Operating Procedure

Natural Resource Report NPS/NRSS/NRR—2015/936



ON THE COVER
Map of modeled areas for soundscape explanatory variables
NPS Inventory and Monitoring and Natural Sounds and Night Skies Divisions

Explanatory Variable Generation for Geospatial Sound Modeling

Standard Operating Procedure

Natural Resource Report NPS/NRSS/NRR—2015/936

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March 2015

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Nelson, L., M. Kinseth, and T. Flowe. 2015. Explanatory variable generation for geospatial soundscape modeling: Standard operating procedure. Natural Resource Report NPS/NRSS/NRR—2015/936. National Park Service, Fort Collins, Colorado.

NPS 999/128310, March 2015

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Abstract

The emerging field of soundscape ecology draws upon many principles from the field of landscape ecology. Of particular relevance to this study is the understanding that landscapes are defined by multi-scaled spatial and temporal relationships between patterns and ecological processes.

A microphone records the sounds at a monitoring site in Great Sand Dunes National Park and Preserve in Colorado. NPS Photo.

Terrestrial environments are filled with sounds that vary in number, structure, and magnitude across time and space. Natural phenomena such as time of day, seasonality, location, terrain, weather, temperature, and animal distribution and behavior influence the structure and complexity of the natural acoustical environment. Statistical models were derived to investigate relationships between long term measurements of the ambient sound pressure level and non-acoustic geospatial features such as topography, climate, hydrology, and anthropogenic activity. These models were used to predict expected acoustical conditions across the contiguous United States, Alaska, and Hawaii. This document describes the processing used to generate the explanatory variables used in the geospatial sound models.

Acknowledgments

Inventory and Monitoring Division GIS interns Caitlin Mahanna, Matt Powers, and Paul Martin provided data acquisition, processing, and documentation support for this project. Their contributions are gratefully acknowledged.

List of Terms

Area of analysis – an area of analysis (AOA) is a spatial feature used for summarizing an explanatory variable. AOAs used in the project include point, circular 200m polygon, and annular 5000m polygon.

Explanatory variable – a geospatial layer estimating biogeophysical and anthropogenic elements in the landscape

Modeled area – modeled areas or regions for the project are the primary spatial extents of analysis and include the continental United States, Alaska, and Hawaii

Sound monitoring site – acoustical monitoring sites are located in national parks; each site is geo-located with a GPS unit

Training data – values extracted from an explanatory variable for a sound monitoring site location

Introduction

The emerging field of soundscape ecology draws upon many principles from the field of landscape ecology (Pijanowski et. al. 2011-2). Of particular relevance to this study is the understanding that landscapes are defined by multi-scaled spatial and temporal relationships between patterns and ecological processes (Urban et. al. 1987, and Turner 1989). A soundscape is loosely defined as “the collection of biological, geophysical and anthropogenic sounds that emanate from a landscape and which vary over space and time” (Pijanowski et. al. 2011-1). With this in mind, explanatory variables are generated with an understanding that pattern influences process (sounds within a landscape) and that soundscapes result from multi-scaled biogeophysical and anthropogenic interactions. Thus explanatory variables were selected to measure patterns in biogeophysical and anthropogenic elements that have known and unknown mechanistic relationships with soundscapes.

Explanatory variables are seamless rasters (GeoTIFF and ASCII format) for three modeled areas: the conterminous U.S., Alaska, and Hawaii. Respective spatial references are: Albers Conical Equal Area USGS (SR-ORG: 6603), Alaska Albers (EPSG: 3338), UTM 4N (EPSG: 32604). Respective spatial resolutions are 270m, 250m, and 270m. Values for sound monitoring sites are extracted (sampled) from these rasters and used to train the random-forest sound level model (Mennitt, D. *et al*, 2014). Once the model is parameterized, selected ASCII format explanatory variable rasters are used as model inputs.

ArcGIS™ versions 10.2.1 and 10.2.2 on Windows 7 are the primary software processing packages used. Both Python (v2.7.2) scripts and manual processing techniques were used to generate explanatory variables and training statistics. Pre-processing operations (if needed) include re-projecting or re-sampling source data to the appropriate spatial reference or resolution, clipping or masking to the analysis extent, and extracting data values via re-classification or raster selection.

Requirements for processing (vary by area of analysis, controlled by script variables or ArcGIS™ environment settings):

- Processing extent
- Snap raster
- Output folder and file

Python scripts use the ArcGIS™ arcpy library and several default libraries. Scripts are logically sequential rather than object-oriented and are run in the following order:

ExplanatoryVariable.py → RasterToASCII_ExplanatoryVariable.py → ExtractTrainingData.py

Explanatory Variables and Units

Because of differential data availability, the set of explanatory variables varies by modeled area. Also, the data unit can vary by source. To account for multi-scale soundscape drivers, some explanatory variables were calculated for one of several area of analysis (AOA) scales. These scales varied by modeled area and variable type (Table 1). The term CONUS refers to the contiguous United States. Labels used for training data are listed in Table 2.

Table 1. Explanatory variable summary

Explanatory Variable[1]	**Statistics/Units**	**Areas of Analysis (AOAs)**
Nighttime Lights		
CONUS	Upward radiance in nano-Watts/(cm2*sr) (2012); annular focal minimum, mean, and maximum	270m, 1080m, 4320m, 17280m, 69120m
Alaska	Upward radiance in nano-Watts/(cm2*sr) (2013); annular focal minimum, mean, and maximum	270m, 1080m, 4320m, 17280m
Hawaii	Upward radiance in nano-Watts/(cm2*sr) (2013); annular focal minimum, mean, and maximum	270m, 1080m, 4320m, 17280m
Road Density and Distance from Roads		
CONUS	km/km^2, meters	Point, 5000m
Alaska	km/km^2, meters (up to 130km)	point
Hawaii	km/km^2, meters (up to 30km)	point
Traffic		
CONUS	A-weighted 24 hour Leq (dB3)	270m, 1080m, 4320m
Alaska	N/A	
Hawaii	N/A	
Population Density, Total, and Distributed Total		
CONUS (block groups)	2010 (block group): $persons/km^2$ and total persons 2010 (distributed within block group): number of persons	point
Alaska (block groups)	2010 (block group): $persons/km^2$ and total persons 2010 (distributed within block group): number of persons	point
Hawaii (block groups)	2010 (block group): $persons/km^2$ and total persons 2010 (distributed within block group): number of persons	point
Distance from Airports (all and military only)		
CONUS	meters	point
Alaska	meters	point
Hawaii (also heliports)	meters	point

Table 1 (continued). Explanatory variable summary

Explanatory Variable[1]	Statistics/Units	Areas of Analysis (AOAs)
Climatic Data (average annual and seasonal temperature and precipitation for date range)		
CONUS (PRISM 1971-2000)	PPT: mm X 100 Temp and mean dew point: degrees Celsius X 100	point
Alaska (SNAP 2000-2009)	PPT: mm Temp: degrees Celsius	point
Hawaii (PRISM 1971-2000)	PPT: mm X 100 Temp and mean dew point: degrees Celsius X 100	point
Proportional Land Cover (discrete)		
CONUS	Proportion of discrete cover type (Barren, Forest (all), Deciduous Forest, Developed, Evergreen Forest, Herbaceous, Mixed Forest, Shrubland, Snow, Water, Wetlands)	circular: 200m, annular: 5000m
Alaska	Proportion of discrete cover type (Barren, Cropland, Deciduous Forest, Developed, Evergreen Forest, Grassland, Mixed Forest, Shrubland, Snow and Ice, Taiga Forest, Water, Wetlands)	circular: 200m, annular: 5000m
Hawaii	Proportion of cover type (Developed, Herbaceous, Mixed Forest, Shrubland, Water, Wetlands)	circular: 200m, annular: 5000m
Proportional Land Use		
CONUS	Proportion of discrete land use intensity (Built, Commercial, Cropland, Cultivated, Extractive, Grazing, Industrial, Institutional, Mining, Park, Pasture, Recreation/Conservation, Suburban, Timber, Transportation, Urban, WaterAnthropogenic, WaterNatural, Wet, Wilderness)	circular: 200m, 5000m
Alaska	Proportion of discrete land use type (developed, recreation-conservation)	circular: 200m, 5000m
Hawaii	Proportion of discrete land use type (developed, recreation-conservation)	circular: 200m, 5000m
Distance from Streams and from Waterbodies		
CONUS	meters (streams: by Strahler stream order)	point
Alaska	meters	point
Hawaii	meters	point
Distance from Coastline		
CONUS	meters	point
Alaska	meters	point
Hawaii	meters	point
Physical Accessibility		
CONUS	Physical accessibility	point
Alaska	N/A	N/A
Hawaii	Physical accessibility	point

Table 1 (continued). Explanatory variable summary

Explanatory Variable[1]	**Statistics/Units**	**Areas of Analysis (AOAs)**
Elevation and Slope		
CONUS	meters (elevation); degrees (slope)	point
Alaska	meters (elevation); degrees (slope)	point
Hawaii	meters (elevation); degrees (slope)	point
Latitude and Longitude		
CONUS	decimal degrees	point
Alaska	decimal degrees	point
Hawaii	decimal degrees	point
Wilderness		
CONUS	sum (cell count)	10 miles
Alaska	sum (cell count)	10 miles
Hawaii	sum (cell count)	10 miles
Wind Speed		
CONUS (1960-1990)	mean speed (meters/second), 10 meters above ground	point
Alaska	N/A	N/A
Hawaii	N/A	N/A

[1]See Appendix A, Table A-1 for complete source data information.

Table 2. Explanatory variable training labels and units.

Variable	Units	CONUS	Alaska	Hawaii
Nighttime Lights	nano-Watts/ (cm2*sr)	VIIRSAlbers270m_270_MINIMUM	viirs2013_270_MINIMUM	viirs2012_270_MINIMUM
		VIIRSAlbers270m_270_MEAN	viirs2013_270_MEAN	viirs2012_270_MEAN
		VIIRSAlbers270m_270_MAXIMUM	viirs2013_270_MAXIMUM	viirs2012_270_MAXIMUM
		VIIRSAlbers270m_1080_MINIMUM	viirs2013_1080_MINIMUM	viirs2012_1080_MINIMUM
		VIIRSAlbers270m_1080_MEAN	viirs2013_1080_MEAN	viirs2012_1080_MEAN
		VIIRSAlbers270m_1080_MAXIMUM	viirs2013_1080_MAXIMUM	viirs2012_1080_MAXIMUM
		VIIRSAlbers270m_4320_MINIMUM	viirs2013_4320_MINIMUM	viirs2012_4320_MINIMUM
		VIIRSAlbers270m_4320_MEAN	viirs2013_4320_MEAN	viirs2012_4320_MEAN
		VIIRSAlbers270m_4320_MAXIMUM	viirs2013_4320_MAXIMUM	viirs2012_4320_MAXIMUM
		VIIRSAlbers270m_17280_MINIMUM	viirs2013_17280_MINIMUM	viirs2012_17280_MINIMUM
		VIIRSAlbers270m_17280_MEAN	viirs2013_17280_MEAN	viirs2012_17280_MEAN
		VIIRSAlbers270m_17280_MAXIMUM	viirs2013_17280_MAXIMUM	viirs2012_17280_MAXIMUM
		VIIRSAlbers270m_69120_MINIMUM		
		VIIRSAlbers270m_69120_MEAN		
		VIIRSAlbers270m_69120_MAXIMUM		
Road Density	km/km^2	RddAllPt_270m	RoadDensity_250m	RoadDensity_270m
		RddAll5km_270m		
		RddMajorPt_270m		
		RddMajor5km_270m		
		RddMajorPt_270m_zeroed		
Distance from Roads	meters	DistRoadsAll_270m	DistRoadsAll_250m	DistRoadsAll_270m
		DistRoadsMajor_270m		
Population Total	individuals	PopTotal_2010_50km_270m	PopTotal_Distributed_250m_zeroed	PopTotal_Distributed_270m_zeroed
Distance from Airports (all and military only)	meters	DistAirportsAllMotorized_270m	DistAirports_Alaska_250m	DistAirports_Hawaii_270m

Table 2 (continued)**.** Explanatory variable training labels and units.

Variable	Units	CONUS	Alaska	Hawaii
Distance from Airports (all and military only) (continued)	meters	DistAirportsSeaplane_270m	DistMilitary_Alaska_250m	DistHeliports_Hawaii_270m
		DistHeliports_270m		DistMilitary_Hawaii_270m
		DistHighAirports_270m		
		DistLowAirports_270m		
		DistModerateAirports_270m		
		DistanceMilitary_270m		
Climatic Data (average annual and seasonal temperature)	CONUS and HI: degrees C * 100 Alaska: degrees C	TMAXAvgSummer_270m	TAVGNorms_Adjusted_250m	TMAXSUMMER_Hawaii_270m
		TMAXAvgWinter_270m	TAVGSummer_Adjusted_250m	TMAXWINTER_Hawaii_270m
		TMAXNorms_270m	TAVGWinter_Adjusted_250m	TMAX_Hawaii_270m
		TMINAvgSummer_270m		TMINSUMMER_Hawaii_270m
		TMINAvgWinter_270m		TMINWINTER_Hawaii_270m
		TMINNorms_270m		TMIN_Hawaii_270m
		TDEWAvgSummer_270m		TDMEANSUMMER_Hawaii_270m
		TDEWAvgWinter_270m		TDMEANWINTER_Hawaii_270m
		TDEWNorms_270m		TDMEAN_Hawaii_270m
Climatic Data (average annual and seasonal precipitation)	CONUS and HI: mm * 100 unless noted Alaska: Mm (total)	PPTNorms_270m (per year)	PPTNorms_Adjusted_250m (mm/month)	PPTSUMMER_Hawaii_270m
		PPTSummer_270m (mm*100/month)	PPTSummer_Adjusted_250m	PPTWINTER_Hawaii_270m
		PPTWinter_270m	PPTWinter_Adjusted_250m	PPT_Hawaii_270m
Proportional Land Cover	proportion (0.0 to 1.0)	Barren200m_270m	Barren_200m	Barren200m_270m
		Barren5000m_270m	Barren_5000m_Annulus	Barren5000m_270m_Annulus
		Cultivated200m_270m	Cropland_200m	Developed200m_270m
		Cultivated5000m_270m	Cropland_5000m_Annulus	Developed5000m_270m_Annulus
		Deciduous200m_270m	DeciduousForest_200m	Herbaceous200m_270m
		Deciduous5000m_270m	DeciduousForest_5000m_Annulus	Herbaceous5000m_270m_Annulus

Table 2 (continued). Explanatory variable training labels and units.

Variable	Units	CONUS	Alaska	Hawaii
Proportional Land Cover (continued)	proportion (0.0 to 1.0)	Developed200m_270m	Developed_200m	MixedForest200m_270m
		Developed5000m_270m	Developed_5000m_Annulus	MixedForest5000m_270m_Annulus
		Evergreen200m_270m	EvergreenForest_200m	Shrubland_200m_270m
		Evergreen5000m_270m	EvergreenForest_5000m_Annulus	Shrubland_5000m_270m_Annulus
		Forest200m_270m	Forest_200m	Water_200m_270m
		Forest5000m_270m	Forest_5000m_Annulus	Water_5000m_270m_Annulus
		Herbaceous200m_270m	Grassland_200m	Wetlands_200m_270m
		Herbaceous5000m_270m	Grassland_5000m_Annulus	Wetlands_5000m_270m_Annulus
		Mixed200m_270m	MixedForest_200m	
		Mixed5000m_270m	MixedForest_5000m_Annulus	
		Shrubland200m_270m	Shrubland_200m	
		Shrubland5000m_270m	Shrubland_5000m_Annulus	
		WaterOnly200m_270m	SnowIce_200m	
		WaterOnly5000m_270m	SnowIce_5000m_Annulus	
		Wetlands200m_270m	TaigaForest_200m	
		Wetlands5000m_270m	TaigaForest_5000m_Annulus	
			Water_200m	
			Water_5000m_Annulus	
			Wetlands_200m	
			Wetlands_5000m_Annulus	
Proportional Land Use	proportion (0.0 to 1.0)	Built200m_270m	Developed_200m	Developed200m_270m
		Built5000m_270m	Developed_5000m_Annulus	Developed5000m_270m
		Commercial200m_270m	RecCon200m_250m	RecCon200m_270m
		Commercial2_5km_270m	RecCon5000m_250m	RecCon5000m_270m
		Cropland200m_270m		

Table 2 (continued). Explanatory variable training labels and units.

Variable	Units	CONUS	Alaska	Hawaii
Proportional Land Use (continued)	proportion (0.0 to 1.0) (continued)	Cropland5km_270m		
		Extractive200m_270m		
		Extractive5000m_270m		
		ExurbanHigh200m_270m		
		ExurbanHigh5km_270m		
		ExurbanLow200m_270m		
		ExurbanLow5km_270m		
		Grazing200m_270m		
		Grazing5km_270m		
		Industrial200m_270m		
		Industrial5km_270m		
		Institutional200m_270m		
		Institutional5km_270m		
		Mining200m_270m		
		Mining5km_270m		
		Park200m_270m		
		Park5km_270m		
		Pasture200m_270m		
		Pasture5km_270m		
		RecCon200m_270m		
		RecCon5km_270m		
		Suburban200m_270m		
		Suburban5km_270m		
		Timber200m_270m		
		Timber5km_270m		

Table 2 (continued). Explanatory variable training labels and units.

Variable	Units	CONUS	Alaska	Hawaii
Proportional Land Use (continued)	proportion (0.0 to 1.0) (continued)	Transportation200m_270m		
		Transportation5km_270m		
		Urban5km_270m		
		UrbanHigh200m_270m		
		UrbanHigh5km_270m		
		UrbanLow200m_270m		
		WaterHum200m_270m		
		WaterHum5km_270m		
		WaterNat200m_270m		
		WaterNat5km_270m		
		Wet200m_270m		
		Wet5km_270m		
Distance from Streams and from Waterbodies	meters	DistStrahlerCalgt1_270m	DistStream_Alaska_250m	DistStream_Hawaii_270m
		DistStrahlerCalgt3_270m	DistWaterbody_Alaska_250m	DistWaterbody_Hawaii_270m
		DistStrahlerCalgt4_270m		
		DistanceWaterbody_270m		
Distance from Coastline	meters	DistanceCoast_270m	DistCoast_Alaska_250m	DistCoast_Hawaii_270m
Physical Accessibility	proportion range (0.0 to 6050)	PhysicalAccess_270m	N/A	PhysicalAccess_Hawaii_270m
Elevation	meters	ELEV_270m	Elevation_Alaska_250m	Elevation_Hawaii_270m
Slope	degrees	Slope_270m	Slope_Alaska_250m	Slope_Hawaii_270m
Latitude	decimal degrees	latitude_270m	AK_Latitude_250m	HI_Latitude_270m
Longitude	decimal degrees	longitude_270m	AK_Longitude_250m	HI_Longitude_270m
Wilderness	range (0.0 to 1.0)	Wilderness_270m	Wilderness_250m	Wilderness_270m
Wind Speed	meters/second	WindSpeedMean_1960_1990_270m	N/A	N/A

Modeling Areas

Three summary modeling areas are used for soundscape modeling explanatory variables: the conterminous U.S., Alaska, and Hawaii.

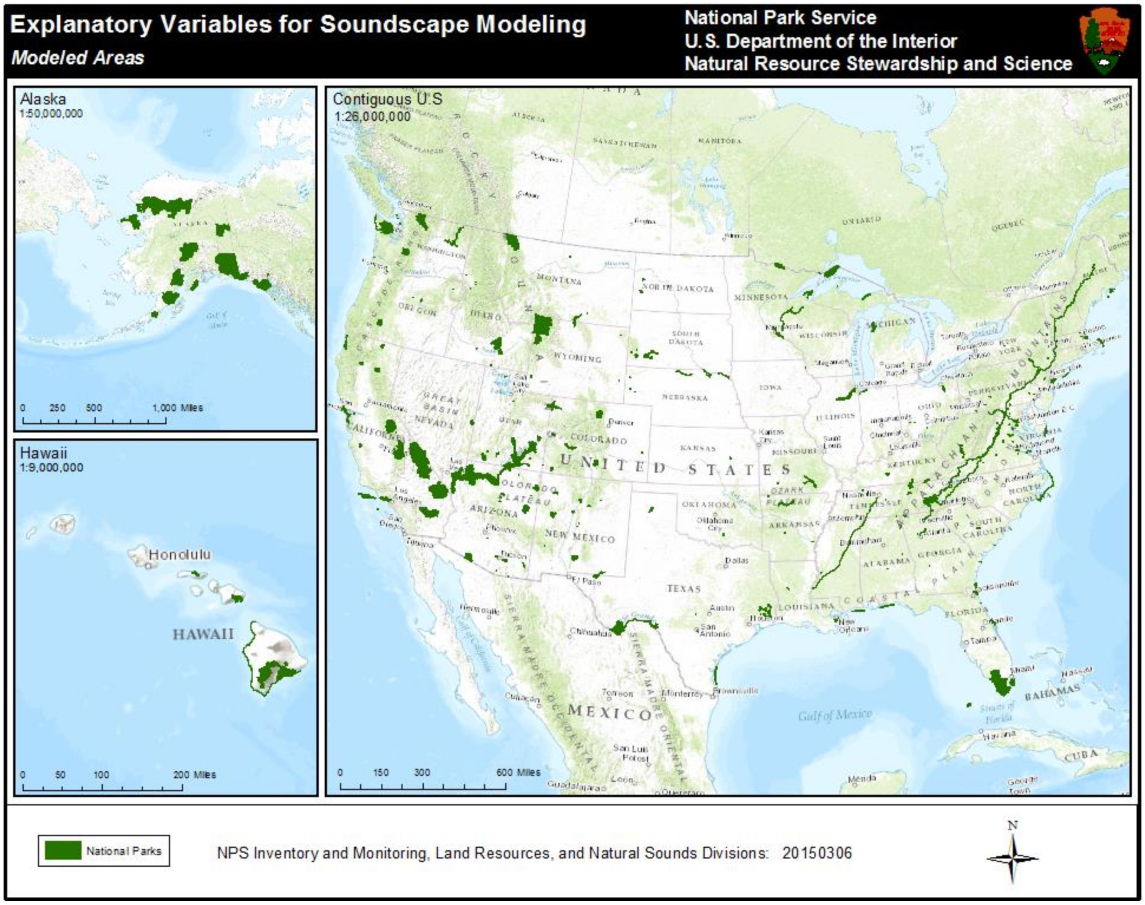

Figure 1: Modeled areas for explanatory variable generation

Spatial Reference Details

Spatial reference, processing extent, snap raster, and spatial resolution vary by modeling area.

Table 3. Spatial references by modeled area

Area	Spatial Reference Used [1]	Processing Extent (m)		Snap Raster	Spatial Resolution (m) and Columns/Rows)
CONUS	Albers Conical Equal Area USGS (SR-ORG: 6603) Datum: D_North_American_1983	North: 3172665 West: -2356095 South: 276915	East: 2258475	NLCD[2] 2006 land cover	270 17091/10725
Alaska	Alaska Albers (EPSG: 3338) Datum: D_North_American_1983	North: 2561343 West: -1737799 South: 121843	East: 1663200	NALC[3] 2005 land cover	250 13604/9758
Hawaii	UTM 4N (EPSG: 32604) Datum: D_WGS_1984	North: 2790696 West: -29459 South: 1851906	East: 1321351	C-CAP[4] 2005 land cover	270 5003/3477

[1]ArcGIS™ coordinate system. [2]National Land Cover Dataset. [3]North American Land Cover. [4]Coastal Change Analysis Program.

Explanatory Variable Processing

VIIRS Nighttime Lights

VIIRS (Visible Infrared Imaging Radiometer Suite) Nighttime Lights data for 2012 (CONUS) and 2013 (Alaska and Hawaii) were downloaded from the NOAA Earth Observation Group VIIRS website (National Oceanic and Atmospheric Administration, 2012, 2013).

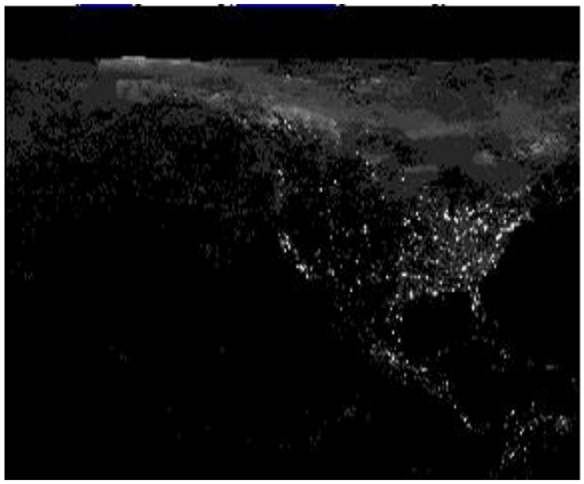

Figure 2: VIIRS source data - 2013

The panchromatic day/night band of the VIIRS satellite comprises the Nighttime Lights dataset which captures upward radiance at night and is a surrogate for human activities like development, roads, and resource extraction (gas flares,etc). The dataset was not filtered for fires, volcanoes, or aurora and contains artifacts of reflectance from coastal phosphorescence, lake beds, and snow fields. However, the CONUS extent of the raster is not strongly affected by these artifacts.

The GeoTIFF Tile 1 for North and Central America was processed as follows. The source raster was re-projected to the Albers Equal Area USGS spatial reference from GCS WGS84, re-sampled (using cubic convolution) to 270m from 504m, and re-scaled to remove negative values created when raster was re-sampled. However, for Alaska, the 2013 data were resampled to 250m to conform to the Alaska land cover raster.

Processing extents were extracted for each study area (CONUS, Alaska, Hawaii) and each output raster was re-projected to the appropriate spatial reference (Table 2). Then, focal statistics were used to calculate annular means, minimums,and maximums. The annular focal statistics rasters were sampled for each study (monitoring) point to derive training data values.

Annular Mean, Minimum, Maximum – Annular mean, minimum, and maximum of the panchromatic day/night band VIIRS raster were calculated for the following distances: 270m, 1080m, 4320m, 17280m, 69120m (CONUS only).

Road Density

For the contiguous United States and Hawaii study areas, road features were obtained from the 2005 ESRI Steetmap (ESRI, 2010) feature class. For Alaska, road features from the Alaska State Geospatial Data Clearinghouse were used (ASGDC, 2013). Each source dataset was projected to the appropriate spatial reference (Table 2) and processing extents were extracted for each study area (CONUS, Alaska, Hawaii). Geometry was repaired for each output feature class. Then, the output feature classes were used as inputs to the NPScape Road Metrics toolbox (National Park Service, 2013). The toolbox generates road density rasters (km/km^2) for all roads and major and weighted roads (CONUS only).

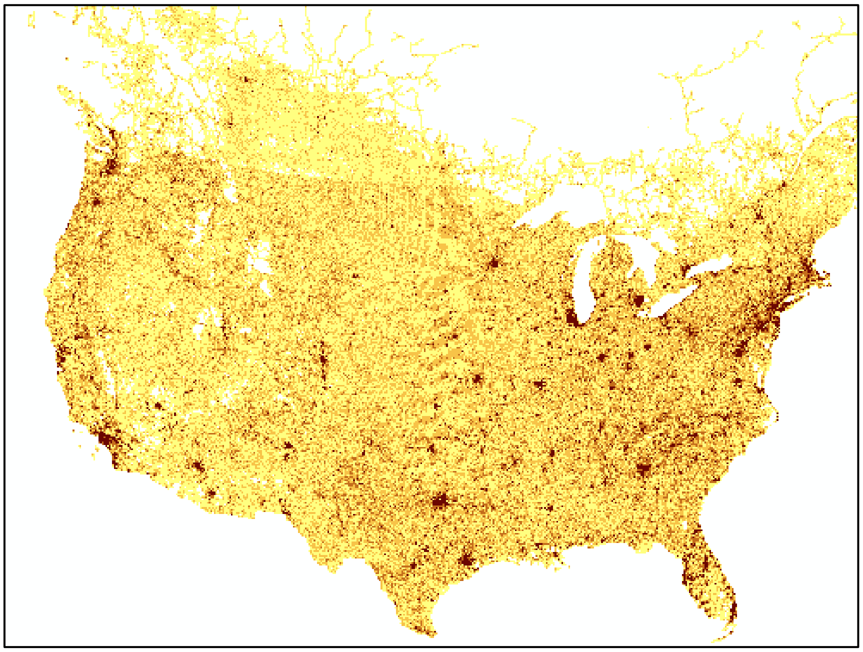

Figure 3: Road density in km/km^2 for the conterminous U.S.

The density rasters were sampled for each study (monitoring) point to derive training data values.

Road density – km/km^2

Distance from Roads

For the contiguous United States and Hawaii study areas, road features were obtained from the 2005 ESRI Steetmap (ESRI, 2010) feature class. For Alaska, road features from the Alaska State Geospatial Data Clearinghouse were used (ASGDC, 2013). Each source dataset was projected to the appropriate spatial reference (Table 2) and processing extents were extracted for each study area (CONUS, Alaska, Hawaii). Geometry was repaired for each output feature class. Then, the output feature classes were used as inputs to the NPScape Road Metrics toolbox (National Park Service, 2013). The toolbox generates distance from road rasters (meters) for all roads.

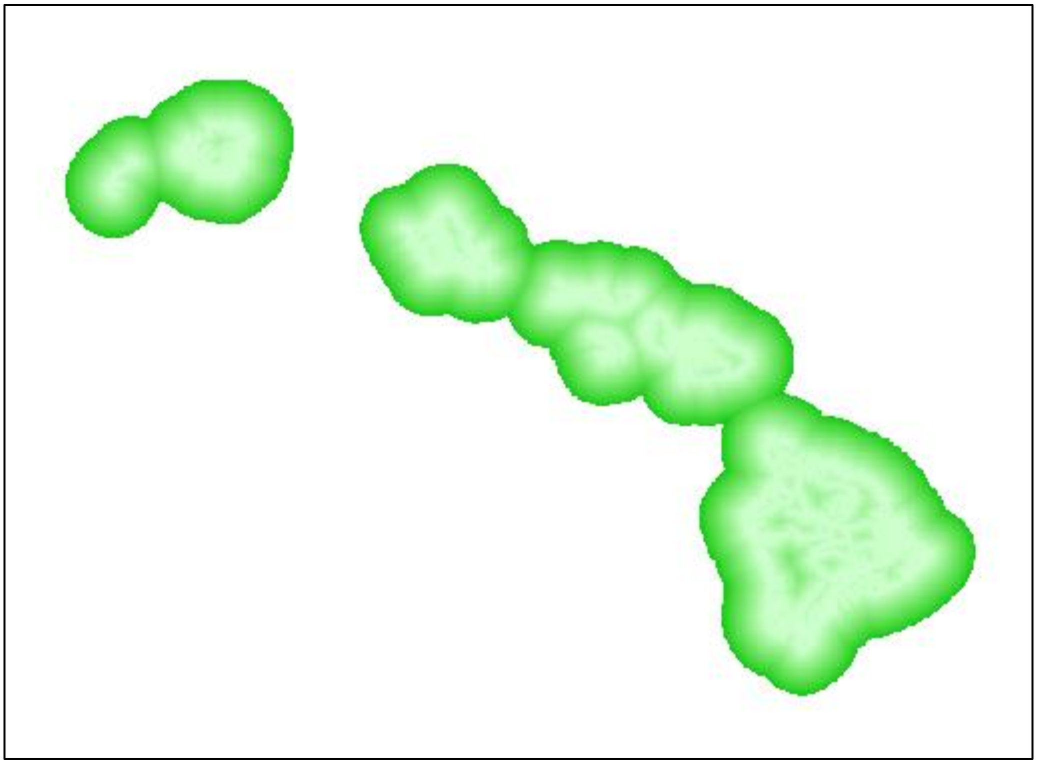

Figure 4: Distance from roads in meters, Hawaii

The distance rasters were sampled for each study (monitoring) point to derive training data values.

Distance from roads – meters; Alaska: limited to 130km from road features, Hawaii: limited to 30km from road features

Population Density, Total, and Distributed Total

US Census block groups for 2010 from the NPScape population metric dataset (National Park Service, 2013) were used to generate population total, distributed total, and population density rasters for each study area (CONUS, Alaska, Hawaii). Population total is the number of individuals in a Census block. Distributed population total is the number of individuals in a 270m x 270m pixel cell (total population divided by number of pixels). Population density is the number of individuals per km^2.

Protected areas (national parks, wilderness, and GAP status areas) are excluded from population calculations. These features are source from the Protected Areas Database of the US (version 1.3; Gergely and McKerrow, 2013). And, the U.S. Census-reported area of water is subtracted as part of the NPScape density processing logic. Therefore, density values are adjusted for both protected area and water area. Population total is adjusted for protected area only.

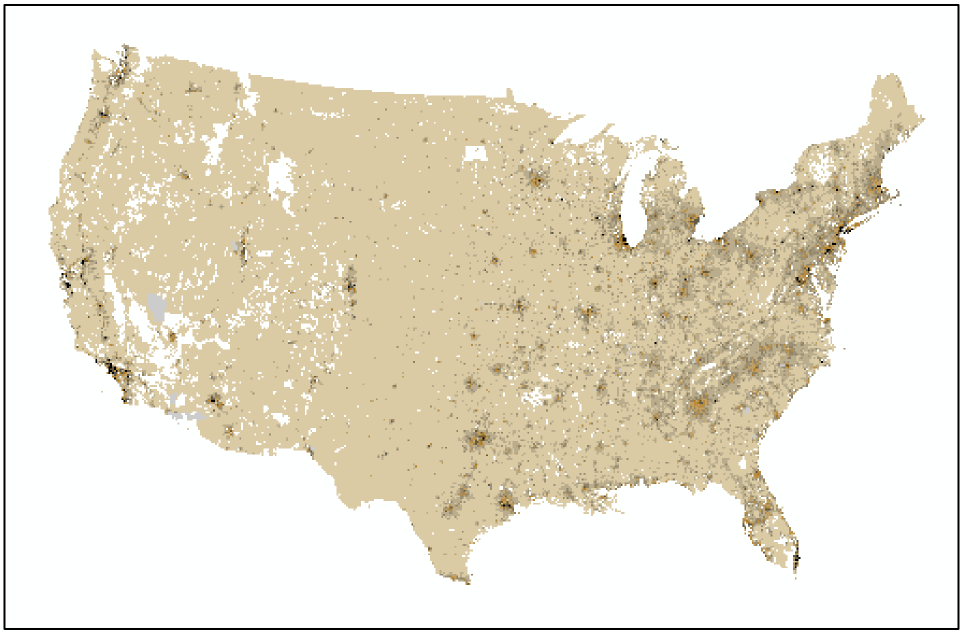

Figure 6: Population density (individuals/km^2) for the conterminous U.S.

For total and density, the NPScape population metric toolbox was used to generate polygon feature classes. These were converted to interim rasters with the appropriate spatial resolution (Table 2). Focal statistics using a 50km radius circular neighborhood was run on these interim rasters to produce the population density and total explanatory variables.

For the distributed population total explanatory variable, the Census block group polygons used for the NPScape population metric dataset were processed by selecting polygons with non-zero population values. Then, the selected polygons were converted to a raster which was joined back to the source polygon layer. The distributed population was calculated as the ratio of total population to the zonal cell count (i.e. area). These values were used to generate an interim raster. For CONUS and Hawaii, this interim raster was aggregated from a 90m cell size to a 270m cell size .

The output rasters were sampled for each study (monitoring) point to derive training data values.

Population density: individuals/km^2

Population total: # of individuals

Distributed Population total: # of individuals per 270m raster cell

Distance from Airports

Airport point locations were extracted from the National Transportation Atlas Database (2012) for each modeled area. Public use and military airport locations were available for all modeled areas while heliport locations were available only for Hawaii. Euclidean distance from airport points was calculated and snapped to the respective land cover rasters. Outputs were resampled to the target output spatial resolution (Table 2).

The output rasters were sampled for each study (monitoring) point to derive training data values.

Distance from Airports, Military Airports, Heliports - meters

Climatic Data

Climatic data were obtained from two sources and vary by modeled area. The available source data contain different interpolated climate variables which determined which explanatory variables could be derived. For the contiguous U.S. and Hawaii, data from the PRISM project (PRISM Climate Group, 2013) were used to generate explanatory variables. PRISM (Parameter-elevation Regressions on Independent Slopes Model) climatic data are modeled from point observations. As noted in the PRISM metadata, PRISM datasets provide estimates of three basic climate elements: precipitation (ppt), minimum temperature (tmin), maximum temperature (tmax), and dew point (tdmean). The long-term average also known as "normals" rasters were used in this analysis. Date range varied by modeled area.

PRISM data for the contiguous US (800m resolution) was processed by downloading and resampling the long-term 'normals' rasters for precipitation and temperature. The annual average rasters were summed across the 2001-2010 timeframe, then divided by 10 (number of years). These calculated decadal annual means became the TMINNorms, TMAXNorms, TDMEANNorms and PTTNorms explanatory variables.

The monthly average rasters for winter (December, January, and February) and summer (June, July, and August) were summed across the 2001-2010 time frame, then divided by 30 (3 months times 10 years) to produce decadal seasonal means (PPTWinter, PPTSummer, TMINWinter, TMINSummer, TMAXWinter, TMAXSummer, TDMEANWinter, TDMEANSummer).

PRISM data for Hawaii are available as a 30-year climatology for 1970-2000. Note that minimum and maximum 'normals' temperature data are not available for Hawaii. These data were downloaded, resampled, and processed as follows. An interim version of the Climate Grid Analysis Toolset (National Park Service, 2013) was used to extract PRISM data for Hawaii. Like the contiguous U.S., these are long-term normal metrics. The CGAT tool extracted data for the Hawaii modeled area into netCDF format rasters. The seasonal averages were calculated using the CGAT Summary Stats tool which uses NumPy logic for statistical calculations. Outputs were converted to GeoTIFFs and resampled to 270m. This produced these explanatory variables: PPT_Hawaii, PPTWinter, PPTSUMMER, TMIN_Hawaii, TMAX_Hawaii, TMINWINTER_Hawaii, TMINSUMMER_Hawaii, TDMEAN_Hawaii, TDMINWINTER_Hawaii, TDMAXWINTER_Hawaii, TDMINSUMMER_Hawaii, and TDMAXSummer_Hawaii.

Scenarios for Alaska and Arctic Planning (SNAP) data were used for Alaska. These source rasters are produced utilizing algorithms from the PRISM project applied to Climate Research Unit (CRU) source data (Scenarios Network for Alaska and Arctic Planning, 2014). Estimated SNAP climate elements are average decadal monthly precipitation and temperature. SNAP does not produce dew point interpolations. Note SNAP source data are monthly-based totals, not annual totals like PRISM's are. As noted in the SNAP metadata for the precipitation source data, *This set of files includes downscaled historical estimates of decadal means of monthly total precipitation (in millimeters, no unit conversion necessary) for each month of every decade from 1910 - 2009 (CRU TS 3.1.01) at 771x771 meter spatial resolution. Each file represents a mean monthly total in a given decade.*

Regarding SNAP temperature source data,

This set of files includes downscaled historical estimates of decadal means of monthly mean temperatures (in degrees Celsius, no unit conversion necessary) for each month of every decade from 1910 - 2009 (CRU TS 3.1) at 771x771 meter spatial resolution. Each file represents a mean monthly mean in a given decade.

SNAP data processing for precipitation involved summing the resampled monthly total precipitation source rasters by month across the 2000-2009 timeframe, then dividing by 10 (number of years). These calculated decadal monthly means were used to generate mean decadal seasonal (winter/summer) by summing the three decadal monthly means for each season then dividing by 3. This produced the PPTWinter and PPTSummer explanatory variables. To produce the annual decadal mean metrics, the decadal monthly means were summed then divided by 12. This produced the PPTNorms explanatory variable.

Note: the SNAP annual processing differs from the CONUS PPTNorms metric in that the PRISM source data included a pre-calculated annual mean raster. For CONUS, the PRISM data did not need to be first summed by month. And, Alaska SNAP precipitation source data are monthly totals, not monthly averages like PRISM for CONUS.

For temperature, SNAP source data are monthly averages. Neither minimum and maximum temperature nor dewpoint source data are available for Alaska. The monthly average temperature source data were resampled then summed using the same procedures as for precipitation. This process produced the TAVGNorms, TAVGWinter, and TAVGSummer explanatory variables.

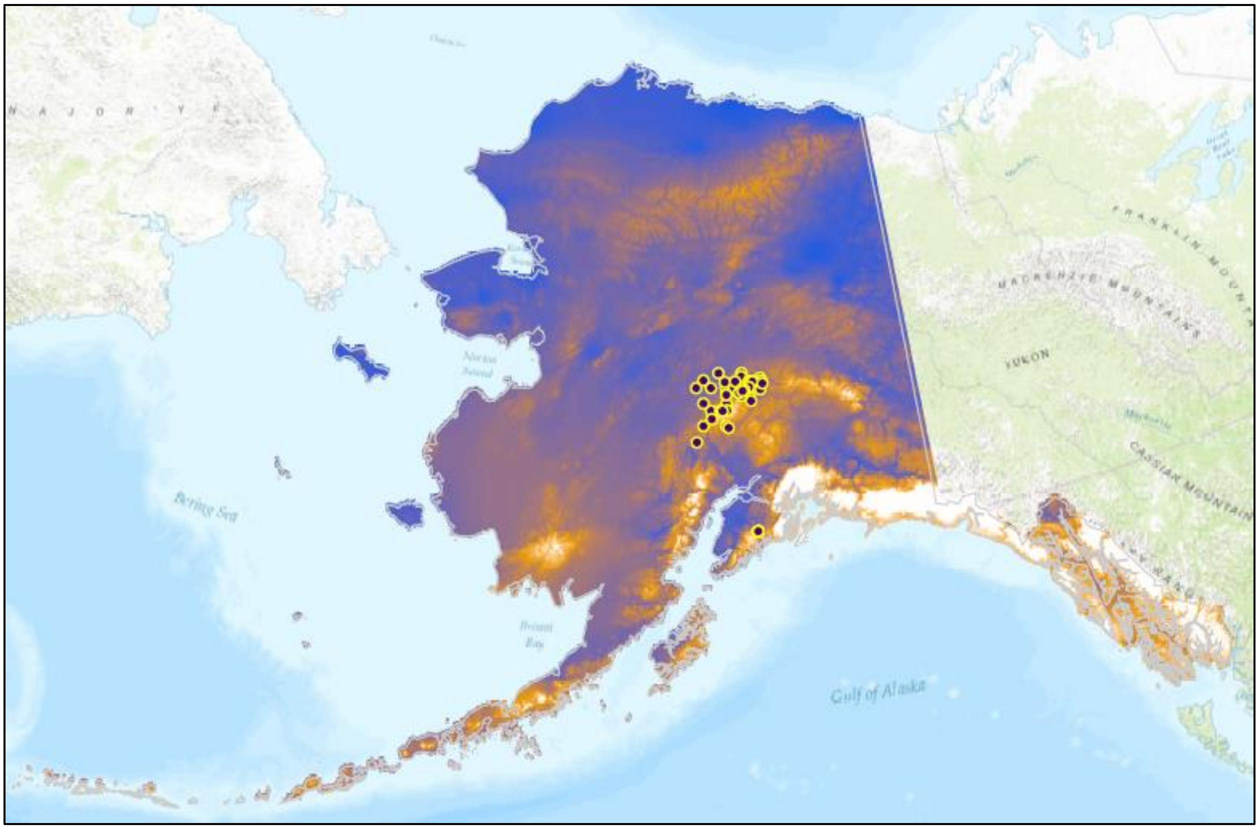

Figure 7: Average monthly summer precipitation for Alaska (2000-2009)

Table 4: Climatic data source and explanatory variable comparison

Modeled Area	Spatial Resolution	Source/Date	Explanatory Variables Produced
Contiguous U.S.	800m	PRISM 2001-2010	decadal annual and monthly (seasonal) average total PPT decadal annual and monthly(seasonal) average temperature and dew point decadal annual and monthly (seasonal) average minimum and maximum temperature
Alaska	771m	SNAP 2000-2009	decadal annual and monthly (seasonal) average PPT decadal monthly average temperature
Hawaii	400m	PRISM 1970-2000	30 year annual and monthly (seasonal) average total PPT 30 year annual and monthly (seasonal) average temperature 30 year annual and monthly (seasonal) minimum and maximum temperature

Source data were combined using raster calculations, then resampled to the spatial resolution for each study area (Table 2). The output rasters were sampled for each study (monitoring) point to derive training data values.

Precipitation, Temperature, and Dew Point – see table 3 for details

Proportional Land Cover

Land cover sources specific to modeled areas were used to generate discrete proportional area metrics for areas of analysis that vary by modeled area. Source land cover rasters are reclassified into indicator (binary) rasters by cover type and then extracted for each area of analysis (AOA) for each monitoring site. These output rasters for each monitoring site have cell values of 0 (no land cover type x in cell) or 1 (complete land cover type x in cell). Then the final site-by-site proportional area metric for each cover type x is calculated by dividing the count of cells of cover type x by the total count of cells with values in the area of analysis. Note for the Hawaii modeled area, the source water land cover raster was modified manually to extend pixels of water beyond the original source extent.

Two levels of land cover classification are used for explanatory variables: consolidated (level 1) classes are used for Forest (deciduous, mixed, evergreen), Developed (open space, low, medium, high intensity), Cultivated (pasture /hay, cultivated crops) and Wetlands (woody, emergent). All other land cover classes are more detailed, level 2 classes (National Land Cover Dataset, 2006).

For the Alaska modeled area, the herbaceous class is noted as Grassland and the cultivated class is noted as Cropland. These classes conform to the NALC classification system (Commission for Environmental Coorperation, 2005).

The example below shows a processed indicator raster for water for one grid cell near Los Angeles International airport for the 5000m annular AOA. The proportional area of water for this site is 43.52% (37913 divided by 87210).

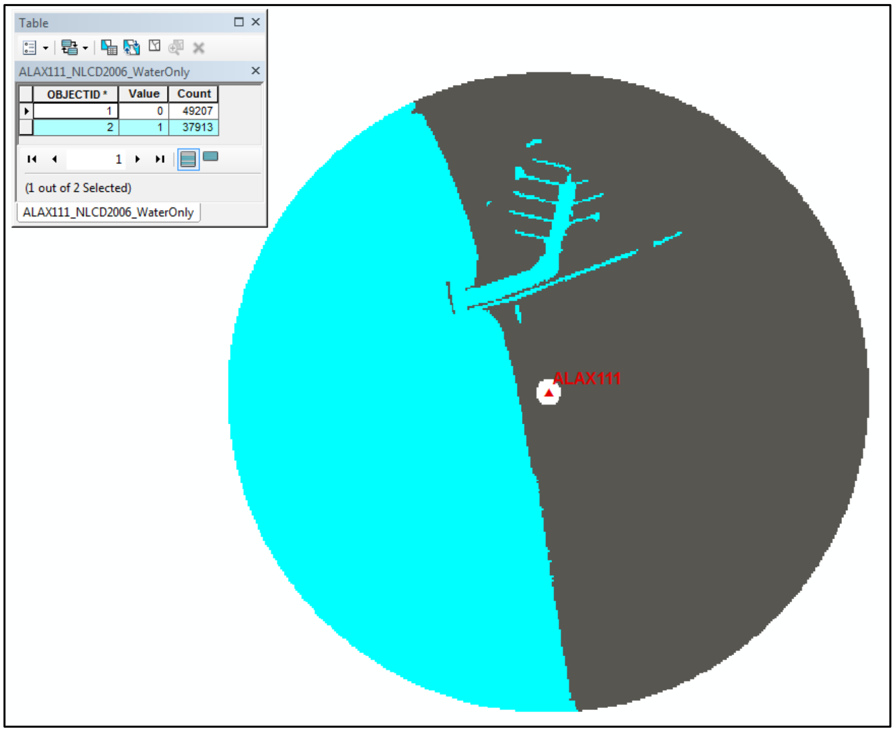

Figure 8: Example water cover type output raster for a grid cell

For 5000m AOAs that fall along the edge of the source raster data (e.g. the U.S. – Canada border or coastal areas) proportional areas will not sum to 1.0 if the AOA extends beyond the edge of the source raster. The example below shows a grid cell for water which extends beyond the source raster data extent (black cells in top third of image). The monitoring site for this annual AOA is a few hundred meters south of the Canadian border. The source data in this case (NLCD 2006) do not extend into Canada.

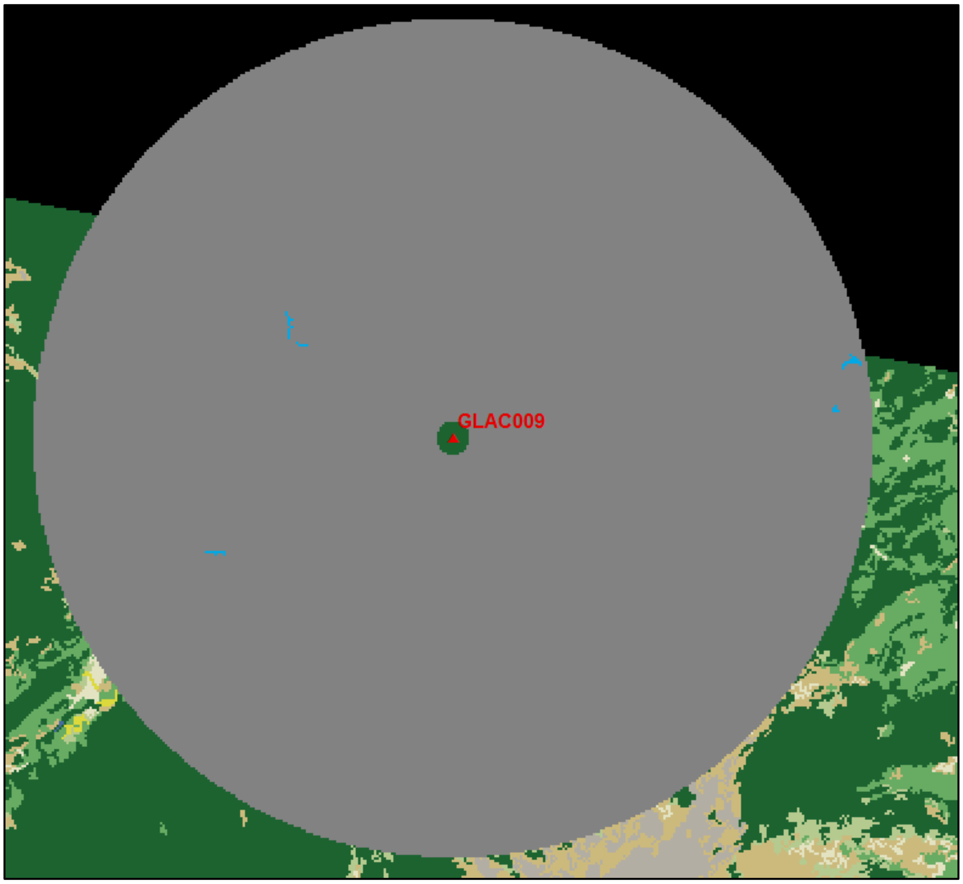

Figure 9: Example grid cell area of analysis along U.S.- Canada border

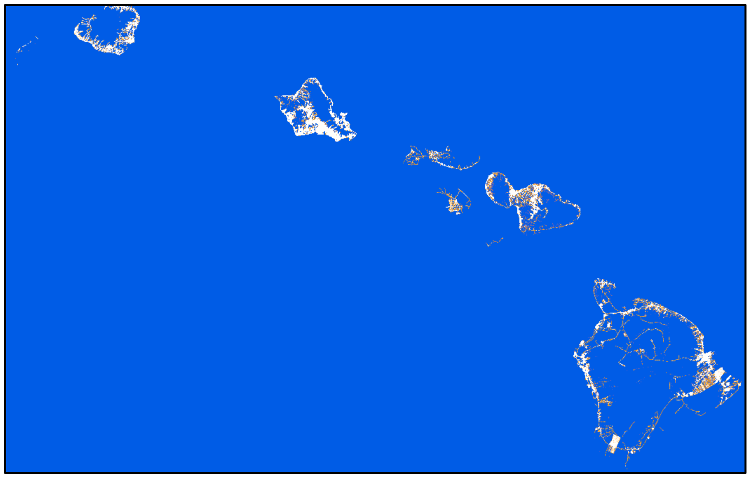

Figure 10: Developed land cover for 200m AOA in Hawaii

Table 5: Land cover source comparison

Modeled Area	Spatial Resolution	Source/Date
Contiguous U.S.	30m	National Land Cover Dataset (NLCD) 2006
Alaska	250m	North American Land Cover (NALC) 2005
Hawaii	30m	Coastal Change Analysis Program (C-CAP) 2006

Proportional area values for each cover type were calculated for each monitoring site.

Proportional land cover – proportion (percentage) of land cover in raster cell for area of analysis.

Proportional Land Use

Land use source rasters specific to modeled areas were used to generate proportional area metrics for areas of analysis that vary by modeled area. For the CONUS modeled area, the source land use data represent intensity of use and the explanatory variable generation process translates these intensities into focal area values. For other modeled areas, land use source is a subset of a classified land cover raster.

Source land use rasters are reclassified into indicator (binary) rasters by land use type and then extracted for each area of analysis (AOA) for each monitoring site. These output rasters for each monitoring site have cell values of 0 (no land use type x in cell) or 1 (complete land use type x in cell). Then the final site-by-site focal area metric (circular neighborhood) for each land use type x is calculated by dividing the count of cells of land use type x by the total count of cells with values in the area of analysis.

Table 6: Land use source comparison

Modeled Area	Spatial Resolution	Source/Date
Contiguous U.S.	30m	Theobald, 2013 and PADUS
Alaska	250m	North American Land Cover (NALC) 2005 and PADUS
Hawaii	30m	Coastal Change Analysis Program (C-CAP) 2006 and PADUS

Focal area values for each land use type were calculated for each monitoring site.

Land use intensity – focal area (percentage) of land use type in raster cell for area of analysis.

Distance from Streams and Waterbodies

Distance from stream calculations were produced for all modeled areas using Euclidean distance calculations on of stream flowlines and rasterized waterbody polygons. Additionally, for the contiguous U.S., distance from streams weighted by Strahler stream order was generated. Steam order values were not available for Alaska or Hawaii.

Euclidean distance rasters were produced at 270m (contiguous U.S. and Hawaii) and 250m (Alaska) resolutions.

These output rasters were sampled for each monitoring site point to derive training data values.

Distance from streams and waterbodies - meters

Distance from Coastline

For each modeled areas, coastline features were extracted from the relevant National Hydrography Dataset (NHD, 2013). Then Euclidean distance calculations were used to produce 270m (contiguous U.S. and Hawaii) resolution and 250m (Alaska) resolution output distance rasters. These output rasters were sampled for each monitoring site point to derive training data values.

Distance from coastline - meters

Physical Accessibility

Source data for physical accessibility varied by modeled area and was not produced for Alaska. In all cases, this metric is a generalized estimate of the ease of access across the modeled area. For the contiguous U.S., a physical accessibility raster produced by David Theobald and colleagues (2010) was used as the source dataset. For Hawaii, a custom analysis was done that incorporated some of the logic from a travel time cost surface model (Sherrill, *et al*, 2010). Input data included National Hydrography Dataset streams and waterbodies, land cover (Coastal Change Analysis Program), a 10m National Elevation Dataset digital elevation model, distance from roads, streets, and city locations. These sources were processed into a cost surface from which accessibility (as the inverse of travel time) from populated areas was calculated.

The Theobald-source and Hawaii output rasters were sampled for each monitoring site point to derive training data values.

Physical accessibility – estimated accessibility (higher value = more accessible)

Elevation and Slope

Elevation explanatory variables were produced for each modeled area using different source digital elevation models. Slope was calculated from these source DEMs. In every case, the DEMs and slope rasters were resampled to the target spatial resolution for the modeled area.

Table 7: Elevation and slope source comparison

Modeled Area	Source Spatial Resolution	Resampled Spatial Resolution
Contiguous U.S.	30m	270m
Alaska	1000m	250m
Hawaii	10m	270m

The output rasters were sampled for each monitoring site point to derive training data values.

Elevation – meters

Slope – calculated slope in degrees

Latitude and Longitude

Explanatory variable rasters for the three study areas were generated using the study areas' processing extent. Row and column numbers (i.e. Cartesian position) were created using the ArcGIS flow accumulation tool then multiplied by cell size and a constant, and minimum coordinates (from extents) added to simulate latitude and longitude values. For longitude, column number increases from left to right (in the Western hemisphere, longitude is negative). For latitude, row number increases from bottom to top.

Logic source (ArcGIS online forums: http://forums.arcgis.com/threads/48248-NCOLS-ROWMAP?p=288698#post288698 and http://resources.arcgis.com/en/help/main/10.1/index.html#/How_Flow_Accumulation_works/009z00000062000000/

These outputs were re-projected to the appropriate spatial reference for the study area. Then, the output rasters were sampled for each study (monitoring) point to derive training data values.

Latitude – latitude value of raster cell in decimal degrees
Longitude - latitude value of raster cell in decimal degrees

Wilderness

The total (sum) of designated wilderness calculated per monitoring site at a 10 mile area of analysis extent was derived using wilderness data which were downloaded from Wilderness.net (2011). The source polygon data were converted to a raster with the appropriate spatial resolution and a focal sum was calculated for a 10 mile area of analysis around each monitoring site. Then, these values were divided by the area of analysis cell count to create the final proportional area metric.

Percent wilderness area - percentage of designated wilderness in raster cell for area of analysis

Wind Speed

For the contiguous U.S. modeled area, global wind speed data (monthly mean speed: 1960-1990) were downloaded from the Climate Research Unit (CRU) site: http://www.ipcc-data.org/obs/get_30yr_means.html (Climate Research Unit, 2013, Mitchell and Jones, 2005). The monthly global rasters were converted from NetCDF format to GeoTIFF using GDAL and clipped to the CONUS extent. The monthly GeoTIFFs (270m cells) were merged into an annual average raster using Raster Calculator in ArcGIS. Specifically, the cumulative monthly mean rasters (Jan-Dec) for 1960-1990 were added together and divided by 12.

The output rasters were sampled for each study (monitoring) point to derive training data values.

Wind speed – annual mean (1960-1990) in meters/second, 10 meters above ground

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Appendix A: Explanatory Variable Source Information

Explanatory variables are derived from several sources that vary by modeling area.

Table A-1. Explanatory variable data sources

Explanatory Variable	Source Data (scale/resolution)
Nighttime Lights	15 arc second GeoTIFFs (approximately 504m cells), panchromatic band
CONUS	VIIRS DayNightBand Cloud Free Composites – October 2012
Alaska	VIIRS DayNightBand Cloud Free Composites – January 2013
Hawaii	VIIRS DayNightBand Cloud Free Composites – January 2013
Road Density and Distance from Roads	
CONUS	U.S. and Canada Detailed Streets - ESRI geodatabase (2005); NPScape roads metric source
Alaska	Roads_1000000_ln.shp – Alaska State Geospatial Data Clearinghouse (1991, 2005)
Hawaii	U.S. and Canada Detailed Streets - ESRI geodatabase (2005); NPScape roads metric source
Population Density and Total	Density: # individuals per km^2; Total: # of individuals
CONUS (block groups)	U.S. Decadal Census block groups (2010) - processed with NPScape tools
Alaska (block groups)	U.S. Decadal Census block groups (2010) - processed with NPScape tools
Hawaii (block groups)	U.S. Decadal Census block groups (2010) - processed with NPScape tools
Distance from Airports (all and military only)	
CONUS	National Transportation Atlas Database 2012, meters
Alaska	National Transportation Atlas Database 2012, meters
Hawaii (also heliports)	National Transportation Atlas Database 2012, meters
Climatic Data	
CONUS (PRISM 2001-2010) *decadal annual and monthly (seasonal) average total PPT; decadal annual and monthly(seasonal) average temperature and dew point; decadal annual and monthly average minimum and maximum temperature*	PPT: mm X 100 (average) Temp and mean dew point: degrees Celsius X 100
Alaska (SNAP 2000-2009) *decadal monthly average PPT; decadal monthly average of temperature*	PPT: mm (total) Temp: degrees Celsius <u>Note: no dew point</u>

Explanatory Variable	Source Data (scale/resolution)
Hawaii (PRISM 1971-2000) *30 year annual and monthly (seasonal) average total PPT;* *30 year annual and monthly (seasonal) average temperature and dewpoint;* *30 year annual and monthly (seasonal) minimum and maximum temperature and dew point*	PPT: mm X 100 (average) Temp: degrees Celsius X 100
Proportional Land Cover	
CONUS	Proportion of cover type (Barren, Forest (all), Deciduous Forest, Developed, Evergreen Forest, Herbaceous, Mixed Forest, Shrubland, Snow, Water, Wetlands)
Alaska	Proportion of cover type (Barren, Cropland, Deciduous Forest, Developed, Evergreen Forest, Grassland, Mixed Forest, Shrubland, Snow and Ice, Taiga Forest, Water, Wetlands)
Hawaii	Proportion of cover type (Developed, Herbaceous, Mixed Forest, Shrubland, Water, Wetlands)
Proportional Land Use	
CONUS	Proportion of land use type (Built, Commercial, Cropland, Cultivated, Extractive, Grazing, Industrial, Institutional, Mining, Park, Pasture, Recreation/Conservation, Suburban, Timber, Transportation, Urban, WaterAnthropogenic, WaterNatural, Wet, Wilderness)
Alaska	Proportion of land use type (developed, recreation-conservation)
Hawaii	Proportion of land use type (developed, recreation-conservation)
Distance from Streams and from Waterbodies	
CONUS	National Hydrography Dataset (1:24,000) and Strahler stream order tables
Alaska	National Hydrography Dataset (1:65,000)
Hawaii	National Hydrography Dataset (1:24,000)
Distance from Coastline	
CONUS	National Hydrography Dataset (1:24,000)
Alaska	National Hydrography Dataset (1:65,000)
Hawaii	National Hydrography Dataset (1:24,000)
Physical Accessibility	
CONUS	Theobald, *et al*, 2010
Alaska	N/A
Hawaii	Custom analysis using NHD streamsand waterbodies, land cover (C-CAP), distance from roads, streets, and city locations
Elevation and Slope	
CONUS	National Elevation Dataset (30m)
Alaska	SNAP ancillary data (1km)
Hawaii	National Elevation Dataset (10m)

Explanatory Variable	Source Data (scale/resolution)
Latitude and Longitude	
CONUS	derived from modeling extent using Python
Alaska	derived from modeling extent using Python
Hawaii	derived from modeling extent using Python
Wilderness	
CONUS	Wilderness.net polygons, converted to raster
Alaska	Wilderness.net polygons, converted to raster
Hawaii	Wilderness.net polygons, converted to raster
Wind Speed	
CONUS (1960-1990)	mean speed (meters/second), 10 meters above ground
Alaska	NA
Hawaii	NA

Appendix B: Explanatory Variable GeoTIFF and ASCII Raster Generation

Explanatory variable GeoTIFF- and ASCII-format rasters are created for metrics deemed relevant to running the soundscape model. In all cases, Python scripts are used to generate the raster outputs. For the ASCII format, row and column totals are validated for each modeled area (Table 3 in Modeled Areas section).

For non-land cover metrics, ASCII rasters are generated from the seamless processed source GeoTIFF. For land cover proportional area metrics, interim processed GeoTIFFs are resampled to the appropriate spatial resolution (contiguous U.S. and Hawaii), then used as input to focal sum calculations. These outputs are divided by the count of raster cells within the appropriate area of analysis, buffered by a one cell size perimeter (Table 1). Geometric calculations of cell counts, for example:

$$count = \frac{\pi r^2}{cell\ size * cell\ size}$$

are not used because, due to offsets of raster cell alignment, this approach underestimates the cell count for an area of analysis.

Table A-2**.** Explanatory variable raster generation values

Modeled area	Area of analysis cell counts	
CONUS (270m)	200m: 6.0 cells	5000m annular: 1192.0 cells
Alaska (250m)	200m: 6.0 cells	5000m annular: 1385.0 cells
Hawaii (270m)	200m: 6.0 cells	5000m annular: 1192.0 cells

The figures below show an example of the coincident cell count for one 5000m annular and one 200m area of analysis. The underlying raster resolution is 250m.

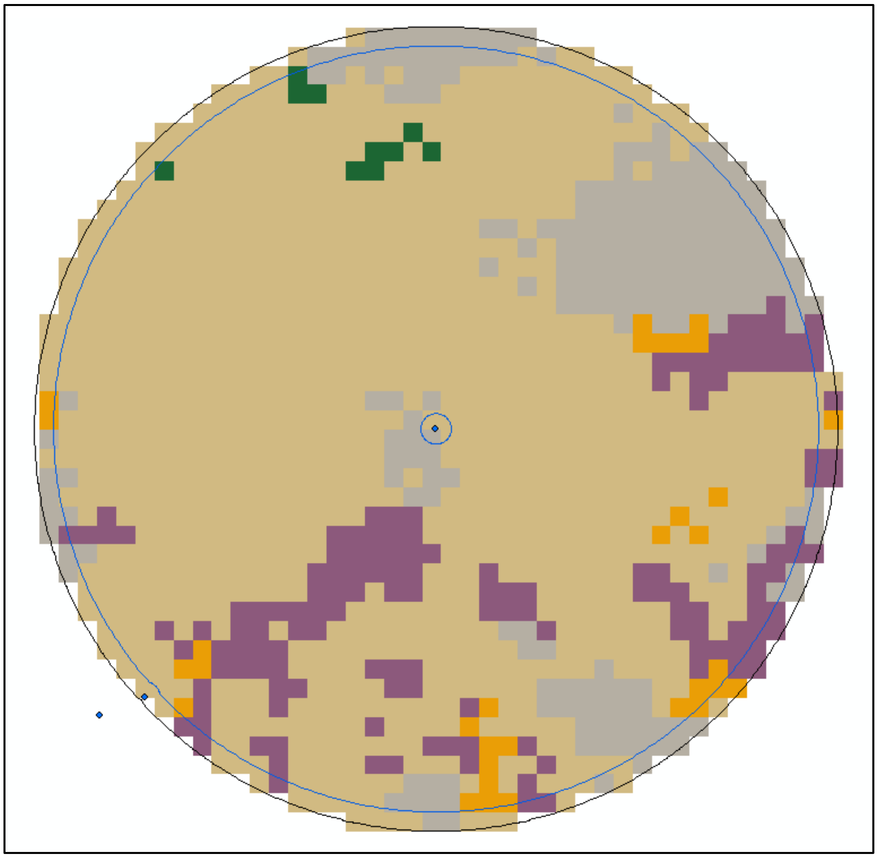

Figure 11: Cells coincident with a 5000m annular area of analysis (250m resolution)

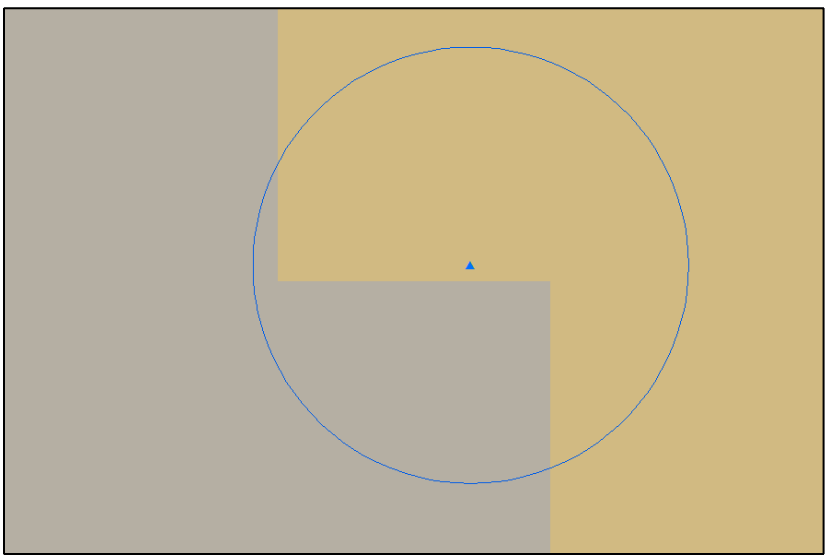

Figure 12: Cells coincident with a 200m annular area of analysis (250m resolution)

NPS NPS 999/128310, March 2015

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U.S. Department of the Interior

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