Characterizing the connectivity of British Columbia's southern interior grasslands

Habitat functionality and movement flow methodology

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ConScape is a new software library implemented in Julia that quantifies habitat connectivity at both a pixel and landscape level for large, high-resolution landscapes (Van Moorter et al., 2023). Unlike other models that require the delineation of source and destination nodes or patches, ConScape can compute connectivity metrics for continuous representations of the landscape, allowing connectivity to be characterized both within and between habitat patches. Habitat functionality and proximity-weighted betweenness are two metrics that formed the primary focus of my analysis. Habitat functionality is a measure of both the suitability and functional connectivity of a pixel (or landscape); regions of high habitat functionality therefore correspond with suitable, well-connected habitat. Proximity-weighted betweenness refers to the ability of a pixel to connect regions of high habitat functionality together based on the quality of the source and target locations as well as the proximity between them, which when visualized at the landscape level helps to capture movement flow.

My primary goal was to characterize habitat functionality and movement flow for grassland-associated species in the southern interior of British Columbia. The Grasslands Conservation Council of BC has defined eight grassland regions in the province, three of which I included in my analysis: the Southern Thompson Upland, Thompson-Pavilion, and Okanagan. To model connectivity for these regions, I first defined the species groups that I was interested in and characterized the permeability of the landscape according to these groups. I then modeled connectivity both for the individual species groups and for all species groups combined. This general process is described below. More information about ConScape and its general workflow and outputs can be found at ConScape.org, or through its accompanying paper by Van Moorter et al. (2023).

1. Characterizing generic focal species

Multispecies connectivity assessments highlight regions of high connectivity value for a wide range of co-occurring species in a landscape, helping to guide conservation efforts aimed at conserving habitat simultaneously for multiple species. A 'generic focal species' approach involves modeling connectivity for one or more hypothetical species whose ecological characteristics and needs reflect those of a group of existing species (Watts et al., 2010; Williamson et al., 2020). This method is less data-intensive than individually modeling connectivity for multiple species while also representing the connectivity needs of a community more accurately than a surrogate or agnostic species approach (Wood et al., 2022).

I developed four generic focal species that together represented a wide range of grassland-associated species with varying degrees of dispersal ability and habitat specialization: high-mobility generalists, high-mobility specialists, low-mobility generalists, and low-mobility specialists (Table 1). The dispersal ability and degree of habitat specialization of each group were defined using existing literature on grassland-associated species in the region (Table 2). To define the dispersal ability of the high-mobility groups, I chose an intermediate value between the mean and maximum reported dispersal distances for existing species within those groups. For low-mobility groups, I selected a slightly higher dispersal ability relative to the reported values from existing literature due to limitations arising from the scale of the analysis.

2. Developing the conductance surface

ConScape requires a surface as one of its primary inputs to reflect the permeability of moving through the landscape. These surfaces are often species-specific and can include various landscape features that are known to influence movement behavior for that species. For multispecies connectivity modeling, the intensity of human modification can act as a broad indicator of landscape permeability (Keeley et al., 2021; Krosby et al., 2015). As part of my analysis, I created a conductance surface individually for each focal species group by beginning with a human modification surface. Movement penalties were then applied to this surface to account for non-anthropogenic barriers to movement, including non-grassland land cover types, high terrain ruggedness, and large water bodies. The result is a conductance surface unique to each grassland species group. This process is described below and can also be visualized in Figure 1.

Human disturbance intensity

The Cumulative Effects Framework (CEF) – Human Disturbance dataset is a consolidated human disturbance footprint surface that was developed for British Columbia in 2024 and visualizes the spatial extent of various human footprint categories across the province, including mining and extraction, urban and built-up areas, rail and infrastructure, airports, oil and gas infrastructure, dams, surveyed and crown rights-of-way, recreation, agriculture, current and historical cutblocks, and transmission lines (Government of BC, 2023). This dataset, once rasterized into a 30-m resolution surface, was the primary input used when developing the human disturbance intensity surface. For each category, I assigned values between zero and one to reflect the intensity of human modification for that type of disturbance (Table 3). Intensity values for each category generally corresponded with those defined by Theobald et al. (2020) who estimated intensity values for human stressors using existing literature and expert opinion. These values were directly used to reflect resistance to movement due to each human footprint category, with the assumption that categories of a higher intensity value correspond with greater resistance to species movement. A 30-m North American land cover surface, which contains both ‘Urban and built-up’ and ‘Cropland’ land cover classes, was also incorporated into the human modification surface at this stage to assign intensity values to regions of anthropogenic land cover that were not identified by the CEF human disturbance dataset (CEC, 2024).

Because the CEF human disturbance surface did not include road features, I incorporated an integrated road dataset developed in 2024 to account for the effects of roads on organism movement (Government of BC, 2024). Two outputs were created using this data. The first, a 30-m road density raster, contained the total density of all roads within the study area, including decommissioned or resource roads. I assigned intensity values to five classes of road density ranging from no road density (0 km/km^2) to very high road density (>6.27 km/km^2) (Table 4), reflecting the avoidance behavior of many species towards regions of high road density (de Rivera et al., 2022). The second output reflected the proximity in meters to the nearest major road as a 30-m raster. Major roads are defined here as freeways, highways, and minor or major arterial roads. I calculated intensity values for road proximity by applying an exponential decay function corresponding with decreasing intensity as the distance to the nearest major road increased, beginning at a high intensity value (0.80) at zero meters and decaying to a low intensity value (0.10) as the distance approached 1000 meters:

$$i = 0.8 * e^{\log\left(\frac{0.1}{1000}\right) * x}$$

Here, i represents the intensity value to be calculated, and x represents the Euclidean distance to the nearest major road. I implemented this decay function to reflect both the presence of the road itself as well as the indirect effects of major roads, including light or noise pollution, which can exacerbate avoidance behaviors by organisms (Fahrig & Rytwinski, 2009).

I incorporated both the road density and road proximity datasets into the consolidated human footprint layer, resulting in a final 30-m human disturbance intensity surface. The maximum intensity value for a given cell among all three input datasets became the final value assigned to this surface.

Natural barriers to movement

To approximate the ease of movement across the landscape according to the presence and intensity of anthropogenic features, I converted the human modification surface into a conductance surface using a negative, linear transformation of intensity values. Conductance values were then multiplied (i.e., penalized) according to the presence of non-anthropogenic features and their ability to act as barriers to movement depending on the species group of interest (Table 5; Williamson et al., 2020). For generalist species, conductance values were multiplied by 0.8 for each pixel containing a non-grassland vegetation type; for specialist species, a conductance multiplier of 0.5 was instead applied to reflect a greater avoidance of non-preferred natural land cover types. The presence or absence of grassland land cover was ascertained using a combination of two datasets: a grasslands extent surface created in 2014 by the Grasslands Conservation Council of BC (GCC, 2014), and the 30-m North American land cover dataset. In regions where the grasslands extent surface identified grasslands and the land cover dataset did not, the former was assumed to be correct.

Using the 30-m North American land cover dataset, non-vegetated land cover types (barren, snow and ice, and water) were assigned a conductance multiplier of 0.5 to reflect the increased difficulty of traversing through structurally simple landscapes that are dissimilar to the preferred habitat type (Prevedello & Vieira, 2010). Conductance values were additionally multiplied by 0.8 if pixels exhibited a very high terrain ruggedness value. Large (>1km^2) water bodies were automatically assigned a conductance value irrespective of other natural or anthropogenic features associated with a pixel: for high-mobility species, I applied a value of 0.5 to reflect the ability of large water bodies to act as moderate barrier to movement, whereas for low-mobility species, I instead used a value of 0.1 to reflect the ability of large water bodies to pose a much greater barrier to movement. The final 30-m conductance surfaces that were developed reflected overall landscape permeability for each of the four generic species groups.

3. Modeling connectivity

Model inputs

ConScape requires several inputs to model habitat functionality and proximity-weighted betweenness: the permeability of the landscape in terms of both its likelihood (A) and cost (C), and the quality of habitat as a source (q^s) and as a target (q^t). These inputs allow for greater flexibility and accuracy in instances where there is comprehensive data for the species of interest; however, ConScape also accepts simplified inputs when data is limited, or the analysis is not specific to any one particular species. Because my analysis lacked species-specific data and aimed to model connectivity for a broad range of species, I provided all inputs as a function of the conductance surfaces created previously (Table 6). Conductance was directly provided as movement likelihood, whereas movement cost was provided as a negatively log-transformed function of likelihood under the assumption that species movement is well-adapted to the environment. Habitat quality, both as a source and as a target, was provided as an exponential transformation of movement likelihood; this assumes that permeability is correlated with habitat quality (Prevedello & Vieira, 2010), but that regions of moderate movement likelihood (e.g., non-grasslands with low disturbance intensity) still represent relatively poor-quality habitat.

Movement behaviour and dispersal ability

By incorporating a randomized shortest paths (RSP) framework into its models, ConScape allows the user to control the randomness of movement using the parameter Θ: as $\Theta \rightarrow 0$, movement approaches a random walk, whereas at $\Theta \rightarrow \infty$, movement approaches a least-cost path. After testing a range of values, I decided to implement a Θ value of 1 to reflect some degree of exploratory movement away from optimal routes as organisms disperse throughout the landscape. ConScape also requires a scaling parameter, α, when exponentially transforming the distance between source and target pixels to proximity based on the movement capabilities of the species of interest. Proximity values can range from zero to one, where zero represents no ecological connectivity between pixels and one represents perfect ecological connectivity between pixels. I defined α as the maximum dispersal distances defined for each focal species group (Table 1) so that the proximity between source and target locations approaches zero as the maximum dispersal distance is exceeded.

Habitat functionality and proximity-weighted betweenness

After defining the required inputs and parameters, I ran ConScape's habitat functionality and proximity-weighted betweenness functions individually for each species group. Because both processes are computationally intensive, I divided the study area into tiles and ran the analysis on each tile individually. Each tile spanned at least double the width and height of the maximum dispersal distance defined for each species group to prevent artificial barriers from being introduced; overlapping buffers surrounding each tile, each at least the size of the maximum dispersal distance of each species group, were also included to prevent the introduction of these barriers and to allow tiles to be subsequently merged (Ravary, 2024) . To further reduce the computational load and runtime to reasonable levels, I resampled the input surfaces to 300-m and 600-m resolutions for low-mobility and high-mobility groups, respectively. After running the analysis for each individual species group, I combined results by calculating mean habitat functionality and proximity-weighted betweenness values across all species groups for each pixel in the landscape, allowing me to identify shared regions of high connectivity value for a broad range of grassland-associated species.

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Tables and figures

Table 1. Generic focal species groups and their defining characteristics.

Generic focal species group	Maximum dispersal distance	Degree of grassland specialization
Low-mobility generalist	3 km	Low
Low-mobility specialist	3 km	High
High-mobility generalist	30 km	Low
High-mobility specialist	30 km	High

Table 2. Movement characteristics of grassland-associated species. An asterisk (*) denotes that the dispersal information for an ecologically similar species was used in the event no dispersal information for the species of interest was available from existing literature.

Species	Mean dispersal distance (km)	Maximum dispersal distance (km)	References	Generic species group
Taxidea taxus jeffersonii	11	81	Kinley & Newhouse, (2008); Messick & Hornocker (1981); COSEWIC (2012)	High-mobility generalist
Tympanuchus phasianellus columbianus	13	45	Robel et al. (1972); Roy & Gregory (2019)	
Odocoileus hemionus hemionus	40	196	Skelton (2010); Government of BC (n.d.)	
Athene cunicularia	7	11	Clayton (n.d.)	High-mobility specialist
Ovis canadensis californiana	25	30	Dwinnell et al. (2019); Werdel et al. (2021)	
Numenius americanus	6*	Unknown	Pakanen et al. (2017); Cannings (1999)	
Microtus pennsylvanicus	1	Unknown	Ostfeld & Manson (1996)	Low-mobility generalist
Thomomys talpoides	0.2	1	Vaughan (1963); Wilson & Ruff (1999)	
Crotalus viridis oreganus	2	4	Harvey & Larsen (2020); Gomez (2007); Gomez et al. (2015)	
Spea intermontane	0.2	0.5	Environment and Climate Change Canada (2017)	Low-mobility specialist
Callophrys affinis	0.6*	Unknown	Environment Canada (2014); BC CDC (2020)	
Pituophis catenifer deserticola	0.5	2	Williams et al. (2012); COSEWIC (2013)	

Table 3. Human footprint categories and their corresponding intensity values.

Human footprint category	Intensity value
Mining and extraction	0.91
Urban and built-up	0.85
Rail and infrastructure	0.80
Airports	0.80
Oil and gras infrastructure	0.80
Dams	0.80
Surveyed and crown rights-of-way	0.50
Recreation	0.50
Agriculture/cropland	0.50
Current cutblocks	0.30
Historic cutblocks	0.20
Transmission lines	0.15

Table 4. Road density features and their corresponding intensity values.

Road density (km/km^2)	Intensity value
0	0
0.01 – 2.64	0.10
2.64 – 4.35	0.20
4.35 – 6.27	0.30
> 6.27	0.40

Table 5. Natural topographic barriers and their associated conductance multipliers or values according to species group.

Non-anthropogenic barrier	Conductance multiplier		Conductance value	
	Specialist	*Generalist*	*High mobility*	*Low mobility*
Non-grassland land cover	0.5	0.8	*n/a*	*n/a*
Non-vegetated land cover	0.5	0.5	*n/a*	*n/a*
Very high TRI (≥7.40)	0.8	0.8	*n/a*	*n/a*
Large water bodies (>1km^2)	*n/a*	*n/a*	0.5	0.1

Table 6. ConScape inputs and their corresponding sources as a function of movement likelihood (i.e., conductance).

Input	Function of likelihood (A)
Movement likelihood (A)	A
Movement cost (C)	$C = -\log(A)$
Quality as source (q^s)	$q^s = A^e$
Quality as target (q^t)	$q^t = A^e$

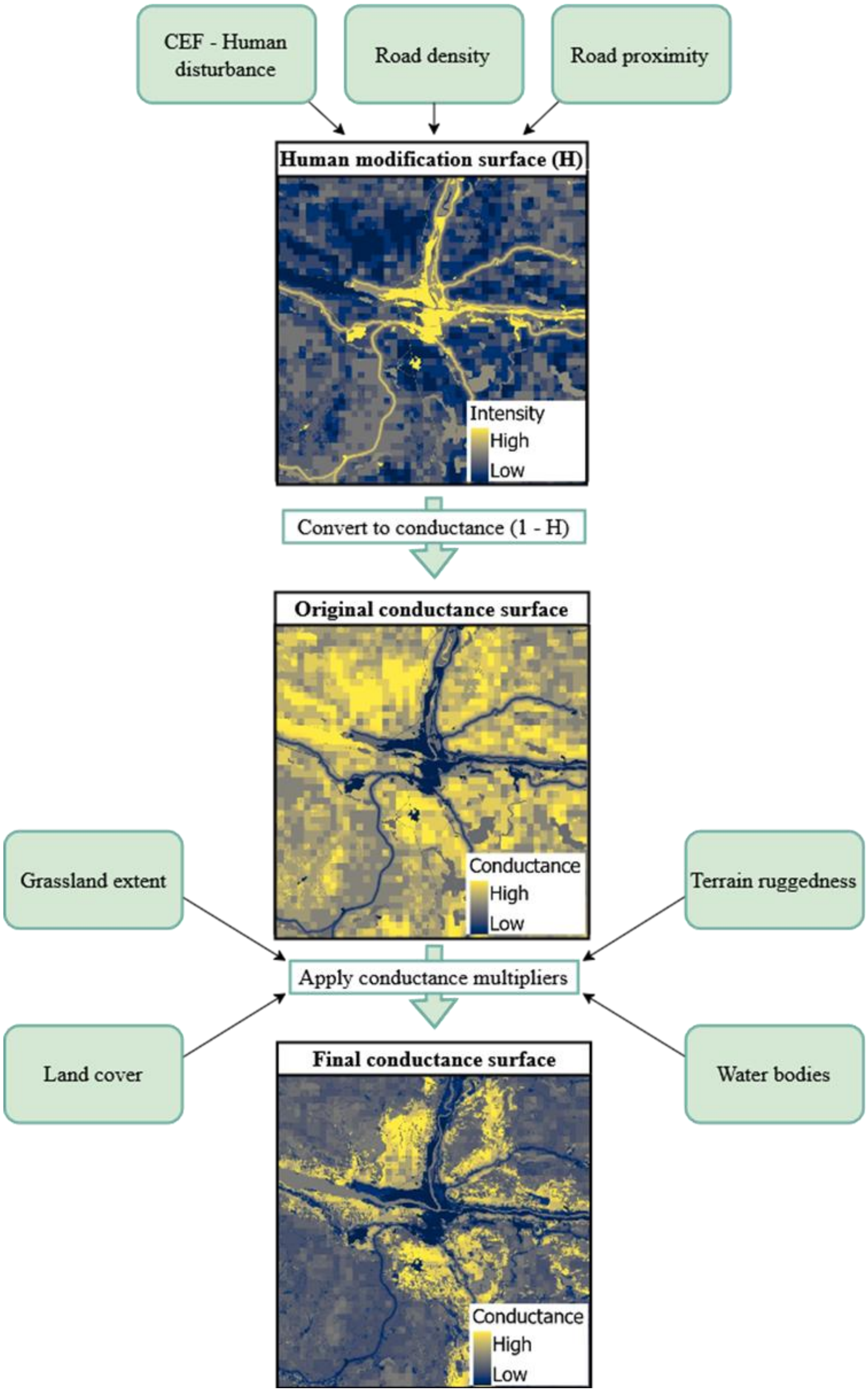

Figure 1. Workflow visualizing the creation of a conductance surface. After developing the human disturbance intensity surface, I transformed it into a conductance surface to approximate the ease of movement across the landscape according to the presence and intensity of anthropogenic features. I then applied conductance penalties (i.e., multipliers) to account for the effects of natural features as barriers to movement, resulting in a final conductance surface for each generic species group.